# SMART GRID AND ITS DEVELOPMENT IN INDIAN SCENARIO.

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**Declaration by the Guide**

This is to certify that Mr. Qamar Inam a Student of MBA Power Management SAP ID 500049534 of UPES has successfully completed report on “Smart Grid and its development in Indian Scenario” under my supervision.

Further, I certify that the work is based on the investigation made, data collected and analyzed by him and it has not been submitted in any other University or Institute for award of any degree. In my Opinion it is fully adequate, in scope and utility, as a dissertation towards partial fulfillment for the award of degree of MBA.


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| | |
|---|---|
| GHG | Green House Gases. |
| QoS | Quality of Service. |
| SG | Smart Grid |
| APDRP | Accelerated Power Development and Reforms |
| R-APDRP | Restructured Accelerated Power Development and Reforms |
| DER | Distributed Energy Resources |
| IT | Information Technology |
| EMS | Energy Management System |
| DSM | Demand Side Management |
| WAMS | Wide Area Management System |
| PMU | Phase Measurement Unit |
| FACTS | Flexible AC Transmission System |
| PV | Photo Voltaic |
| RES | Renewable Energy Sources |
| OECD | Organization for Economic Co-operation & Development |
| HDI | Human Development Index |
| UNFCCC | UN Framework Convention on Climate Change |
| IEA | International Energy Agency |
| GDP | Gross Domestic Product |
| EV | Electric Vehicles |
| IEGC | Indian Electricity Grid Code |
| CEA | Central Electricity Authority |
| CERC | Central Electricity Regulatory Commission |
| VPP | Virtual Power Plant |
| PMU | Phase Measurement Units |
| C-WET | Centre for Wind Energy Technology |
| MNRE | Ministry of New & Renewable Energy |
| IWTMA | Indian Wind Turbine manufacturers Association |
| WISE | World Institute for Sustainable Energy |

| | |
|---|---|
| HAWT | Horizontal Axis Wind Turbine |
| NSM | National Solar Mission |
| MPPT | Maximum Power point tracker |
| MATLAB | MATrix LABoratory |
| BAPV | Building Adopted PV |
| BIPV | Building Integrated PV |
| SERC | State Electricity Regulatory Commission |
| ABT | Availability Based Tariff |
| STOA | Short Term Open Access |
| CIM | Component Interface Specification |
| WAM | Wide Area Monitoring |
| IREDA | Indian Renewable Energy Development Agency |
| RPO | Renewable Purchase Obligations |
| REC | Renewable Energy Certificate |
| GCR | Grid Connection Requirement |
| TSO | Transmission System Operation |
| AMI | Advance metering Infrastructure |
| HSIL | High Surge Impedance Loading |
| HTLS | High Temperature Low Sag |
| ICT | Information and communication technology |
| IHD | In Home Display |
| KEPCO | Korea Electricity Power Company |
| SMT | Synchrophasor measurement Technology |
| EIPP | Eastern Interconnect Phasor Project |
| EPRI | Electrical Power Research Institute |
| SSG | Super Smart Grid |
| CIS | Common Wealth of Independent States |
| SGMM | Smart Grid Maturity Model |
| SGTF | Smart Grid Task Force |
| ESS | Energy Storage System |

| | |
|---|---|
| IED | Intelligent Electronic Devices |
| PLCC | Power Line Carrier Communication |
| DPS | Distributed Power System |
| DNO | Distributed Network Operators |
| IEEE | Institute of Electrical & Electronic Engineers |
| SU | State Utilities |
| SLDC | State Load Dispatch Centre |
| FRT | Fault Ride Through |
| PCC | Point of Common Coupling |
| SCADA | Supervisory Control & Data Acquisition |
| UI | Un scheduled Interchange |
| MGAS | Micro Grid Agent Control System |
| CIM | Common Information Model |
| SMES | Super Conducting Magnet Energy Storage |
| CAES | Compressed Air energy Storage |
| FWS | Flywheel Storage |
| UCS | Ultra Capacitor Storage |
| V2GS | Vehicle to grid storage |
| GWEC | Global Wind Energy Council |
| EREC | European renewable Energy Council |
| MoP | Ministry of Power |
| GeSI | Global e-sustainability Initiative |
| REC | Rural Electricity Corporation |
| RGGVY | Rajiv Gandhi Gramin Vidyutkaram Yojana |
| PMGY | Pradhan Mantri Gramodaya Yojana |
| KJP | Kutir Jyoti Program |
| MNP | Minimum Needs Program |
| AREP | Accelerated Electrification Program |
| REST | Rural Electricity Supply Technology Missin |
| RVREP | Remote Village renewable Energy Program |

## EXECUTIVE SUMMARY / ABSTRACT.

It is expected that the world wide population will be escalated by a factor of 1.4 billion with a power consumption expectancy of around 27,000 TWh by next decade. The statistics is being shared by both developing and developed countries with a percentage of 45% and 55% respectively.

For the needs of strongly growing world population with the simultaneous reduction in fossils, we have to deal with an area of conflicts between reliability of supply, environmental sustainability and economic efficiency. These can be resolved with the help of ideas, intelligent solutions as well as innovative technologies, which are today's and tomorrow's challenges for the planning and power engineers worldwide.

The global energy deficiency has directly foiled the economics, society, development of the nations, and environments through greenhouse gases (GHGs) and by gaining carbon credits. The growing demand of power across the globe is being envisaged and logged to be exponential. Lack of asset with outdated network infrastructure, climate change, rising fuel costs, has resulted inefficient and increasingly unstable electric system. With this, the global concern has raised certain critical points upon which the energy revolution for a green and sustainable future are guaranteed and ensued.

*[ref: Bossart S.J.]*

India is a fast expanding economy. Several challenges for the Power system Engineers have increased after Restructuring of the power industry.

With the growing challenge of electrical power, Quality of Service (QoS) and continuity of supply has been the utmost primacy for all major power utility sectors across the world, prior to the global market strategy. Smart Grid is predominantly proposed as the quantum leap in harnessing communication and information technologies to enhance grid reliability, and to enable integration of various smart grid resources such as renewable energy, demand response, electric storage and electric transportation. It allow greater competition between the providers, enabling greater use of intermittent power resources,

establishing the wide area automation and monitoring capabilities needed for both bulk transmission over wide distances and distributed power generation, empowering more efficient outage management, streamline back office operations, aiding the use of market forces to drive retail demand response and energy conservation.

The proposed vision of introducing viable Smart Grid (SG) at various levels in the Indian power systems has recommended that an advanced automation mechanism needs to be adapted. Smart Grids are introduced to make the grid operation smarter and intelligent. Smart grid operations, upon appropriate deployment can open up new avenues and Opportunities with significant financial implications. This work presents various Smart grid initiatives and implications in the context of power market evolution in India. Various examples of existing structures of automation in India are employed to underscore some of the views presented in this report. It also reviews the progress made in Smart grid technology research and development since its inception. Attempts are made to highlight the current and future issues involved for the development of Smart Grid technology for future demands in Indian perspective.
*[ref: Balijepalli V.S.K.M.]*

With the introduction of the Indian Electricity Act 2003, the APDRP was transformed to restructured APDRP (R-APDRP) which has improvised the operation and control, and has attempted a seamless integration of generation (including distributed energy resources (DER), transmission and distributed system through usage of intervening information technology (IT) that uses high speed computers and advance communication network, and employing open standard with vendor-neutrality is deemed a cornerstone for embracing the up-and-coming conceptualization of Smart Grid for India scenario.
*[ref: http://www.ipds.gov.in/Default_RAPDRP.aspx accessed on 20.08.2019]*

To augment the socio-economic development and meet the energy demand, large power plants were being installed and are being transmitted over HV transmission lines across different power deprived regions. But, such engrossment not only surges huge investment, but also invites numerous non-technical issues based on environment and judiciary matters. In order to regulate the world-wide power market and bringing down the ambiguous events in power system, power sectors are flourishing with new advancement in technology, by initiation of non-technical principles such as Energy Management System (EMS), Demand Side Management (DSM), optimized Assets Management etc.

In addition to this, the new emerging technologies like Wide Area Monitoring System (WAMS), Phase Measurement Units (PMUs), Distributed Energy Resources (DER), Flexible AC Transmission System (FACTS) etc. enriches the modern power system and buzzes to new opportunities. In the nearest future the world will overcome a major problem, the issue of demographic deviation in developing and developed countries. The development goes hand in hand with an unremitting reduction in non-renewable energy resources.

*[ref: C.Martinez]*

As the report only had pulled the grid connection requirement for wind power generation, which has been planned to stretch upon to the study of photovoltaic (PV) and its grid connection planning in Indian scenario. Also, few more work related to micro grids and hybrid energy with energy storage system is premeditated to complete by near future. Upon the finalizing of the entire study, research perspective would deliberately act as an advocate to discover the rank and strategy of nation's development in power and energy with respect to current and future energy demand.

India's energy generation and consumption are on high growth rate. Climatic change concerns due to emission combined with resource and infrastructure constraints are dampers. With nearly 40% of its 1.3 billion population deprived of grid electricity, present installed power capacity may have to be doubled by the end of this decade to meet energy need of its growing population and expectations of a high GDP growth economy. An overview of Indian Power Market along with brief analysis about the power system unit is described. Power market in India is generally characterized by the poor demand side management and response for lack of proper infrastructure and awareness. Smart Grid Technology can intuitively overcome these issues.

In addition to that, it can acknowledge reduction in line losses to overcome prevailing power shortages, improve the reliability of supply, power quality improvement and its management, safeguarding revenues, preventing theft etc.. Integration of RES is expected to play significant influence on the operation of the power system for sustainable energy in future. Grid codes are set up to specify the relevant requirements for efficient and secure operation of power system for all network users and these specifications have to be met in order to integrate wind turbine into the grid. Several technical and operational issues with increased power penetration has discussed for emerging Indian power system. *[ref: Jhadav G.N]*

# CHAPTER – 1 : INTRODUCTION:

## 1.1. OVERVIEW

The global energy deficiency has directly foiled the economics, society, development of the nations, and environments through greenhouse gases (GHGs) and by gaining carbon credits. The growing demand of power across the globe is being envisaged and logged to be exponential. Lack of asset with outdated network infrastructure, climate change, rising fuel costs, has resulted inefficient and increasingly unstable electric system.

***1.1.1 Fossil fuel deadlock:*** Raising energy demand is knocking pressure on fossil fuel supply and now oil exploration towards "unconventional" oil resources. Switching from fossil fuels to renewables also offers substantial benefits such as independence from world market fossil fuel prices and the creation of millions of new green jobs. It can also provide energy to the two billion people currently without access to energy services. A closer look at the measures required to phase-out oil faster in order to save the Arctic from oil exploration, avoid dangerous deep sea drilling projects and to leave oil shale in the ground are well thought-out. The changeover from the fossil-driven based energy sources to the renewable energy sources (RES) is being addressed globally according to significant benchmarks. The dynamic characteristics of the RESs and its developing sparingly sustainable means to produce energy with less environmental challenges, is one of its foremost.

***1.1.2 Climatic change threat:*** The threat of climate change, caused by rising global temperatures, is the most significant environmental challenge being encountered by the world since the beginning of the 21$^{st}$ century. It has major implications for the world's social and economic stability, its natural resources and in particular, the way we produce our energy.

In order to avoid the most catastrophic impacts of climatic change, the global temperature increase must be kept as far below 2°C as possible. The main greenhouse gas is carbon dioxide ($CO_2$) produced by using fossil fuels for energy and transport. Keeping the global temperature until 2°C is often referred to as a 'safe level' of warming; beyond which unacceptable risks to the world's key natural and human systems might occur. Even with a 1.5°C warming, increase in drought, heat waves and floods, along with other adverse impacts such as increased water stress for up to 1.7 billion people, wildfire frequency and flood risks, are projected in many regions. Partial de-glaciation of the Greenland ice sheet, and possibly the West Antarctic ice sheet, could even occur from additional warming within a range of 0.8 – 3.8°C above current levels. If rising temperatures are to be kept within acceptable limits then we need to significantly reduce our GHG emissions.

***1.1.3 Global negotiation:*** In 1961 to stimulate economic progress and world trade, a forum of countries committed to democracy and the market economy, providing a platform to compare policy experiences, seek answers to common problems like global warming, and identify good practices and co-ordinate domestic and international policies of its members, like fortification of renewable energy. This lead to the formation of the Organization for Economic Co-operation and Development (OECD), and the member

Nations are high income economies with a very high Human Development Index (HDI) and are regarded as developed countries. Also, recognizing the global threats of climate change, the signatories to the 1992 UN Framework Convention on Climate Change (UNFCCC) agreed to the Kyoto Protocol in 1997. The Protocol entered into force in early 2005 and its 193 members meet continuously to negotiate further refinement and development of the agreement. In 2009, the UNFCCC were not able to deliver a new climate change agreement towards ambitious and fair emission reductions. At the 2012 Conference, there was agreement to reach a new agreement by 2015 and to adopt a second commitment period at the end of 2012. The proposed mitigation pledges put forward by governments are likely to allow global warming to at least 2.5 to 5 degrees temperature increase above pre-industrial levels.

***1.1.4 Nuclear issues:*** To both climate protection and energy security, however their claims are not supported by data. The most recent Energy Technology Perspectives report published by the International Energy Agency (IEA) includes a Blue Map scenario including a quadrupling of nuclear capacity between current years and 2050. To achieve this, the report says that on average 32 large reactors (1,000 MW each) would have to be built every year from now until 2050. According to the IEA's own scenario, such massive nuclear expansion would cut carbon emissions by less than 5%. More realistic data analysis shows the past development history of nuclear power and the global production capacity make such expansion extremely unviable. With a temperament of its catastrophic aftermath and its indispensable biohazard activities, during the past situations and the future valuations, many reactors has been terminated and slowdown in various expanses across the sphere. Japan's major nuclear accident at Fukushima in March 2011 following a tsunami came 25 years after the devastating explosion in the Chernobyl Nuclear Power Plant, illustrating the inherent risks of nuclear energy. Nuclear energy is simply unsafe, expensive, has continuing waste disposal problems and cannot reduce emissions by a large enough amount. In contrast, renewable energy is also a viable solution for replacing the world's elusive, hazardous and intolerably expensive nuclear energy.

***1.1.5 Climate change and security of supply:*** Access to both supplies and financial stability is now at the top of the energy policy agenda. Rapidly fluctuating oil prices are lined to a combination of many events, however one reason for these price fluctuations is that supplies of all proven resources of fossil fuels are becoming infrequent and more expensive to produce. Some 'non-conventional' resources such as shale oil have become economic, with devastating consequences for the local environment. Uranium, the fuel for nuclear power, is also a finite resource. By contrast, the reserves of renewable energy that are technically accessible globally are large enough to provide more than 40 times more energy than the world currently consumes, forever, according to the latest IPCC Special Report Renewables (SRREN). Cost reductions in just the past two years have changed the economics of renewables fundamentally, especially wind and solar photovoltaic (PV) along with the common features like, emission of little or no GHG and are a virtually inexhaustible fuel. Some technologies are already competitive; the solar and the wind industry have maintained double digit growth rates over 10 years now, leading to faster technology deployment worldwide.

***1.1.6 Energy efficiency:*** The most cost competitive way to reform the energy sector. There is enormous potential for reducing our consumption of energy, while providing the same level of energy services. New business models to implement energy efficiency must be developed and must get more political support. The challenge ahead will require an innovative power system architecture involving both new technologies and new ways of managing the network to ensure a balance between fluctuations in energy demand and supply. The key elements of this new power system architecture are micro grids, smart grids and an efficient large scale super grid, which could play a dynamic role in remodeling the global energy scenario with factors like policies, regulation, and efficiency of market with costs, benefits and services which also normalizes the power and energy market with the reduction of carbon footprints and foot dragging the GHG emissions.

*[ref: Balijepalli V.S.K.M.]*

## 1.2 BACKGROUND.

The economic growth of a nation, depends heavily on reliability and eminence of its electric power supply. Global energy demands are expected to grow by 60% over the next 25 years subjected to three significant factors; population growth, rate of gross domestic product (GDP) and energy intensification. This has the potential to cause a significant increase in GHG emissions associated with climate change. Secure, reliable and affordable energy sources are fundamental to economic stability and development. Rising energy demand poses a challenge to energy security given increased reliance on global energy markets. The electricity industry, in particular in the industrialized world, holds an important and pro-active role in providing solutions to security of supply and to reduction of GHG emissions with economically feasible solutions. Achieving this transition, the power industry has only increased several challenges for the power system. Innovative power system architectures at various level in power system involving both new technologies and new ways of managing the network to ensure a balance fluctuations in energy demand and supply are incorporated. In addition, RES which continued to cultivate strongly in all end-use segments, delivering close to 20% of global electricity supply in 2010, and expected to procure 39% and 77% of the global power supply from all sources by 2030 and 2050 as per recent market policy. It will play an essential role in advancing development by improving the access of millions to energy, whilst helping ensure energy security, and mitigating the existential risk of climatic change by reducing emission.

The power market in India is characterized with poor demand side management (DSM) and consequences on technical and non-technical aspects with response to lack of proper infrastructure and awareness. In order to mitigate these preventable challenges, the innovative power system architecture with incorporation of RES can acknowledge reduction in line losses to overcome prevailing power shortages, improve the reliability of supply, power quality improvement and its management, safeguarding revenues, preventing theft etc.. The future pathways for India's energy demand has been shown in Fig. I.1 [1].

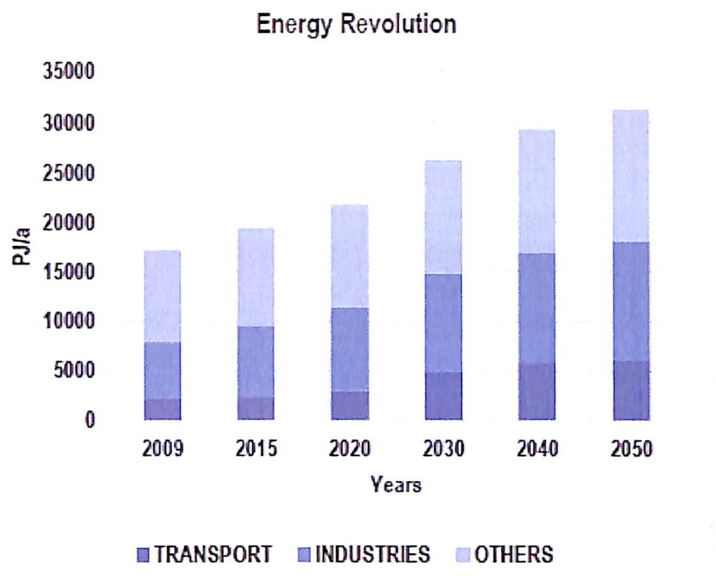



Fig I.1 (a)

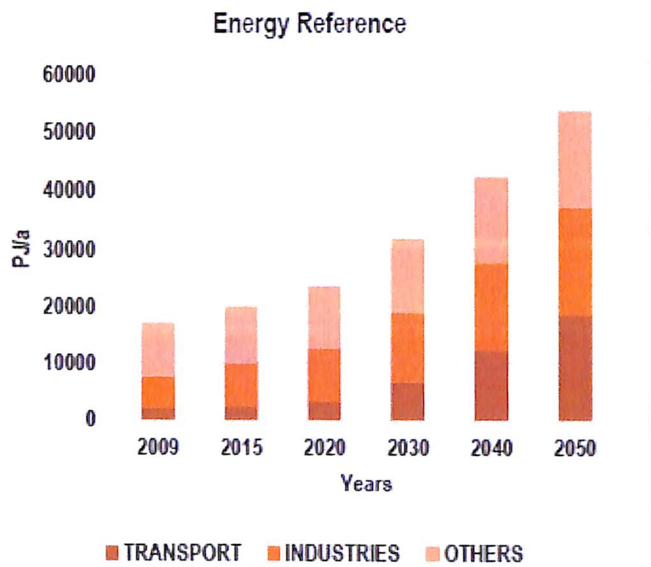



Fig I.1 (b)

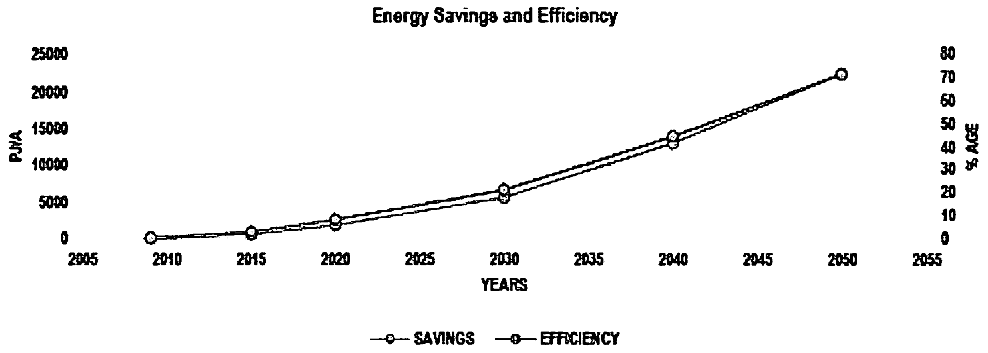



Fig I.1 (c)

**Fig. I.1: Indian Final Energy Demand.**

(a) Indian energy demand as per Energy Revolution (ER)* Scenario.

(b) Indian energy demand as per Energy Reference (RE)* Scenario.

(c) Comparative study shows the results in change in energy consumption projected as savings** and efficiency**.

**efficiency corresponds the reduction compared to the Energy Reference.

PJ/a is Peta Joules per annum.

*[ref: www.mnes.nic.in]*

***POINT TO REMEMBER**

***Energy Revolution*** is projected to achieve certain policy target designed by Nation's policy maker to build a sustainable world with implication of RES.

***Energy Reference*** is reflecting the current trends and policy as similar to classical times. The development of the electricity supply market is characterized by dynamically growing RES market and an increasing share of renewable electricity. It preferably acts and will compensate for the phasing out of the nuclear energy and reduce the number of fossil fired power plants required for grid stabilization.

By 2050, around 92% of electricity power generation would be by renewable energy fired power station, where wind, PV and solar thermal would contribute 71% of electricity generation. The installed capacity would rise from 52 % in 2030 to 94% in 2050 by 1149 GW. This would therefore marks the expansion of smart grids, DSM and storage capacity with the increase share of electric vehicles (EVs) for a better grid integration and power generation management. The generation structure of India has been shown in Fig. I.2.

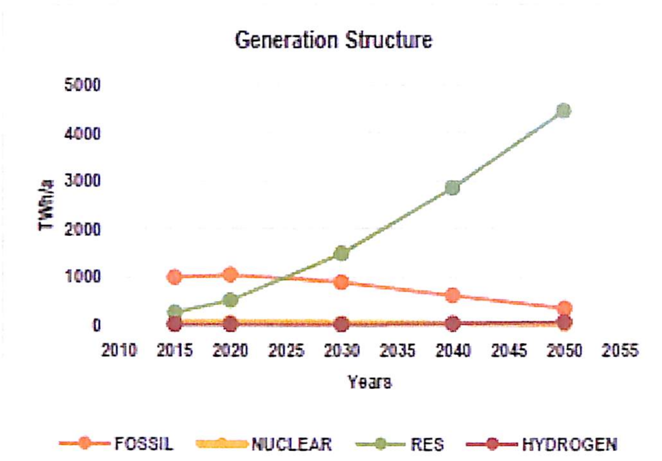



Fig I.2 (a)

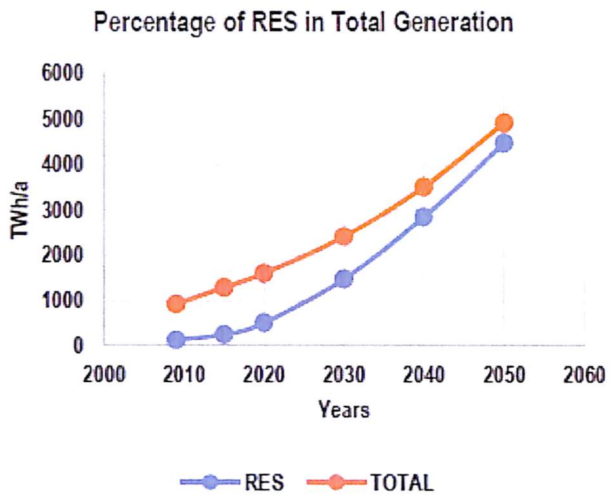



Fig I.2 (b)

**Fig. I.2: Indian Generation Structure.**

(a) Indian generation structure based on various sources.

(b) Comparative study on RES share w.r.t total generation.

*fossil includes coal, lignite, oil, natural gas and diesel

TW/h is Tera Watt per annum.

In account, considering the rise in distribution by 27.8 %, 53.6 % rise in own consumption electricity, and the electricity required for the production of hydrogen estimated around 99.7 %, the so estimated electricity generation reduces to 4053 TWh/a. Whilst India's emissions of $CO_2$ will decrease from 1,704 million tons in 2009 to 426 million tons in 2050.

Annual per capita emissions will fall from 1.4 tons to 1 ton in 2030 and 0.3 tons in 2050. In the long run, efficiency gains and the increased use of renewable electricity in vehicles will also significantly reduce emissions in the transport sector. With a share of 34% of $CO_2$ emissions in 2050, the transport sector will remain the largest energy related source of emissions. By 2050, India's $CO_2$ emissions are 72% of 1990 levels. Fig. I.3 depicts a clear idea of the development of the $CO_2$ emission as per sectors.

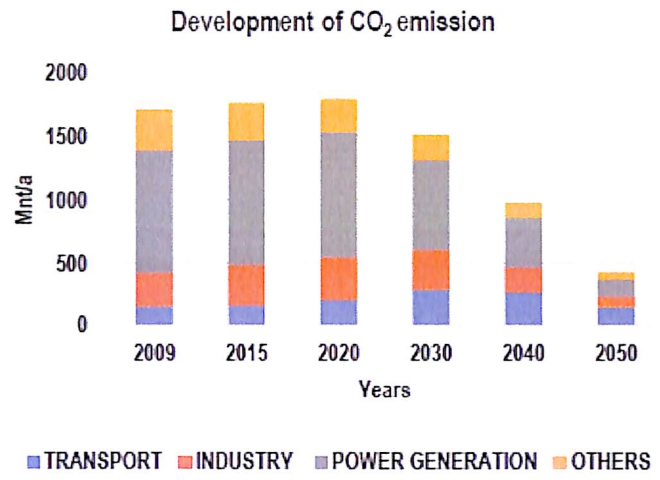



Fig I.3 (a)

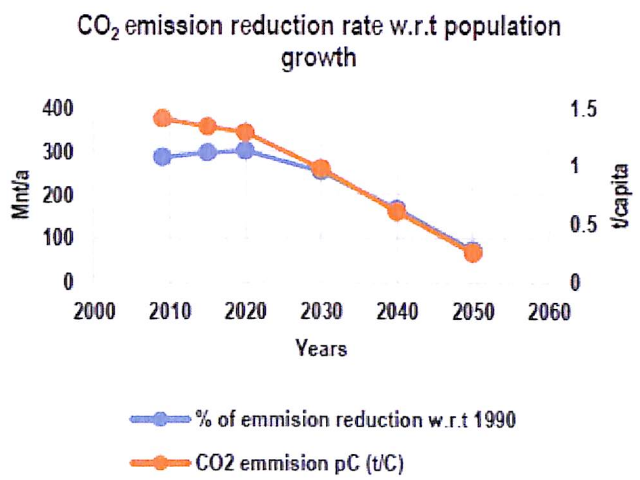



Fig I.3 (b)

**Fig. I.3: Development of $CO_2$ emission in India.**

(a) By sector-wise.

(b) Reduction of $CO_2$ emission w.r.t 1990 and per capita analysis.

Mnt/a is Million ton per annum

Around 81% of the remaining demand (including non-energy consumption) will be covered by renewable energy sources. The phases out coal and oil about 10 to 15 years faster than the previous Energy Revolution scenario published in 2010. This is made possible mainly by replacement of coal power plants with renewables after 20 rather than 40 years lifetime and a faster introduction of electric vehicles in the transport sector to replace oil combustion engines. This leads to an overall renewable primary energy share of 48% in 2030 and 81% in 2050. Nuclear energy is phased out just after 2045.

The introduction of renewable technologies under the Energy Revolution scenario slightly increases the costs of electricity generation in India compared to the Reference scenario. This difference will be less than $ 1 cent/kWh up to 2020, however. Because of the lower $CO_2$ intensity of electricity generation, electricity generation costs will become economically favorable under the Energy Revolution scenario and by 2050 costs will be $ 7.2 cents/kWh below those in the Reference version. Under the Reference Scenario, by contrast, unchecked growth in demand, an increase in fossil fuel prices and the cost of $CO_2$ emissions result in total electricity supply costs rising from today's $100 billion per year to more than $ 932 billion in 2050. But, the Energy Revolution scenario not only complies with India's $CO_2$ reduction targets but also helps to stabilize energy costs. Increasing energy efficiency and shifting energy supply to renewables lead to long term costs for electricity supply that are 23% lower than in the Reference scenario.

Fig. I.4 illustrates the total electricity supply cost and total electricity generation costs fewer than two scenarios.

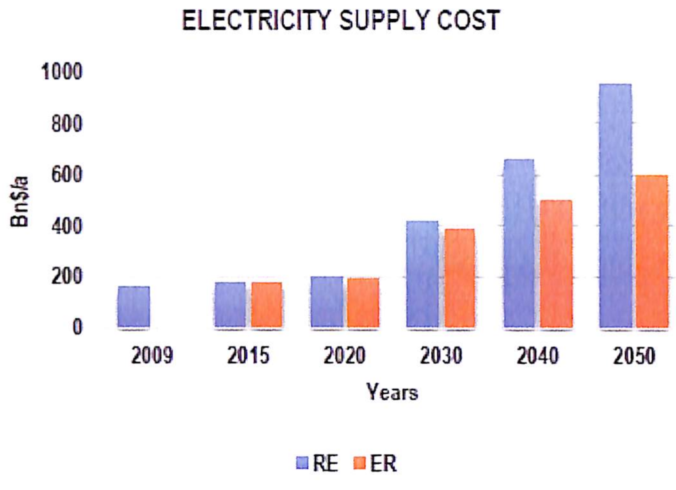



Fig I.4 (a)

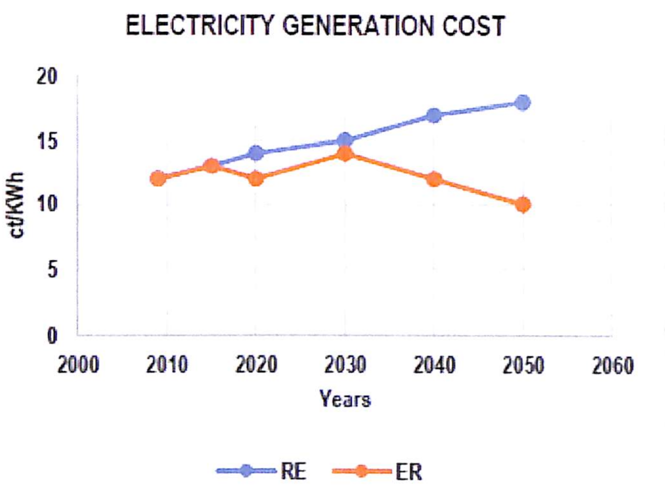



Fig I.4 (b)

**Fig. I.4: Comparative study under two scenario upon costs.**

(a) Total electricity supply costs

(b) Specific electricity generation costs.

Bn$/a is Billion $ per annum and ct/kWh is cents per kWh

It would require about \$ 4,775 billion in additional investment for the Energy Revolution scenario to become reality (including investments for replacement after the economic lifetime of the plants) - approximately \$ 119 billion annually or \$ 69 billion more than in the Reference scenario (\$ 1,905 billion). Under the Reference version, the levels of investment in conventional power plants add up to almost 56% while approximately 44% would be invested in renewable energy and cogeneration (CHP) until 2050.

Under the Energy Revolution scenario, however, India would shift almost 97% of the entire investment towards renewables and cogeneration. Until 2030, the fossil fuel share of power sector investment would be focused mainly on CHP plants. As, renewable energy has no fuel costs, however, the fuel cost savings in the Energy Revolution scenario reach a total of \$ 5,500 billion up to 2050, or \$ 138 billion per year.

The total fuel cost savings here fore would cover 200% of the total additional investments compared to the Reference scenario. These renewable energy sources would then go on to produce electricity without any further fuel costs beyond 2050, while the costs for coal and gas will continue to be a burden on national economies. The future investments shares of different sources are shown in Fig. I.5

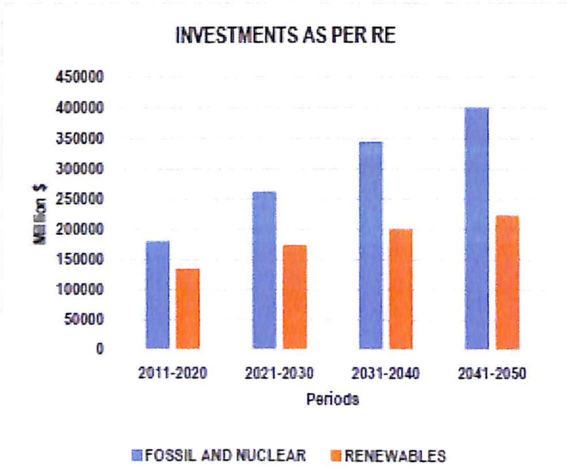



Fig I.5 (a)

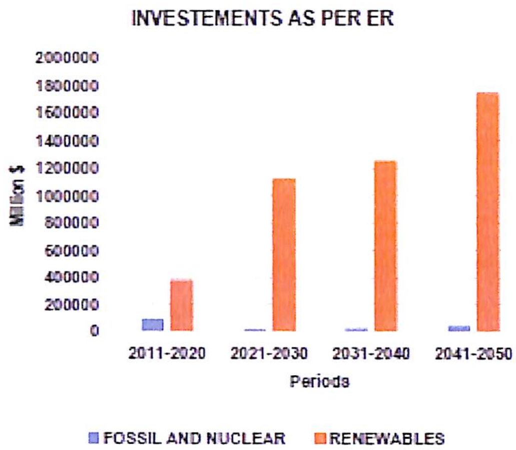



Fig I.5 (b)

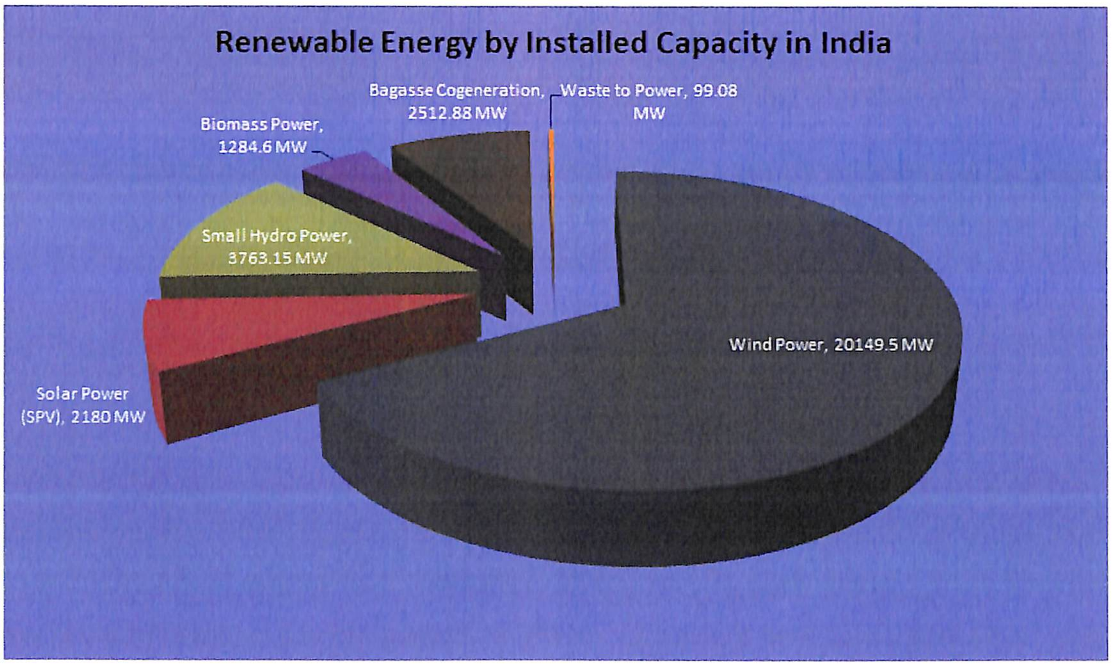



**Fig. I.5: Total investment in power sector in India.**

(a) Total investment in Reference Energy Scenario.

(b) Total investment in Energy Revolution Scenario.

(c) Renewable Energy by Installed capacity in India.

*Source (https://www.power-technology.com/features/100-renewable-india-can-done/)*

The Indian Electricity Grid Code (IEGC) outlines the minimum technical grid connection requirements that new and renewable energy and associate systems at the connection point to the transmission network have to provide safe and reliability operation of the system. The new connection shall not cause any adverse effect to the electric grid which shall continue to perform with specified reliability, security, and quality as per the central electricity authority (CEA) regulations, as and when they come into force.
These developments must clearly indicate the need to search for effective solutions to alleviate the negative impacts, if any, of the large scale integration of renewable energy (like wind power) to the grid so that the benefit of the renewable energy source can be maximized.

These grid code requirements and specific grid codes (like *Indian electricity grid code for wind farm, IEGCWF*) must be read in conjunction with the following:

(a) Indian electricity grid code (IEGC) issued by central electricity regulatory commission CERC.

(b) Technical standards for connectivity to the grid, Regulations 2007, issued by CEA.

(c) State electricity grid codes issued by respective states of India.

Incorporation of RES into the existing bulk generation power system can be accomplished through smarter power grid when integration also includes complex, end-to-end control strategies and consumer incentives to participate. These kind of involvement leads to decentralization of power. As such, a new concept of micro grid, virtual power plant (VPP) and hybrid energy system develops, integration and optimization of grid control logic are areas that stand as key enablers to rapid growth of renewable generation
*[Reference: Central Electricity Authority. Technical standard for connectivity to the grid. Regulations 2007; 2007].*

## 1.3. PURPOSE OF THE STUDY

The study says that this fundamental shift in the way we consume and generate energy must begin immediately and be well ongoing within the next ten years in order to avert the worst impacts of climate change. The scale of the challenge requires a complete transformation of the way we produce, consume and distribute energy, while maintaining economic growth. The five key principles behind this Energy Revolution will be to:

- *Implement renewable solutions, especially through decentralized energy systems and grid expansions.*
- *Respect the natural limits of the environment.*
- *Phase out dirty, unsustainable energy sources.*
- *Create greater equity in the use of resources.*
- *Decouple economic growth from the consumption of fossil fuels.*

Decentralized energy systems, where power and heat are produced close to the point of final use, reduces grid loads and energy losses in distribution. Investments in 'climate infrastructure' such as smart interactive grids and transmission grids to transport large quantities of offshore and onshore wind and concentrating. solar power and PV are essential. Building up clusters of renewable *micro grids*, especially for people living in remote areas, will be a central tool in providing sustainable electricity to the almost two billion people around who currently don't have access to electricity.

## 1.4. RESEARCH HYPOTHESIS

Renewable energy sources account for 25.4% of the India's primary energy demand in 2009. The main source is biomass, which is mostly used in the heat sector. For electricity generation renewables contribute about 13% and for heat supply, around 55.4%, much of this is from traditional uses such as firewood.

About 86.9% of the primary energy supply today still comes from fossil fuels and 1.95% from nuclear energy.

The Energy Revolution scenario describes development pathways to a sustainable energy supply, achieving the urgently needed $CO_2$ reduction target and a nuclear phase-out, without unconventional oil resources. The results of the Energy Revolution scenario upon Indian context, which will be achieved through the following measures:

***1.4.1 Curbing Indian Energy Demand*** The Indian energy demand is projected by combining population development, GDP growth and energy intensity. Under the Reference scenario, total primary energy demand increases by 206.2% from about 29 EJ (Exajoules) per year in 2009 to 88 EJ per year in 2050.

In the Energy Revolution scenario, demand increases by only 23.7% compared to current consumption until 2020 and increases slightly afterwards to 2050.

***1.4.2 Controlling Indian Power Demand*:** Under the Energy Revolution scenario, electricity demand is expected to increase disproportionately, the main growth in households and services. With adequate efficiency measures, however, a higher increase can be avoided, leading to electricity generation of around 4,258 TWh/a in 2050. Compared to the Reference scenario, efficiency measures avoid the generation of 812 TWh/a.

***1.4.3 Reducing Indian Heating Demand:*** Efficiency gains in the heat supply sector are even larger than in the electricity sector. Compared to the Reference scenario, consumption equivalent to 3,562 PJ/a. is avoided through efficiency measures by 2050. The lower demand can be achieved by energy-related renovation of the existing stock of buildings, introduction of low energy standards; even '*energy-plushouses*' for new buildings, with same comfort and energy services.

***1.4.4 Development of Indian Industry Energy Demand:*** While the economic growth rates in the Reference and the Energy Revolution scenario are identical, the growth of the overall energy demand is different due to a faster increase of the energy intensity in the alternative case. Decoupling economic growth with the energy demand is key to reach a sustainable energy supply by 2050, the Energy Revolution scenario saves 40% less energy per $ GDP than the Reference case.

***1.4.5 Electricity generation:*** A dynamically growing renewable energy market compensates for phasing out nuclear energy and fewer fossil fuel-fired power plants. By 2050, 92% of the electricity produced worldwide will come from renewable energy sources. 'New' renewables – mainly wind, PV and ocean energy – will contribute 40% of electricity generation. The Energy Revolution scenario projects an immediate market development with high annual growth rates achieving a renewable electricity share of 32% already by 2020 and 62% by 2030. The installed capacity of renewables will reach almost 718 GW
in 2030 and 1,446 GW by 2050.

***1.4.6 Future costs of electricity generation:*** Under the Energy Revolution scenario the costs of electricity generation increase slightly compared to the Reference scenario. This difference will be less than $1 cent/kWh up to 2020. However, if fossil fuel prices go any higher than the model assumes, this gap will decrease. Electricity generation costs will become economically favorable under the Energy Revolution scenario by 2025 and by 2050, costs will be significantly lower: about 7.2 $cents/kWh – or 45% below
those in the Reference version.

***1.4.7 Future investment in power generation:*** The overall level of investment required in new power plants up to 2020 will be in the region of $ 11.5 trillion in the Reference case and $ 20.1 trillion in the Energy Revolution. For the Energy Revolution scenario until 2050 to become reality would require about $ 4,775 billion investment in the power sector (including investments for replacement after the economic lifetime of the plants). Under the Reference scenario, total investment would be split 48% to 52% between conventional power plants and renewable energy plus CHP up to 2050.

***1.4.8 Fuel costs savings:*** As, renewable energy has no fuel costs, however, the fuel cost savings in the Energy Revolution scenario reach a total of $ 5,500 billion up to 2050, or $ 138 billion per year. The total fuel cost savings here fore would cover 200% of the total additional investments compared to the Reference scenario.

***1.4.9 Heating supply:*** Renewables currently provide 55.4% of the Indian energy demand for heat supply, the main contribution coming from the use of biomass. In the Energy Revolution scenario, renewables provide 61% of the world's total heat demand in 2030 and 91% in 2050.

***1.4.10 Future investments in the heat sector:*** The heat sector in the Energy Revolution scenario would require a major revision of current investment strategies in heating technologies. In particular enormous increases in installations are required to realize the potential of the not yet common solar and geothermal technologies and heat pumps. Installed capacity needs to increase by a factor of 60 for solar thermal and by a factor of over 1,000 for geothermal and heat pumps which requires around $ 18.48 billion investment

in renewable heating technologies up to 2050.

***1.4.11 Primary energy consumption:*** Under the Energy Revolution scenario the overall primary energy demand will be reduced by 80.2% in 2050 compared to the Reference scenario. In this projection almost the electricity supply, including the majority of the energy used in buildings and industry, would come from renewable energy sources. The transport sector, in particular aviation and shipping, would be the last sector to become fossil fuel free.

***1.4.12 Development of $CO_2$ emissions:*** $CO_2$ emissions under the Energy Revolution scenario they will decrease from 1,704 million tons in 2009 to 426 million t in 2050. Annual per capita emissions will drop from 1.4 tons $CO_2$ to 1.0 tons $CO_2$ in 2030 and 0.3 tons $CO_2$ in 2050. Even with a phase out of nuclear energy and increasing demand, $CO_2$ emissions will decrease in the electricity sector. With a share of 33% of $CO_2$ emissions in 2050, the transport sector will be the main source of emissions ahead of the industry and power generation.

To make the Energy Revolution real and to avoid dangerous climate change, Greenpeace, GWEC, EREC, MoP, MNRE, Smart Grid Task Force, Smart Grid Forum, CERC, CEA etc. demand that the following policies and actions are implemented in the energy sector:

**1.** Phase out all subsidies for *fossil fuels* and *nuclear energy*.
**2.** Internalize the external (social and environmental) costs of energy production through '*cap and trade*' emissions trading.
**3.** Mandate strict *efficiency standards* for all energy consuming appliances, buildings and vehicles.
**4.** Establish legally binding targets for *renewable energy* and *combined heat and power generation*.
**5.** Reform the *electricity markets* by guaranteeing priority access to the grid for renewable power generators.
**6.** Provide defined and stable returns for investors, for example by *feed-in tariff programme*.
**7.** Implementation of *grid connection planning* for steady interconnection of RES into the existing grid.
**8.** Development of *standalone system, microgrid, hybrid energy system* along with *energy storage* system.

**9.** Incorporation of *Information, Communication and Technology (ICT)* in the prevailing power grid.

The thesis proposes a serious discussion of the significant renewable energy generation which can wage against the existing power system and how sophisticated smart grid control elements can address its integration into distributed energy systems in India. In addition, it has also address various grid code strategies, requirements and codes for wind power and PV integration in India and discusses several technical and operational issues arising due to high penetration of renewable power generation in Indian power systems.

The role of enabling technologies, automation and communication for sustainable development of smart grid is also explained here. In addition, this study designates about the microgrid initiatives and development of hybrid energy system, along with various examples of existing structures of automation in India. It also reviews the encroachment made in such technology in R&D, initiated by various public and private sector organizations supported by prominent institutions across the globe.

Limelight on the current and future issues involved for the development of Smart Grid technology for future demands has also been contested.

*[Ref: http://powermin.nic.in]*

# CHAPTER 2: LITERATURE REVIEW.

## 2.1 Review Area Broad.

To augment the socio-economic development and meet the energy demand, large power plants were being installed and are being transmitted over HV transmission lines across different power deprived regions. But, such engrossment not only surges huge investment, but also invites numerous non-technical issues based on environment and judiciary matters. In order to regulate the world-wide power market and bringing down the ambiguous events in power system, power sectors are flourishing with new advancement in technology, by initiation of non-technical principles such as Energy Management System (EMS), Demand Side Management (DSM), optimized Assets Management etc.

In addition to this, the new emerging technologies like Wide Area Monitoring System (WAMS), Phase Measurement Units (PMUs), Distributed Energy Resources (DER), Flexible AC Transmission System (FACTS) etc. enriches the modern power system and buzzes to new opportunities. In the nearest future the world will overcome a major problem, the issue of demographic deviation in developing and developed countries. The development goes hand in hand with an unremitting reduction in non-renewable energy resources.

Renewable energy is "*a form of energy from solar, geophysical or biological sources that is replenished by natural process at a rate that equals or exceed its rate of use.*" These covers a range of natural sources which are constantly renewed and therefore, unlike fossil fuels and uranium, will never be exhausted.

They are obtained from the continuing and repetitive flows of energy occurring in the natural environment and includes resources such as **biomass, solar energy, geothermal heat, hydropower, tide and waves and ocean thermal energy, and wind energy.**

The RES exploitation is mainly a question of how to convert solar, wind, biomass or hydro into electricity, heat or power as efficiently, sustainably and cost-effectively as possible. So as a consequence, it is worth understanding the upper limits of their potentials and by when this potential can been exploited. The typical potentials under which RES are subjected for utilizations is categorized in table II.1.

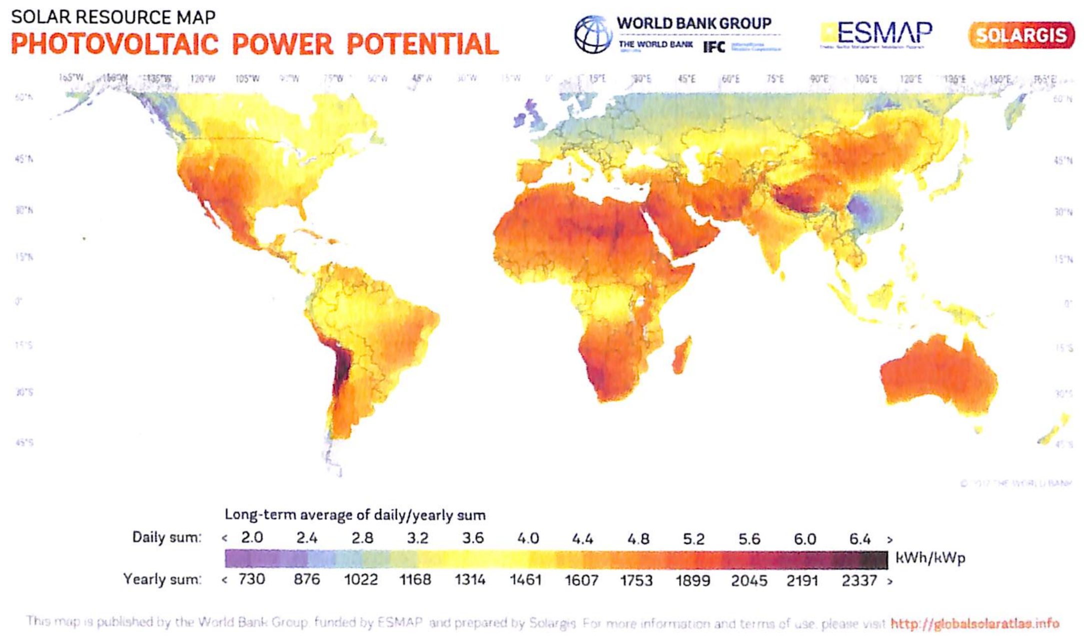
**Table II.1**

Definition of types of energy resource potential.

| ENERGY RESOURCE POTENTIALS | |
|---|---|
| **Theoretical Potential** | The physical upper limit of the energy available from a certain source or maximum power point (MPP) |
| **Conversion Potential** | This is derived from the annual efficiency of the respective conversion technology. It is therefore not a strictly defined value, since the efficiency of a particular technology depends on technological progress. |
| **Technical Potential** | This takes into account additional restrictions regarding the area that is realistically available for energy generation. Technological, structural and ecological restrictions, as well as legislative requirements, are accounted for. |
| **Economic Potential** | The proportion of the technical potential that can be utilized economically. |
| **Sustainable Potential** | This limits the potential of an energy source based on evaluation of ecological and socioeconomic factors. |

The overall technical potential of renewable energy is huge and several times higher than current total energy demand. Technical potential is defined as the amount of renewable energy output obtainable by full implementation of demonstrated technologies or practices that are likely to develop. It takes into account the primary resources, the socio-geographical constraints and the technical losses in the conversion process. Calculating renewable energy potentials is highly complex because these technologies are comparatively young and their exploitation involves changes to the way in which energy is both generated and distributed. The technical potential is dependent on a number of uncertainties, e.g. a technology breakthrough, for example, could have a dramatic impact, changing the technical potential assessment within a very short time frame i.e. the intermittent nature of the RES. Further, because of the speed of technology change, many existing studies are based on out of date information. More recent data, e.g. significantly increased average wind turbine capacity and output, would increase the technical potentials still further.

***2.1.1 Renewable Energy In India:*** With the study, in India it has been proven under Energy Revolution scenario that, around 67,076 $km_2$ area is intended to support for the 3,300 PJ of energy production per region and 542 PJ of energy production per capita by wind power, subjected to mean wind speed of 14-17 mph at 80m by 2050 as shown in Fig. II.1. Similarly, around 44,105 $km_2$ area is projected to support for the 12,254 PJ of energy production per region and 2,011 PJ of energy production per capita by solar power, subjected to horizontal irradiance level of 180-200 $Wm_{-2}$ by 2050 as shown in Fig. II.2. Upon such geophysical and climatic studies, the section further organizes the renewable energy sources (only wind and PV) and their technologies being used in India for the implementation and incorporation new and renewable energy to achieve a sustainable and promising energy revolution scenario.




*Source (https://en.wikipedia.org/wiki/Solar_power_by_country)*

*2.1.1.1 Wind Power:* Wind energy has grown faster than all other electricity sources in the last 20 years and turbine technology has advanced sufficiency that a single machine can power about 5,000 homes. The total potential for wind power in India was first estimated by the Centre for Wind Energy Technology (C-WET) at around 45 GW, and was recently increased to 48.5 GW. This Fig. was also adopted by the government as the official estimate.

*[ref: Ackermann T].*

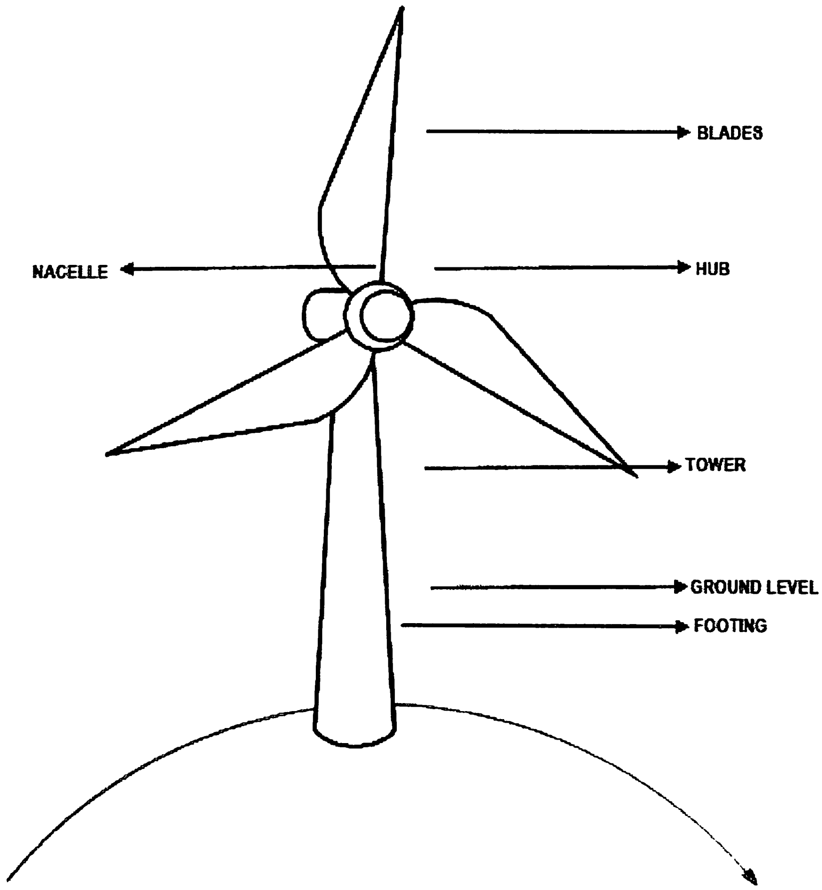
The C-WET study was based on a comprehensive wind mapping exercise initiated by MNRE, which established a country-wide network of 1050 wind monitoring and wind mapping stations in 25 Indian States. This effort made it possible to assess the national wind potential and identify suitable areas for harnessing wind power for commercial use, and 216 suitable sites have been identified.

Prior to the installation of a wind turbine or a wind farm, a specific test programme must be agreed with the area regarding the capability of the wind turbine or wind farm to meet the requirements in this connection code. As a part of the test programme, a simulation model of the wind turbine or wind farm must be provided in a given format and the model shall show the characteristics of the wind turbine or wind farm in both static simulations (load flow) and dynamic simulations (time simulations). The model shall be used in feasibility studies prior to the installation of the wind turbine or wind farm and the commissioning tests for the wind turbine or the wind farm shall include a verification of the model. These requirements are similar to the conventional power sources and mentioned in detail in IEGC and respective state electricity grid codes.

*2.1.1.2 Wind Turbine Design and Technology:* The wind measurements were carried out at lower hub heights and did not take into account technological innovation and improvements and repowering of old turbines to replace them with bigger ones. At heights of 55-65 meters, to replace them with bigger ones. At heights of 55-65 meters, the Indian Wind Turbine Manufacturers Association (IWTMA) estimates that the potential for wind development in India is around 65-70 GW. The World Institute for Sustainable

Energy, India (WISE) considers that with larger turbines, greater land availability and expanded resource exploration, the potential could be as big as 100 GW.

The wind resource out at sea is particularly productive and is now being harnessed by offshore wind parks with foundations embedded in the ocean floor. As of now, the horizontal axis design dominates, and most designs now center on the three blade, upwind rotor; locating the turbine blades upwind of the tower prevents the tower from blocking wind flow and avoid extra aerodynamic noise and loading as shown in Fig. II.3. Also, basic components present inside a wind turbine of a modern HAWT with gearbox is shown in Fig. II.4.




**FigII.3: Prototype of Horizontal Axis Wind Turbine (HAWT).**

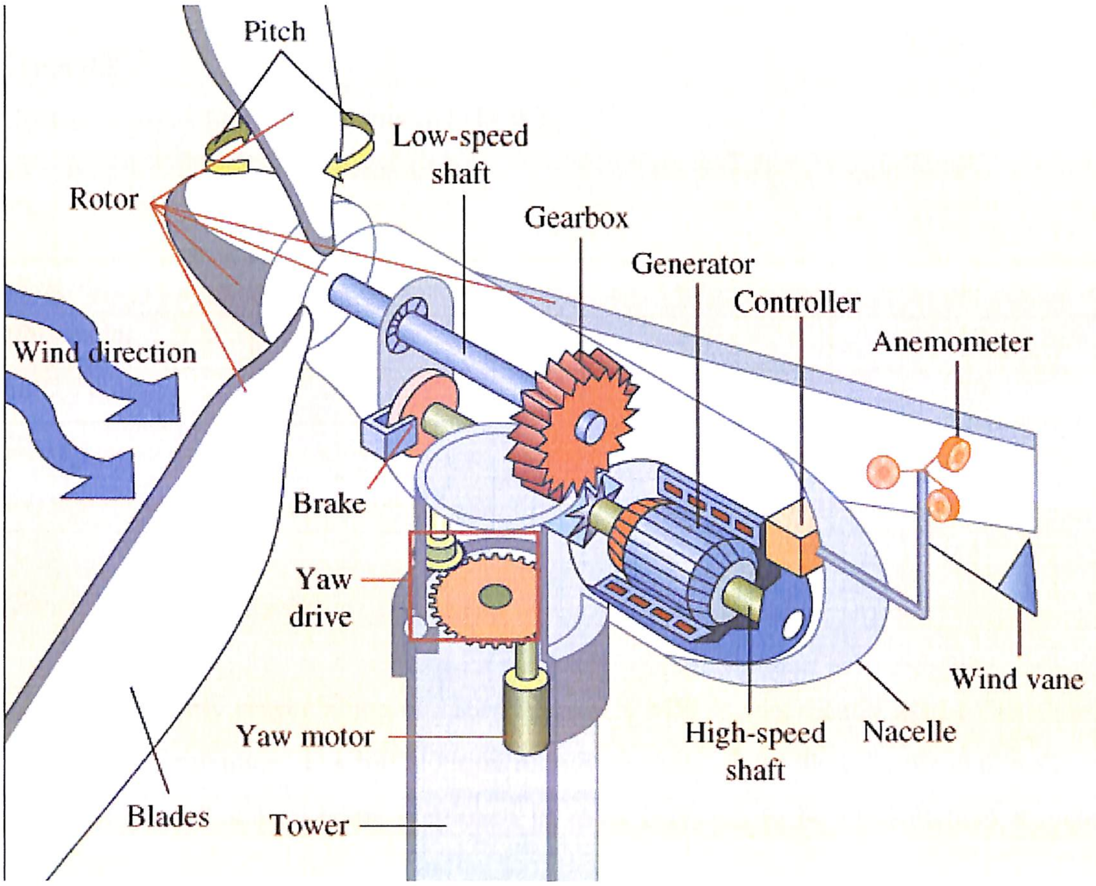



**Fig II.4 Basic components present inside a wind turbine of a modern HAWT.**

Modern wind turbine typically operate at variable speed using full-span blade pitch control. With the significant growth of advance science and turbine technology, onshore wind turbine has ominously increased from 3.5 to 7.5 MW, with 50-100 m high towers, along with 50-100 m rotor diameter. The typical speed of the rotor varies from 12-20 RPM. Eventually turbines are deigned larger in size to reduce cost of generation by improving power coefficient, reduce investment per unit of capacity and reduce operation and maintenance cost. Upon theoretical maximum limit of aerodynamic efficiency, modern turbine has proven the power coefficient to be near about 0.54-0.57 by 2015. Table II.2 shows a special report on growth in the size of typical wind turbines prepared by IPCC on global basis.

Table II.2

Growth in size of typical commercial HAWT.

| YEAR | POWER RATING (in KW) | TOWER HEIGHT (in m) | ROTOR DIAMETER (in m) |
|---|---|---|---|
| 1980-90 | 75 | 20 | 17 |
| 1995-2000 | 750 | 50 | 50 |
| 2005-10 | 1800 | 80 | 80 |
| 2010- | 5000 | 125 | 125 |
| Beyond 2030/2050 | 20000 | 180 | 250 |

*(Source: https://www.researchgate.net)*

In India, currently power rating of 1800kW i.e. 1.8 MW is specifically used for onshore wind power generation. The forthcoming section explains about the offshore and onshore wind energy technology being employed or even expected to be implemented in near future both on global context and Indian too.

Their up to date installed and potential capacity, along with issues and challenges has been briefly discussed certainly.

### *2.1.2 Onshore and Offshore Wind Farms*

**2.1.2.1 Onshore wind turbines** are grouped together in a large specified area resulting in huge generating capacity of around 10-100 MW, called wind farms. These kind of wind farms are active since the inception of the wind power technology in 1880 for non-electrical applications in Denmark. Eventually the wind power generation has stepped in electric power generation which has shaped the future of power and energy application. Since then large number of wind power generation plants are being set up across the world with optimization of technologies in every step of implementation. India has an installed capacity of around 17.64 GW of wind power generation which is purely onshore wind generation power.

But, for such kind of installation, there are engineering and logistics constraints to size because the components are transported via road. In that case, the evolution of **offshore wind turbine** has made its progression since 1977 in Europe, as the name suggest that they are setup on the sea generally in shallow water less than 30 m in depth. Apart from this, the higher value (>25 % than on onshore) of mean wind speed, reduction in fatigue loads (lower shear near hub height) with longer life span with dominant and stable wind direction adds to its advantages over onshore wind power. However, only 1.3% of the installed wind capacity is being shared by offshore wind power, across the globe. Considerable interest and implementation of the offshore wind power technology is being envisaged, likewise in Demark (around 209 MW offshore wind generation), despite of higher costs relative to onshore wind energy. Table II.3 show the development of offshore wind power since the inception to modern times.

**Table II.3**

**Offshore wind turbine development.**

| YEAR | REGION | POWER RATINGS IN (MW) | REMARKS |
|---|---|---|---|
| 1970 | Netherlands, Germany and Denmark | 0.5 | 1st prototype designed and tested OK |
| 2000 (1st generation MW class WT) | US, Denmark and Germany | 1 | Anti-corrosion feature, ship maintenance |
| 2000 (2nd generation MW class WT) | | 3-5 | Anti-corrosion feature with rotor dia. 90-115m robust design, high dependability and efficiency. |
| 2000 (3rd generation MW class WT) | US. Denmark and Germany | >5 | Rotor dia. 120, with higher energy yield |

*(Source: https://www.researchgate.net)*

Offshore wind turbine technology has been very similar to onshore designs, with some structural modifications and special foundation viz. HVDC electrical transmission sea link using UG cables, traditional concrete foundation, gravity and steel foundation, monopole foundation and tripod foundation.

Other design features include marine navigational equipment and monitoring and infrastructure to minimize expensive servicing.

At present, the global manufacturers like Vestas (Denmark), Bonus (Denmark), NEG-Micon (Denmark), GE Wind Energy (United States), Nordex (Germany), Enercon (Germany), REpower (Germany) are playing major role in R&D of the offshore wind power.

**2.1.2.2 Solar Power (Photovoltaic or PV):** There are more than enough solar radiation available all over the world to satisfy a vastly increased demand for solar power systems. The total installed for solar power (PV) in India is estimated by the National Solar Mission (NSM) at around 1095 MW, projected on January 2013. This Fig. was also adopted by the government as the official estimate. Upon the projected installment of PV, Gujarat shares highest of 41 % which counts 214 MW of the total PV generation in the country.

The overall efficiency of the conversion of solar power into usable electrical energy by the PV power system, comprising PV arrays, converters, cable connections, etc., is quite low (<6%). Because of the specific nature of its I-V characteristics, the output power is maximized at a specific load for a given level of solar insolation and cell temperature. Moreover, unlike a conventional power generating system, where the fuel input can be controlled depending on the power demand, the input can be controlled depending

50% of the total cost. Under these circumstances, it makes good economic sense to operate the solar array in such a way as to extract the maximum power for any isolation level and operating temperature.

A typical MPPT algorithm is being designed based upon incremental conductance method to track the maximum power upon voltage at maximum power point ($V_{MPP}$) and current at maximum power point ($I_{MPP}$). The algorithm and the results are being simulated in MATLAB environment as shown in Fig. II.5.

The maximum power of the PV module has been estimated at various level of irradiance and temperature as shown in Fig. II.6. Such kind of algorithm implementation helps to track maximum power at any variable environmental conditions.

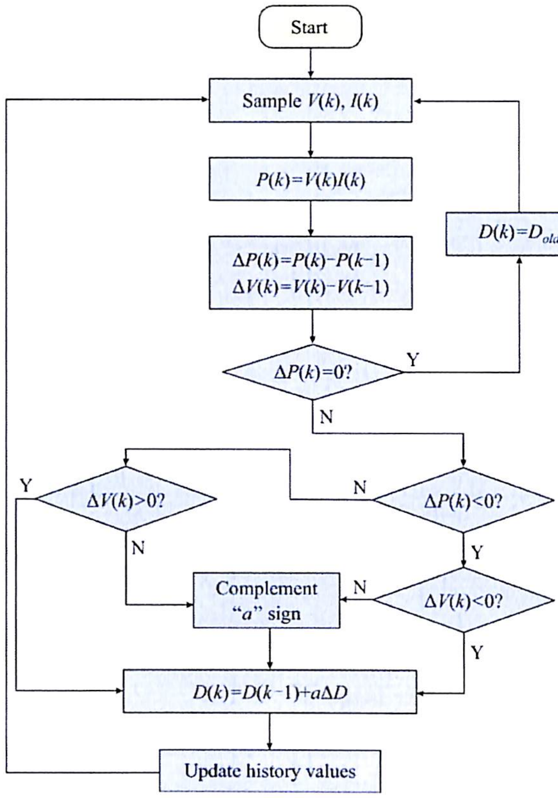



Fig: II.5 (a)

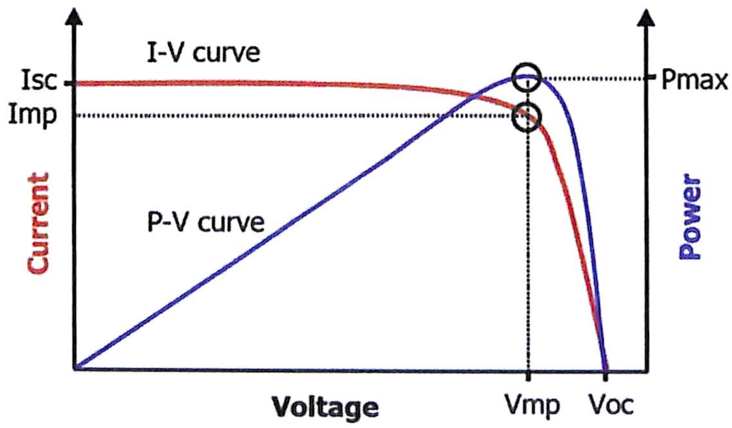



Fig: II.5 (b)

*(Source: https://www.powerelectronics.com)*

**Fig. II.5: MPPT for Photovoltaic (PV) System.**

(a) MPPT algorithm on incremental conductance method.

(b) P-V curve for PV system with $P_{MPP}$ and $V_{MPP}$ & I-V curve for PV system with $I_{MPP}$ and $V_{MPP}$

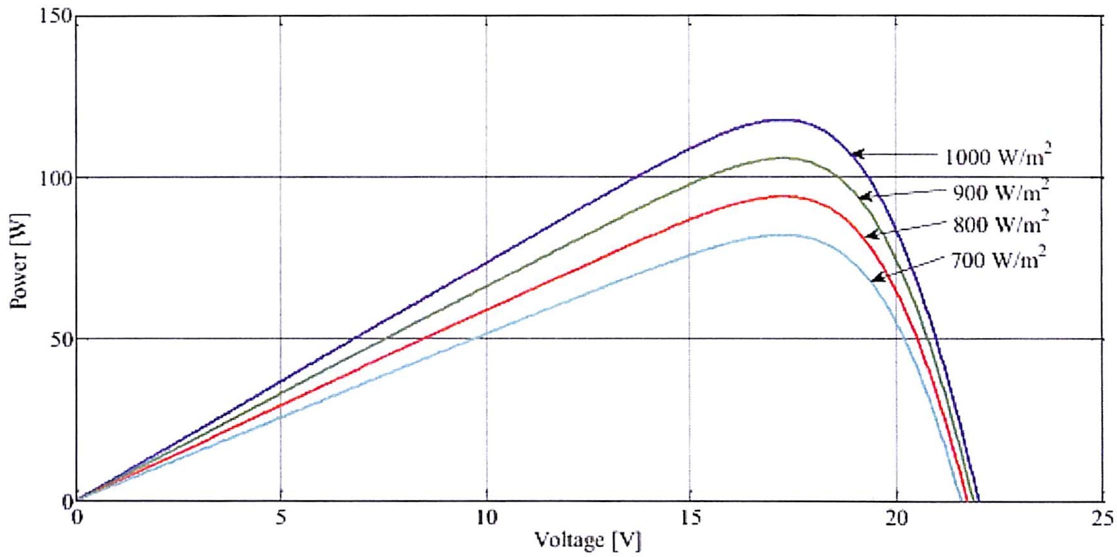



Fig: II.6(a)

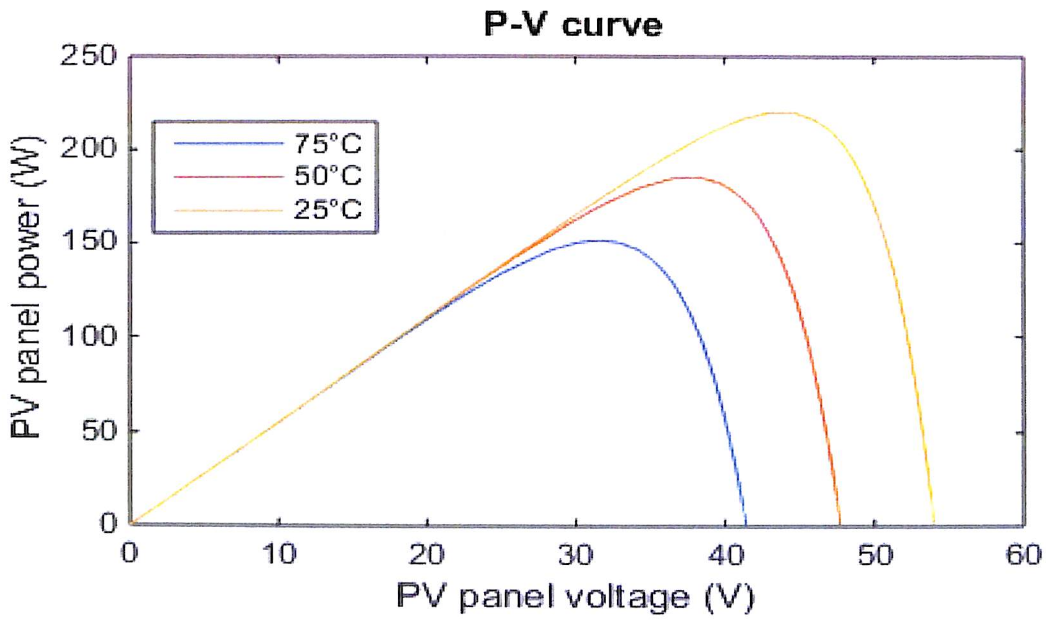



Fig: II.6(b)

**Fig. II.6: MPPT for Photovoltaic (PV) System Simulation Results**

(a) For different value of irradiance level and constant temperature (25°C).

(b) For different value of temperature and constant irradiance level (1000 W/m2).

*(Source: https://www.powerelectronics.com)*

*2.1.2a Photovoltaic (PV) Technology*

As the most important part of a PV system are the cells which form the basic building blocks, converting directly the light energy into electrical energy. The PV technology varies accordingly depending upon the geographic location of installation and mode of application, independent homes, colony, offices or public buildings. The major PV technologies are being described in table II.4.

**TableII.4:**

Major PV Technologies

| | | | |
|---|---|---|---|
| Crystalline Silicon Technology | Mono-crystalline Silicon PV Cell | Thin slices from single crystal of silicon | Cell thickness of 200-400μm, conversion efficiency 16-18% used in satellite powering system |
| | Poly-crystalline PV Cell | Block of silicon crystals | |
| Thin Film Technology | TFT PV Cell | Thin layer pf photosensitive material on a substrate such as glass, stainless steel or flexible plastic | TFT modules of Silicon (amp), CdTe, Cul/CuGa, Se2/S2, used in building integration and end consumer purposed. |
| Other Technologies | Amorphous PV cell | | - |
| | Spherical PV cell | | - |
| | Concentrated PV | Cells build into concentrating collectors using lens to focus sunlight onto the cells | - |
| | Organic PV cell | Active material consists at least partially of organic dye, small, volatile organic molecules or polymers | - |

*(Source: https://www.powerelectronics.com)*

A common photovoltaic (PV) technology has been illustrated with brief detailing about its basic components present inside a PV unit shown in Fig. II.7.

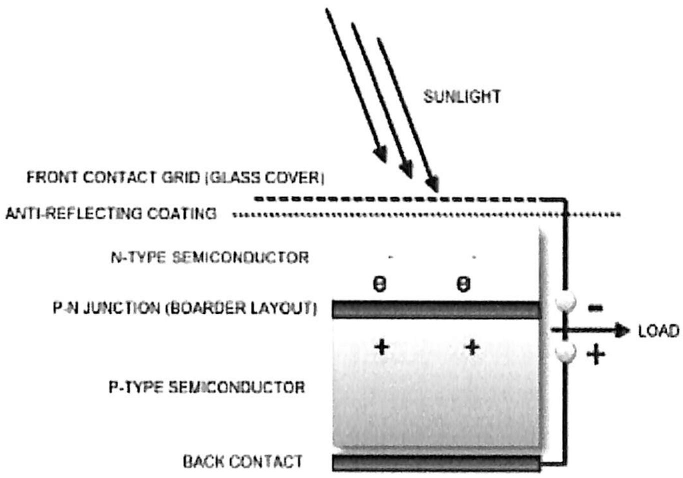



**Fig. II.7: Photovoltaic (PV) technology.**

The functioning of PV technology are so designed that they function in system depending upon the installation type. PV installation that operate in isolated locations are known as *stand-alone systems*. In commercial buildings, likewise *BAPV* (Building Adapted PV) systems are incorporated by mounting PV systems on roof-tops. Whereas, *BIPV* (Building Integrated PV) system are integrated in to the roof or building facade. In order to provide reliable supply from stand-alone generating systems using renewable energy sources, it is necessary to provide battery backup. If the extracted power during daytime is higher that the demand, the balance is used to charge batteries, which are in turn used to meet the demand when solar power is insufficient or unavailable. When the batteries are fully charged, the extra power is disposed of into dummy loads.

The next sub-section examines about chief PV system used in present days and expected to be employed upon future energy demand.

### *2.1.2.b PV Systems*

<table>
<tr><th colspan="4">PV SYSTEMS</th></tr>
<tr><td colspan="3">Industrial and utility-scale power plant system</td><td>kW-MW generation of power, for energy intensive consumer</td></tr>
<tr><td rowspan="3">Residential and commercial system</td><td colspan="2">Grid connected</td><td>Connected to local AC distribution grid, use as grid support and use of battery or any storage devices.</td></tr>
<tr><td rowspan="2">Stand-alone or off grid</td><td>For RE</td><td>Remote areas, mini-grids for individual homes or a small locality</td></tr>
<tr><td>For Industrial Application</td><td>Used in repeater stations, traffic and remote lighting; cost effective approach relatively</td></tr>
<tr><td colspan="3">Consumer goods and portable systems</td><td>Electrical and electronic appliances like cell phone chargers etc.</td></tr>
<tr><td colspan="3">Hybrid systems</td><td>Combination of different power source like- DG set, Wind-PV etc.</td></tr>
</table>

As per explained earlier, the PV output voltage of the solar array is generally not the same as the voltage of the dc-link connected to the battery, which operates at an almost constant voltage. Self-adapted dc-dc converters converts the photovoltaic panel output voltage into the dc-link voltage, as required by the battery or load. So a change in the converter's duty cycle alters the input voltage to the converter, which is also the panel's output voltage. The controller, through its adaptive action, can then adjust the input voltage to be equal to the panel's maximum power point voltage. A typical stand-alone PV system with an integrated maximum power point tracking (MPPT) converter and battery back-up is shown in Fig. II.8.

Such kinds of step are practically used in individuals or in group with same integrated arrangement. The merits and limitations are judged in terms its simplicity, accuracy, adaptability to temperature and irradiance variations, control circuit complexity, and relative implementation cost.

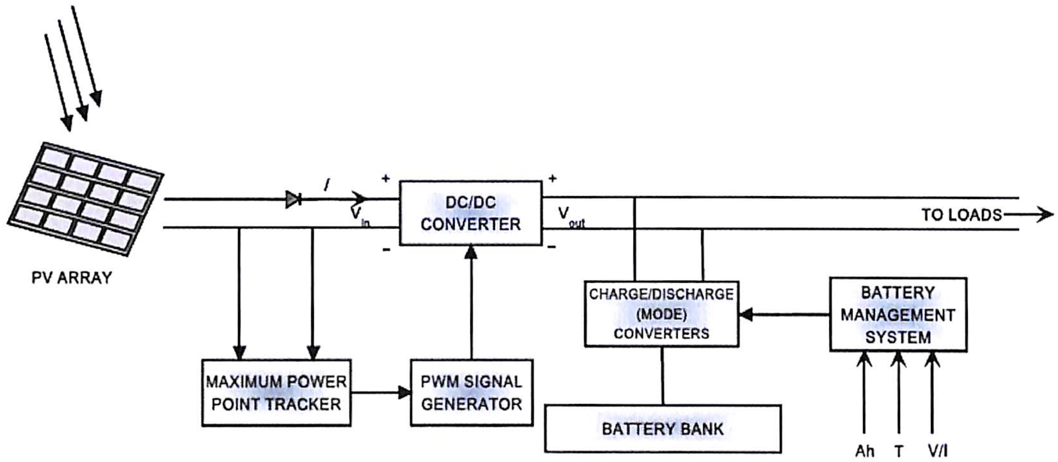



**Fig. II.8: Stand-alone PV power system with an MPPT converter and battery backup.**

Typically the battery bank is used to store energy for emergency purposes for the continuity of the supply during outage. This battery does usually have fast response time in few milliseconds to few micro seconds depending upon the application type and requirement. Likewise, the capacitor at in best applicable for integrated PV based power supply. Another typical grid connected PV system with an integrated maximum power point tracking (MPPT) converter and battery back-up is shown in Fig. II.9 for more reliability and tenacity of power *[ref: Pradeep J]*.

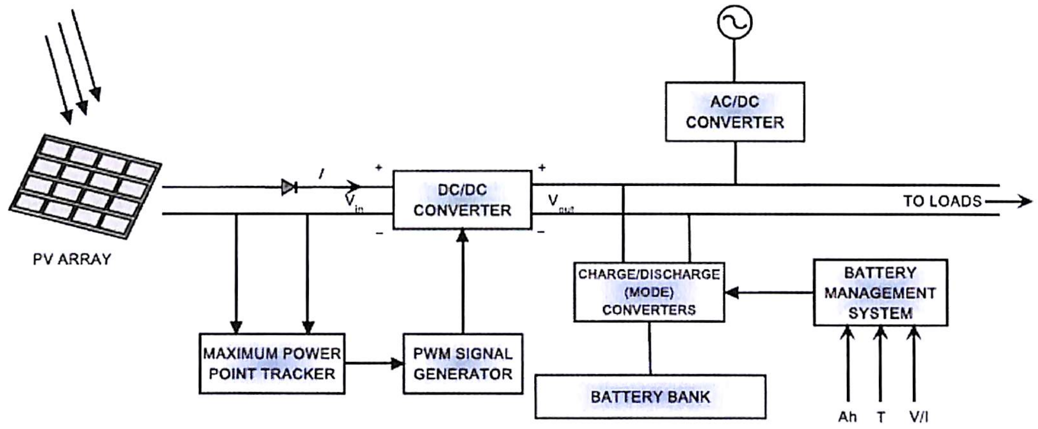



Fig. II.9: Grid connected PV power system with an MPPT converter and battery backup.

Fig. II.9: Grid connected PV power system with an MPPT converter and battery backup.

### 2.1.3 The Indian Power Grid, Power Market and Reforms

#### 2.1.3.1 Indian Power Grid

The re-evaluation of the Indian Electricity Supply Act, 1948 and Indian Electricity Act, 1910, has led the Electricity Act 2003 which has facilitated government and many non-government organizations to participate and to alleviate the electricity demand. The act redefines the power market economy, protection of consumer's interest and provision of power to urban, sub-urban and rural regions across the country.

The act recommends the provision for national policy, Rural Electrification (RE), open access in transmission, phased open access in distribution, mandatory state electricity regularity commission (SERCs), license free generation and distribution, power trading, mandatory metering, and stringent penalties for theft of electricity. In addition to these guidelines, a concept called as Availability Based Tariff (ABT) has also been implemented to bring effective day ahead scheduling and frequency sensitive charges for the deviation from the schedule for efficient real-time balancing and grid discipline. Exclusive terms like fixed cost and variable cost, and unscheduled interchange (UI) mechanism in ABT acts as a balancing market in which real-time price of the electricity is determined by the availability and its capacity to deliver GWs on day-to-day basis, on scheduled energy production and system frequency *[ref:http:powergridindia.com]*.

Indian power system has an installed capacity of around 164 GW and meets a peak demand of 103 GW. According to the current five year plan (2007-2012) by the year 2012, the installed capacity is estimated to be over 220 GW and the peak demand is expected to be around 157 GW and is projected to reach about 800 GW by next two decades. However certain complexities are envisaged in integrating IPPs into grid such as, demarcation, scheduling, settlement and gaming. But these issues are being addressed by proper technical and regulatory initiatives. In addition to that, the transmission sector has progressed in a very subsequent rate, currently at installed capacity of 325,000 MVA at 765, 400, 220kV voltage levels with 242,400 circuit kilometers (ckt-km) of HVAC and HVDC transmission network, including 765kV transmission system of 3810 ckt-km. On distribution sector, the Ministry of Power has also maneuvered to leverage the digital technology to transform and reshape the power sector in India to make an open and flexible architecture so as to meet the core challenges and burning issues, and get the highest return on investment for the technology.

The Electricity Act 2003, created a liberal and competitive environment, facilitating investments by removal of energy barriers, redefining the role of system operation of the national grids. New transmission pricing, loss allocation schemes, introduction of ULDC scheme and Short Term Open Access (STOA) schemes have been introduced based on distance and direction so that power could be traded from any utility to any utility across the nation on a non-discriminatory basis. Currently, Indian transmission grid is operated by a pyramid of 1 NLDC, 5 RLDCs and 31 SLDCs, monitoring round the clock with SCADA system enabled with fish as well as bird eye view, along with advance wideband speech and data communication infrastructure. In addition, other key features like smart energy metering, CIM, Component Interface Specification (CIS), Synchrophasor technology, Wide Area Monitoring (WAM) system using phasor measurements, enhanced visualization and self-healing functions are being exclusively employed.
*[Ref: CE.1]*

**2.1.3.2 Indian Renewable Energy Guidelines**

India has over 25.86 GW of installed renewable power generating capacity. Installed wind capacity is the largest share at over 18.55 GW, followed by small hydro at 2.8 GW. The remainder is dominated by bioenergy, with solar contributing only 1.2 GW. JNNSM targets total capacity of 20 GW grid-connected solar power by 2022. Fig. III.1 shows the current and future perspective RES in India. Renewable energy technologies are being deployed at industrial facilities to provide supplemental power from the grid, and over 70% of wind installations are used for this purpose. Biofuels have not yet reached a significant scale in India. India's Ministry of New and Renewable Energy (MNRE) supports the further deployment of renewable technologies through policy actions, capacity building, and oversight of their wind and solar research institutes.

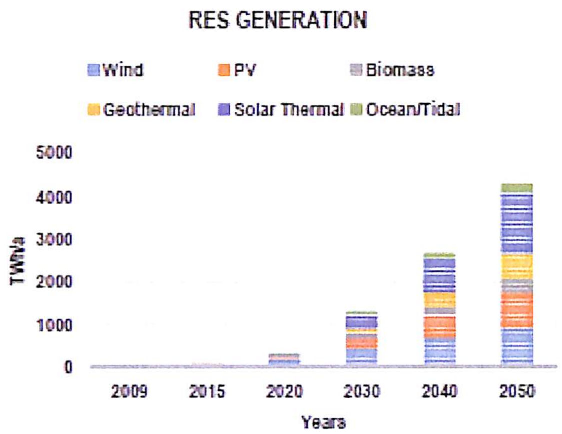



Fig:III.1(a)

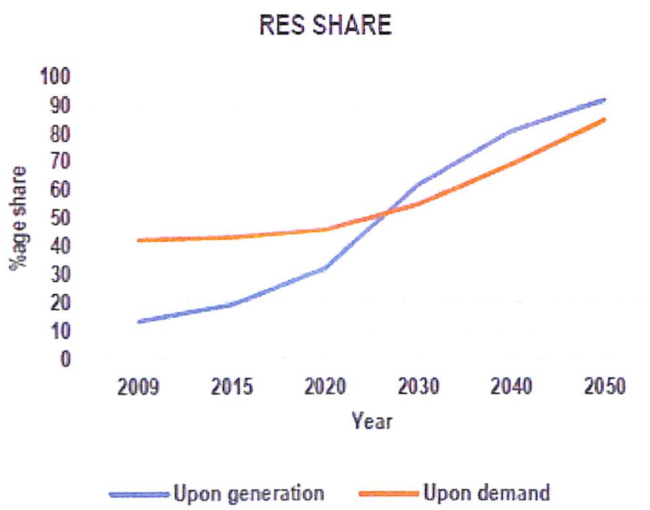



Fig:III.1(b)

**Fig. III.1: Indian RES strategy.**

(a) Indian RES generation statistics (2009-50).

(b) RES shared upon generation and demand until 2050.

The Indian Renewable Energy Development Agency (IREDA) provides financial assistance for renewable projects with funding from the Indian government and international organizations; they are also responsible for implementing many of the Indian government's renewable energy incentive policies. There are several additional

Indian government bodies with initiatives that extends into renewable energy, and there have been several major policy actions in the last decade that have increased the viability of increased deployment of renewable technologies in India, ranging from electricity sector reform to rural electrification initiatives.

Several incentive schemes are available for the various renewable technologies, and these range from investment-oriented depreciation benefits to generation-oriented preferential tariffs. Many states are now establishing Renewable Purchase Obligations (RPOs), which has stimulated development of a tradable Renewable Energy Certificate (REC) program. This is in a way laying foundation of a new economy that is inclusive, sustainable and aspires for de-carbonization of energy in a definite time frame. In order to create an enabling environment, the Ministry as a policy maker will have a significant contribution to make. While policy and budgetary support for renewable energy have progressively increased over the years, particularly for large scale grid connected power, there continue to exist many barriers that hinder up-scaling of renewable energy deployment. And perhaps more importantly, some critical gaps remain, particularly for decentralized distribution in the areas of access to capital, technology development & adaptation, innovation induction, and strategies to up-scale deployment. Nevertheless, India is currently one of the few top attractive destinations for renewable energy investments, which implements policies regarding grid support for grid interactive and integrative renewable power also.

*a. Electricity Act 2003*

Section 86. (1); the state commission shall discharge the following functions. . . (e): promote cogeneration and generation of electricity from renewable sources of energy by providing suitable measures for connectivity with the grid and sale of electricity to any person, and also specify, for purchase of electricity from such sources, a percentage of the total consumption of electricity in the area of a distribution licensee. The particular term for such activity is regarded as "**renewable purchase obligation.**"

*b. National Electricity Policy 2005*

The national electricity policy 2005 specifies that gradually the share of electricity from non-conventional sources would need to be increased; such purchase by distribution companies shall be through competitive bidding process; considering the fact that it will take some time before non-conventional technologies compete, in terms of cost, with conventional sources, the commission may determine an appropriate deferential in prices to promote these technologies.

*c. Tariff Policy 2006*

The tariff policy announced in January 2006 has the following provisions:

• Pursuant to provisions of Section 86 (1) (e) of the Act, the appropriate commission shall fix a minimum percentage for purchase of energy from such sources taking into account the availability of such resources in the region and its impact on retail tariffs. Such percentages of energy purchase should be made applicable for the tariffs to be determined by the state electricity regulatory commission (SERCs) latest by April 01, 2006.

• It will take some time before non-conventional technologies can compete with conventional sources in terms of cost of electricity. Therefore, the procurement by distribution companies shall be done at preferential tariffs determined by the appropriate commission.

• Such procurement by distribution licensees for future requirements shall be done, as far as possible, through competitive bidding process under Section 63 of the Act within suppliers offering energy from the same type of non-conventional sources. In the long-term, renewable energy technologies based power generation would need to compete with other sources in terms of full costs.

• The central commission should lay down guidelines within 3 months for pricing non-firm power, especially from non-conventional sources, to be followed in cases where such procurement is not through competitive bidding.

*d. Renewable Energy Certificate 2010*

The Renewable energy certificate mechanism entitles under the terms and conditions of Central Electricity Regulatory Commission (CERC) for the recognition and issuance of Renewable Energy Certificate for Renewable Energy Generation to the states of India. This mechanism is expected to overcome geographical constraints and provide flexibility for effective implementation of RPO compliance, reduce risks for local Discom by limiting its liability to only electricity purchase, reduce transaction costs and create competition among different RE technologies. Explicitly, there are two types of REC viz., *solar certificates* issued to eligible entities for generation of electricity based on solar as renewable energy source, and *non-solar certificates* issued to eligible entities for generation of electricity based on renewable energy sources other than solar. Above all these, risk assessment and allocation is at the center of project finance preferably for any developing nation like India. Accordingly, project structuring and expected return are directly related to the risk profile of the project. The four main risk factors to consider when investing in renewable energy assets are:

✓ *Regulatory Risk*

It refers to adverse changes in laws and regulations, uncomplimentary tariff setting and change or breach of contracts. As long as renewable energy depend on government policy dependent tariff schemes, it will remain vulnerable to changes in regulation. However a diversified investment through regulatory jurisdictions, geographies, and technologies can help mitigate those risks.

✓ *Construction Risk*

It relates to the delayed or expensive delivery of an asset, the default of a contracting party, or an engineering/design failure. Construction risks are less prevalent for renewable energy projects because they have relatively simple design, however, construction risks can be mitigated by selecting high-quality and experienced turnkey partners, using proven technologies and established equipment suppliers as well as agreeing on retentions and construction guarantees.

✓ *Financing Risk*

It refers to the inadequate use of debt in the financial structure of an asset. This comprises the abusive use of leverage, the exposure to interest rate volatility as well as the need to refinance at less favorable terms.

✓ *Operational Risk*

It includes equipment failure, counterparty default and reduced availability of the primary energy source (e.g. wind, heat, radiation). For renewable assets a lower than forecasted resource availability will result in lower revenues and profitability so this risk can damage the business case. Indeed, technically grid connection planning and requirement also being encountered for the integration and interconnection with grid.

In the past, grid connection requirement (GCR) for renewable power generators was not necessary due to low level of RES power penetration. IEEE Standard 1001 '*IEEE Guide for Interfacing Dispersed Storage and Generation Facilities with Electric Utility Systems*' was the only guideline for the connection of generation facilities to the distribution networks. The standard included the basic issues of power quality, equipment protection and safety. The standard expired and, therefore, in 1998, the IEEE Working Group SCC21 P1547, the IEEE Standard for Interconnecting Distributed Resources with Electric Power Systems started to work on a general recommendation for the interconnection of distributed generation. The interconnection rules are continuously reformulated because of the increasing RES penetration (specifically, wind power) in to the grid and the rapid development of RES power generation system technology.

The main focus in the electricity grid codes has been on the fault ride-through issue, where the Transmission System Operators (TSO) requires wind power generators to stay connected to the grid during and after a fault in the transmission system. In the several countries, new grid codes are already in place for the RES power integration and these specifications have to be met. Indian Government policy and regulatory framework both at the state and central levels are encouraging power generation from new and renewable energy sources. In the next section a common grid code requirements have been suggested and some technical and operational issues of high penetration of wind power and PV for Indian power system are addressed.

## 2.2 Review Area Narrow.

With the growing ultimatum of electrical power, Quality of Service (QoS) and continuity of supply has been the utmost primacy for all major power utility sectors across the world, prior to the global market strategy. Smart Grid is predominantly proposed as the quantum leap in harnessing communication and information technologies to enhance grid reliability, and to enable integration of various smart grid resources such as renewable energy, demand response, electric storage and electric transportation. It allow greater competition between the providers, enabling greater use of intermittent power resources, establishing the wide area automation and monitoring capabilities needed for both bulk transmission over wide distances and distributed power generation, empowering more efficient outage management, streamline back office operations, aiding the use of market forces to drive retail demand response and energy conservation. Smart Grid technology underscores factors like policies, regulation, and efficiency of market, costs and benefits, and services that normalizes the marketing strategy, by restructuring the global power scenario in a very dynamic approach. In addition to this, the concerns like secure communication, standard protocols, advance database management and efficient architecture with ethical data exchange, adds to its requisites.

*[ref: Bossart S.J.]*

The development of Information and Communication Technology (ICT) has updated the technology by supporting dynamic real-time two-way energy and information flow, facilitating the integration of renewable energy sources into the grid, empowering the consumer with tools for optimizing their energy consumption, by introducing Advance Metering Infrastructures (AMI), Virtual Power Plant (VPP) and other such incipient implements. In addition, it helps grid to continuously self-monitor and self-adjust to achieve self-healing function, so as to monitor all kinds of turbulences, carry on compensations, redeploy the power flow, avoid the intensification of accident and make each kind of different intelligent devices to realize the network communication topologies. Power engineers across the rondure have developed a curiosity in decarbonizing the electrical power while minimizing the dependency of the fossils. Such interest has fortified the growth of renewable energy by ensuing the efficiency and economy of the power grids. Integrated distributed power sources, includes renewable energy such as Fuel cells, Photovoltaic cells, Wind turbine, Micro hydro generators etc. could prolific the needs like power stability, improve grid efficiency, recruit use of the Plug-in EVs, support customer in changing their energy usage patterns, by reduction in power consumption and saving money.

High power electronics is also a key technology to build the smart grid technology in an eventual way by adding new DC grids and AC Var sources at the T&D level, serving as backbones and additional stability pillars to existing grids. Fig. IV.1 visualizes a typical paradigm of Smart Grid Technology and its distinctive feature.

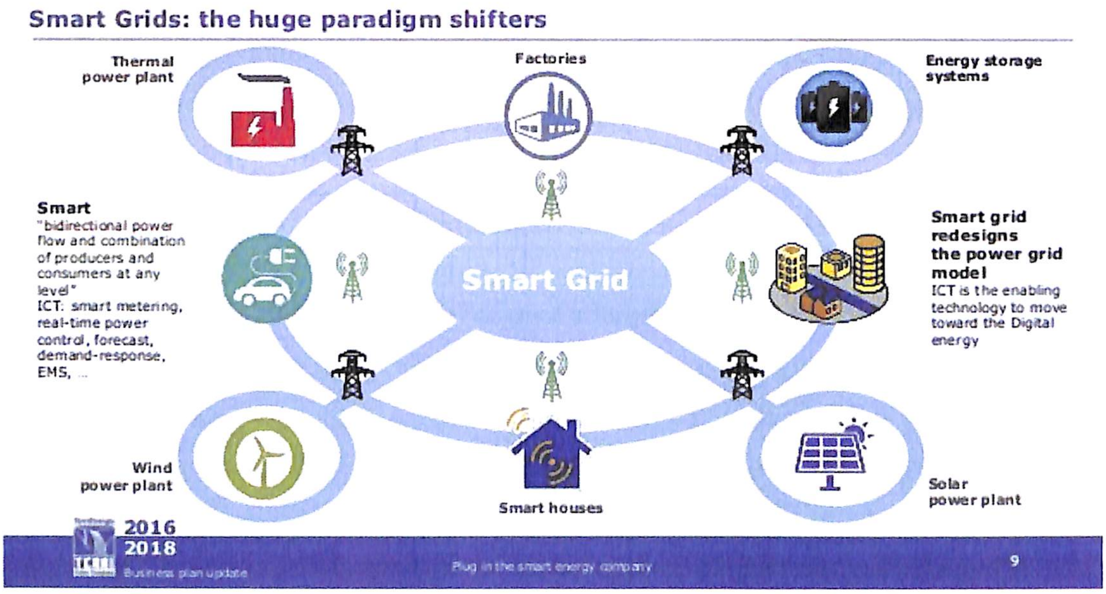



**Fig. IV.1. A paradigm of Smart Electricity Grid or Smart Grid**

Unlike such inevitable benefits, Smart Grid technology does have some burgeoning issues in both technical and non-technical aspects. Researchers and power engineers are encroached to eliminate these key issues for the proper and sound implementation of the technology across a large network. Such approach is being initiated under the department of R&D in partnership with numerous world-class institutes and multi-national companies in a due course of time.

### 2.2.1 Global Outline of Smart Grids

To augment the socio-economic development and meet the energy demand, large power plants were being installed and are being transmitted over HV transmission lines across different power deprived regions. But, such engrossment not only surges huge investment, but also invites numerous non-technical issues based on environment and judiciary matters *[ref.Hasmi M]*. In order to regulate the world-wide power market and bringing down the ambiguous events in power system, power sectors are flourishing with new

advancement in technology, by initiation of non-technical principles such as Energy Management System (EMS), Demand Side Management (DSM), optimized Assets Management etc. *[ref: Taqqali W.M]*. In addition to this, the new emerging technologies like Wide Area Monitoring System (WAMS), Phase Measurement Units (PMUs), Distributed Energy Resources (DER), Flexible AC Transmission System (FACTS) etc. enriches the modern power system and buzzes to new opportunities *[ref: Sooriyabandara M]*.

In the nearest future the world will overcome a major problem, the issue of demographic deviation in developing and developed countries. The development goes hand in hand with an unremitting reduction in non-renewable energy resources. It has been anticipated that the global population will be escalated by a factor of 1.4 billion with a power consumption expectancy of 27,000 TWh by next decade. The statistics is being shared by both developing and developed countries with a percentage of 45% and 55% respectively *[Ref: W.Breuer]*. For the needs of dramatically growing world population with the simultaneous reduction in fossils, we have to deal with an area of conflicts between reliability of supply, environmental sustainability and economic efficiency. These can be resolved with the help of ideas, intelligent solutions as well as innovative technologies, which are today's and tomorrow's challenges for the planning and power engineers worldwide.

*Smart Grid Visions, Roadmaps and Developments*

In spite of the common view that the power industry would enter the smart grid development stage, the smart grid research is still on evolutionary stage. Different development environment and drive force, different countries' power grid enterprise and organizations comprehend the smart grid concept in their own way. In fact, the smart grid concept itself is being developed, enriched and cleared every day. As a result of which, the research and practical approaches, methodologies and key points are quite different, depending upon the factors like geographical locations as well as their advancement in sciences and technology. Table 1 characterizes the comparison of development and advancement of Smart Grid among the major nations in details *[Ref: Hashmi M]*.

**Table IV.1**

Smart Grid Initiatives in Major Nations

| COUNTRIES | IMPROVEMENTS | IMPLEMENTABLITY | OUTCOMES | CONSORTIUMS/ SMART GRID PROGRAM |
|---|---|---|---|---|
| **UNITED STATES OF AMERICA (US)** | Smart Metering, AMI, VPP, WAMS etc. | Smart Grid related projects to be around $13bn per year, estimated $20bn per year to be spent on T&D projects, pilot studies on WAMS etc. | Reduction in annual electricity bill by 10%, savage up to $200bn in capital expenditure on new plant and grid investments by $30bn. | EPRI's IntelliGrid Program, DOE's GridWise Alliance, Pacific Northwest National Laboratory (PNNL) |
| **EUROPE** | Renewables, Smart meters, Plug-in EVs, Energy Storage etc. | Development of RES, Smart metering with ToU pricing, intelligent appliances etc. | Load Management, power quality improvement, grid stability, energy efficiency. | ETP, EEGI, EERA, IEA DSM Task XVII, ENEL. |
| **INDIA** | Reduction in T&D losses, WAMS, SGMM, QoS etc. | Using DSM to selectively curtail electricity use, improving power quality, | Rural Electrification, on-line condition monitoring, improvised market | PGCIL's and REC's RGGVJY, APDRP; MNRE's APP Programme, |

| | | | | |
|---|---|---|---|---|
| | | increase use of renewables, intelligent energy efficiency in the form of DG etc. | strategy by real-time pricing technique. | GE Smart Grid, Tata Power, CGL India etc. |
| **CHINA** | Expand T&D capacity, reduce line losses, uplifting transmission voltage, installing high efficiency distribution transformer etc. | Development of UHVAC and UHVDC, use efficient distribution transformer, more stress on HV transmission network | Wide area power network, efficient and economical transmission and distribution of power across the country | China State Cooperation's Strengthened Smart grid Plan |
| **FINLAND** | AMI, IHDs, ICTs, Smart Meters etc. | Installation of AMI and smart meters equipped with advance ICTs like RF, PLC, Broadband, GPRS, 3G, Zigbee, Wi-Fi, HAN etc., | Fault diagnosis, fault location, service restoration, voltage and reactive power control and network reconfiguration. | - |

### 2.2.2 Smart Grid Technology

Smart Grid has been deployed across various nations with the impact of cutting edge technology; still there are some more essentials to be accentuated to endeavor an ingrained operative system. Three very incipient and crucial technologies are being discussed vividly in this section with detail analysis.

*1. Smart Transmission Grid*

The backbone to deliver electric power from the generation station to the loads and consumers' side, the transmission network has frolicked vital role and has been highly recognized entity of power system engineering. Commencing of the transmission of electric power to be a direct current (DC) transmission, the scope of the transmission has been diversified to HVAC, HVDC transmission at various voltage levels along with

profuse complex network topologies. Up-gradation of transmission network by increasing high
capacity multi-circuit/bundle conductor lines, High Surge Impedance Loading (HSIL) Line, high capacity HVDC system, High Temperature Low Sag (HTLS) Line, etc. facilitates the quality of power transmission with the crux of reliability and economy of the system *[ref. www.powergridindia.com]*. But still thriving challenges and issues which are being faced off by todays' transmission network such as; environmental challenges, market/customer
needs, infrastructure challenges and innovative technologies.

With the state of art technology advances in the areas of sensing, communication, control, computing and information technology, it has quarried a unique vision of the future smart transmission grids by identifying the major smart characteristics and performance features to handle the challenges. Fig. IV.2 depicts the features and their characteristics of a Smart Transmission Grid.. A detailed analysis on the smart transmission grid development is being described under three main interactive and smart components; smart control centers, smart transmission networks and smart substations.

| | | |
|---|---|---|
| **SMART TRANSMISSION GRID** | **DIGITIZATION** | Fast and reliable, sensing communication, effective protection, user friendly, visualization. |
| | **CUSTOMIZATION** | Smart consumer, Market liberty, transparency, efficient power consumption. |
| | **SUSTAINIBILITY** | Eco-friendly, alternative energy resources, de-carbonization, mitigation network congestion. |
| | **RESILIENCY** | Rapid response, robustness, real time analysis, Self-healing. |
| | **INTELLIGENCE** | Self-awareness, online monitoring, system stability, self-healing, system security. |
| | **FLEXIBLITY** | Innovation and diverse generation technologies, adaptability, multiple control strategies, system upgradation. |

**Fig. IV.2. Features and characteristics of Smart Transmission Grid**

With this unique vision of smart transmission grid, it aims in promoting technology innovation to achieve an inexpensive, reliable, flexible and sustainable delivery of electric power. It also enables some of the key features such as:

- ✓ Increased flexibility in control, operation and expansion.
- ✓ Development of embedded intelligence
- ✓ Foster resilience and sustainability of the grids.
- ✓ Improve customer benefits and quality of service.

*2. Information and Communication Technology (ICT)*

In the smart grid, consistent and RT information is the key factor for the reliable delivery of electric power from the generation unit to the end-users. Lack of automated analysis, poor visibility, sluggish response of mechanical switches, and dearth of situational awareness were some of the drawbacks of the classical power system. With the incorporation of advance technologies and applications, the smart grid architecture increases the capacity and flexibility of the network and provides advance sensing and control through modern communication protocols and topologies.

Wired and Wireless modes are being complied for the transmission and communication of data and information between the smart consumers and the utility sectors. Each of the modes of the communication has its own advantages and disadvantages over each other, depending on the various factors such as geographical location, capital investment, economy of use etc. Fig. VI.3 exemplifies some of the types of wired and wireless type of communication *[ref: Fang X]*.

| | | |
|---|---|---|
| COMMUNICATION TECHNOLOGIES | WIRED | Optical Fibre Communication.<br>Powerline Communication (PLC).<br>Data Subscriber Line (DSL). |
| | WIRELESS | Satellite Communication.<br>Wireless network.<br>Cellular Communication.<br>Cognitive Radio<br>IEEE E02.15 (Zighen, Wireless HART etc) |

**Fig. IV.3. Types of Information and Communication Technology (ICT).**

Two-way flows of electricity and information lay the infrastructure foundation for the smart grid. Smart communication subsystem or the ICT are a dynamic sector of the Smart Grid infrastructure. The infrastructure mainly visualizes the communication pattern in two conduits viz. sensor and electrical appliance to smart meters, moreover between smart meters and utility data center. The communication infrastructure between energy generation, transmission, and distribution and utilization requires two-way communications; interoperability between advanced applications and end-to-end reliable and secure communication with low-latencies and sufficient bandwidth. Along with advancement of system security and robustness towards cyber-attacks which provides system stability and reliability with advanced control adds to its essentials. Table IV.2 articulates some of the important communication topologies along with their brief details, with emphasis on its advantages and disadvantages *[Ref: Gungor V.C.]*.

**Table IV.2**

Smart Grid Network Topologies

| NETWORK TOPOLOGIES | TECHNICAL SPECIFICATIONS * | ADVANTAGES | DISADVANTAGES | APPLICATIONS |
|---|---|---|---|---|
| **ZIGBEE COM** | 2.4 GHz – 915Mhz, 250Kbps, 30-50 m | Simplicity, mobility, robustness, low bandwidth requirement, load control and reduction, demand response, real-time pricing, real-time system monitoring and advance metering support | Low processing capability, small memory size, small delay requirement, noise and EMI, shares common frequency band ranging from IEEE 802.11 WLANs, Wi-Fi, Bluetooth and Microwave | Advance Metering Infrastructure (AMI) and Home Area Network (HAN) |
| **WIRELESS MESH NETWORK** | NA | Cost effective solution, dynamic self-organization, self-healing, selfconfiguration, high scalability services, improved network performance, balanced load network, extended network coverage | Network capacity, EMI, Urban coverage issue, complex infrastructure, bandwidth reduction, high maintenance | Advance Metering Infrastructure (AMI), Home Energy Management and Home Area Network (HAN) |
| **CELLULAR NETWORK** | GSM (900-1800MHz, 14.4Kbps, 1-10km) GPRS (900-1800MHz, 170Kbps, 1-10km) 3G (1.92 – 2.17 GHz, 2Mbps, 1-10km) WiMAX (2.5-5.8GHz, 75Mbps, 10-50 km (LOS) and 1-5 km (NLOS)) | Cost-effective, widespread, sufficient bandwidth, strong security control, excellent coverage, low maintenance cost, quick installation, authentication, demand response | Network congestion, poor emergency response, involvement of various private ventures for use of various spectrum band | Advance Metering Infrastructure (AMI), Home Area Network (HAN), Outage management, Demand side management |

| | | | | |
|---|---|---|---|---|
| **POWERLINE COMMUNICATION (PLC)** | 1-30 Mhz, 2-3Mbps, 1-3 km | Cost-effective, ubiquitous nature, widely available infrastructure, wide range, enhanced system security | EMI, noise, low-bandwidth, device sensitivity towards disturbances and quality of signal, multilevel protocols | Advance Metering Infrastructure (AMI), Fraud Detection, System monitoring and control |
| **DIGITAL SUBSCRIBER LINE (DSL)** | 1.1-4 MHz, 256Kbps-40Mbps, 2-16km | Widespread availability, low-cost, high bandwidth data transmission | Distance dependency, lack of standardization, costly set-up, high maintenance, | Advance Metering Infrastructure (AMI) and Home Area Network (HAN) |

* Technical specification specifies bandwidth (Hz), speed (bps) and network coverage (km).

In one hand wired technologies like DSL, PLC, optical fiber, are costly for wide area deployment but they elites communication capacity, reliability and data security. On other hand, wireless technologies aids reduced installation costs, but accolades constrained bandwidth and security. Although reliable and effective information exchange is a key to the success of the future smart grid technologies, as communication infrastructure must gratify QoS of data, reliability in data exchange, wide coverage, fidelity of signal, and security and privacy of information.

*3. Smart Metering Technology*

Smart metering system has been considered as an effective method for improving the pattern in power consumption and efficiency of energy consumers thus reducing the financial burden of electricity. It is the combination of power system, telecommunication and several other technologies. Indisputably, with the development of science and cutting edge technology, more facilities have been added to this area. Smart meter is an advance energy meter that measures the energy consumption of a consumer and provides added information to the utility company compared to a regular energy meter. The bidirectional communication of data enables the ability to collect information premeditated with communication infrastructure and control devices. In addition, the meter is used to monitor and control home appliances and devices, collect diagnostics information about the utility grid, support decentralized generation sources, energy storage devices, and consolidate the metering units.

Advanced metering Infrastructure (AMI), an appellation of smart metering technology which consists of set of smart meters, communication modules, LAN, data collectors, WAN, network management system (NMS), Outage Management System (OMS), Meter Data Management Systems (MDMS), and other subsystems. With an advance feature of data collection, the system procures a safe, secure, fast and self-upgradable with developed vision of reliable and flexible access to electricity consumption of the subscribers using power and distribution grid. A proposed architecture of open smart metering system has been illustrated in Fig. IV.4 which also gives and brief view of application of AMI and other subsystems.

The model planned results and unified system for acquisition and control of power distribution systems. The Data Model shown contains Virtual Meters which is a part of a wider concept called Virtual Power Plant (VPP).

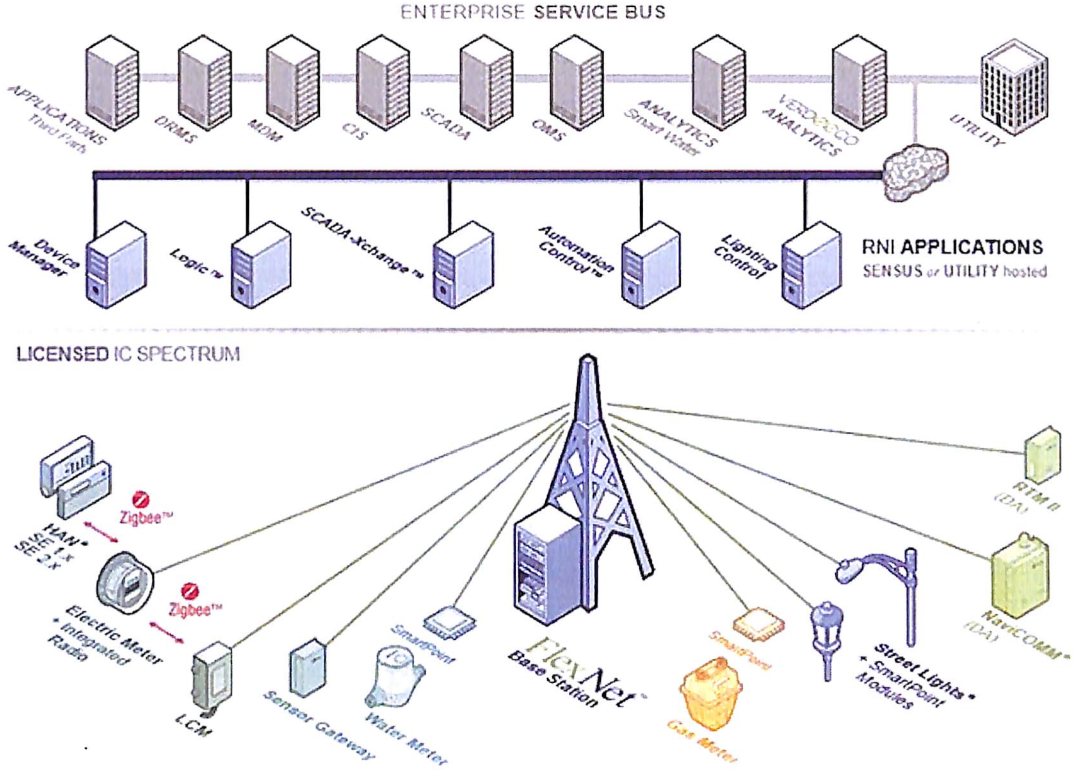



**Fig: IV.4. Advance Metering Infrastructure.**

An important technological device called the In-Home Display (IHD) is an imperative development for the advancement and implementation of smart metering system. A briefing has been revealed in table IV.3. The proposed architecture was implemented within a Meter Data Management system, thereby proving it worth.

Table IV.3

Smart Metering System using In-Home Display (IHD) units.

| SMART METERING SYSTEM | PRINCIPLE OR NORM | OBJECTIVES | FACILITIES | LOCATION/REGIONS |
|---|---|---|---|---|
| Ami-Related System | Induces power savings by time varying tariff | Improvement in efficiency of power distribution network by control of power peak and demand response | Information of power consumption and price rate change in a simple form | Australia and United States |
| EMS-type System | Induces self-power savings by offering detailed information of energy consumption w.r.t. time | Improvement in efficiency of power distribution network by control of consumption level of power by the consumers | Information of power consumption, higher resolution colour display, multiple information of other utilities | Japan |

In the view of the wide range of advantages and applications, smart meter systems are being under large scale development and deployment across the globe. Renowned power utilities organizations like Austin Energy (US), Centerpoint Energy (Houston), Enel (Italy), Govt. of Ontario (Canada), KEPCO (Korea) etc. are on a rapid fire temperament to implement the smart metering technology within its expected and as-per planned dates. Around $50 billion has been invested in North America with a target reach of 89% by 2012. Still huge investments are being arrayed across various developing and developed countries supported by various organizations and venture capitalist firms.

*4. Smart Control and Monitoring System*

With the invasion of very complex adaptive system of smart power grid; a dynamic, stochastic, computational and scalable (DSCS) with innovative control technologies can be a promising trait for a reliable, secure and efficient power network *[Ref: G.K Genayagamoorthy]*. This complexity and interconnectivity of the electric power grid is aggregating with distributed integration of renewable sources of energy and energy storage of all kinds. In contrary, different approaches to traditional modelling, control and optimization can be augmented or relieved with in the grids for rapid adaptation, dynamic foresight, self-healing, power system islanding, fault-tolerance, and robustness to disturbances and randomness. Global Dynamic Optimization (GDO) is an important aspect to achieve for a DSCS strategy for smart control of the grid, where Computational Intelligence (CI) and Adaptive Critic Designs (ADCs) are referred as the promising and potential approaches. These are an adaptive mechanism inspired from natural phenomena and AI paradigm which facilitates intelligent and smart behavior during complex, uncertain and changing environments *[Ref. P.Werbos]*. These paradigms of CI inter-combine to form hybrids viz. neuro-fuzzy systems, neuroswarm systems, fuzzy-PSO systems, fuzzy-GA systems, neuro-genetic systems etc., and ensuing superior than any specific paradigm. In addition, the ADCs are based on the combined concept of reinforcement learning and approximate dynamic programming using neural network-based designs for optimization *[ref. Funika W]*. Table IV.4 exemplifies the control technologies using the GDO.

**Table IV.4 Innovative Control Technologies using GDO (CI and ADCs based)**

| CONTROL TECHNOLOGIES (CI and ADCs based) | OUTCOMES |
|---|---|
| Neutral Networks and Fuzzy System | Captures non-linearity in power systems and smart grids |
| Neural Networks | Behavioral modelling, fast, dynamic decision in smart grids. |
| Fuzzy and Neuro-Fizzy | Fast and accurate decision making during uncertainty and invariability in the system |
| Artificial Immune Systems | Immunizes against transients that results from disturbances and fault in smart grids, thus provides fault-tolerance. |
| Swarm Intelligent and Evolutionary Computation | Allows office, large scale optimization of smart grid operation |
| Adaptive Critic Designs (ACDs) | Allows design of robust, adaptive and optimal controllers in a dynamic, uncertain and variable smart grid environment, dynamic optimization and scheduling, |
| Computational Intelligence (CI) | Self-healing characteristics in power grids |

Some of key features of Smart Grid control and monitoring have been discussed as follows:

*i. Self-Healing*

To ensure grid stability and improve the supply quality, avoid or mitigate power outages, power quality problem, and service disruption using real-time information from embedded sensor and automated control to anticipate, detect and respond to system problem, is conferred to be a self-healing power network. Such systems are independent of user interaction, where decisions making are based on the knowledge from the pre-estimated and pre-monitored results. In general, the self-healing is distinguished in two levels: self healing in the physical (monitored hardware) layer and the logical (monitored application/system) layer, according to situation of concerns *[ref. Funika W]*.

*ii. Wide Area Monitoring and Control (WAMC)*

Wide Area Monitoring and Control (WAMC) and Wide-area monitoring, protection, and control (WAMPAC) encompasses the use of system-wide information and the communication of specific local information to a remote location to counteract the propagation of large disturbances in a system. With the invasion of adaptive system of smart power grid; a dynamic, stochastic, computational and scalable (DSCS) with innovative control technologies can be a promising trait for a reliable, secure and efficient functioning of WAMPAC. Synchrophasor Measurement Technology (SMT) is an important element to WAMPAC which includes both short-term objectives such as enhanced visualization of the power system, post disturbance analysis, and model validations, and long-term objectives such as the development of a WAMPAC system. Such type of conceptual architecture has been employed in Eastern Interconnect Phasor Project (EIPP) in United States. With the increased international research and development, several monitoring and control application are based on Synchrophasor-based Wide-Area Monitoring, Protection and Control System (WAMPAC).

Though with small scale adoption, it has played a major role in some large transmission system operators. The WAMPAC system consist of a measurement device, the Phase Measurement Units (PMUs), their supporting infrastructure which is formed by communication networks and computer systems capable of handling PMU data and other information, usually called the Phase Data Concentrators (PDCs). The set PMUs and their aiding ICT infrastructure are termed as Synchrophasor Measurement Technology (SMT).

The basic components of a WAMC system are the following: PMUs, PDCs, a PMU-based application system, and a communication network to connect the interfaces. Similar to traditional SCADA systems, there are three layers in a WAMC system. Fig. IV.5 illustrates a typical schematic of different layers and components of a basic WAMC system.

In *Layer 1*, the WAMC system interfaces with the power system on substation bars and power lines where the PMUs are placed, this is called the Data Acquisition layer.

*Layer 2* is known as the Data Management layer, in this layer the Synchrophasor measurements are collected and sorted into a single time synchronized dataset.

Finally, *Layer 3* is the Application Layer; it represents the real-time PMU data-based application functions that process the time-synchronized PMU measurements provided by Layer 2.

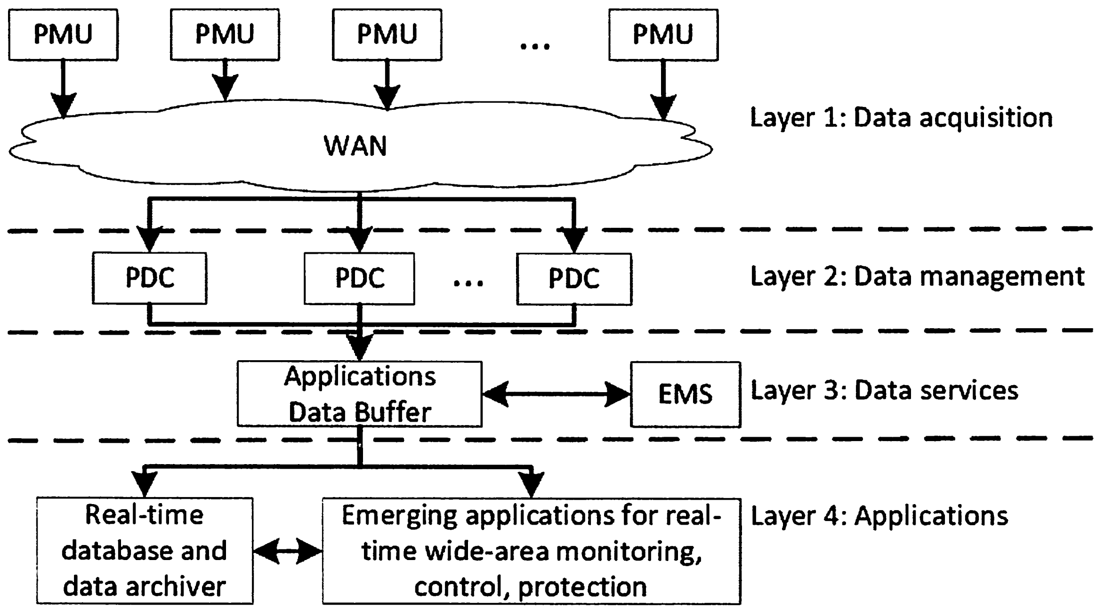



**Fig. IV.5. Components of Wide Area Monitoring and Control**

The architecture depends on specific system needs, its topology, generation profile, and the quality of the communication infrastructure. Accordingly, several applications are being design as per requirements and system understanding using the desired WAM architecture and components as discussed. The application of the WAM system and control, are based on mainly two aspects viz. online application and offline application. As per the name goes, an online application entitles continuous up-gradation of data over a data link from client to server and vice-versa, measured at every pre-specified intervals. Whereas, an offline data application is archived and stored, and the process incorporated quarrying as per batches or sets defined as per data volume. The WAMPAC demonstrates some applications namely, dynamic recording, real-time system state determination, tuning of system parameters, congestion management, phase angle and disturbance propagation monitoring, estimation of load model parameters, as well as protection and control related applications *[Ref. V.Teja]*.

These applications that route real-time sub-second incoming continuous streams of measurement data have a greater number of challenges and constraints. If the data was inaccurate or distorted this could lead to an application failure or worst, producing misleading results which could deceive the operators. Another aspect is the overwhelming volume of incoming data that a client system has to process, which could inhibit performance. As a foremost concern, future works are being focused on implementing more algorithms and evaluating such ICT challenges and constraints.

*iii. Power System Islanding*

When interconnected power system out-of-step occurs, it is authoritative to sense it rapidly, and islanding should be taken to prevent widespread blackout of the system. Due to system transient instability, which causes large separation of generator rotor angles, large swings of power flows, large fluctuations of voltages and currents, and eventually lead to a loss of synchronism between groups of generators or between neighboring utility systems, for certain severe disturbances, shall be intentionally spilt into two or more 'islands' to preserve as much of the generation and load as possible.

An islanding scheme has widespread application in Microgrid, significantly in distribution grids that can operate in controllable, intentional islanding conditions, decoupled from the main grid. In addition, islanding detection is also employed in order to switch the control modes of distributed generators from power injection to voltage and frequency control during disconnection and opposite during reconnection to the main grid. In order to endure a seamless islanding scheme, some restraints are to be satisfied for splitting operation as such;

- Pre-planned splitting should be procured as well as system should be isolated at pre-determined splitting points during fault.

- Synchronism of the generators at each island and isolation of asynchronous groups of generators into different islands should be incorporated, and

- Balance of the power should be maintained in each island.

Different adaption strategies and multi-functionality (voltage, frequency and power) algorithms are being deployed for the islanding of the power system for the proficient and steadfast control of the power grid resulting in smart operations. Few of such incorporative techniques are being described in.

As mentioned earlier the smart power grid becomes much more complex than the classical grid as time varying sources of energy and integration of new technologies. Apparently, numerous organizations and institutional aids are being associated for the design and development of optimized and reckless dynamic response control algorithms for the smart operation of the grid networks.

### 2.2.3 Further Advancements in Smart Grid Technology

Modern power system and the future ones are none different than the classical ones, as the system includes some of the advance and smart devices with the use of state-of-art technology such as RES Integration, Energy Storages, Microgrid and Hybrid energy system control, super smart grids, along with wide spread application of information and communication technology.

The Electrical Power Research Institute (EPRI) of US has reported in 2005 an estimation that around 2100 TWh/year of power capacity can be generated by tidal or wave energy, near Northern Europe, Southern Chile, South Africa, South-Western Australia, and Alaska due to high value of wave power flux *[ref. R.Bedard]*.

However, greater challenges are being confronted as the tremendous and catastrophic impact of such energy can cost billions of investment in both technical and non-technical aspects. Still researchers and power engineers are intensifying their optimization techniques with their extensive ideas. Also, biomass and fuel cell development are also at the forefront of the evolution due to the impact of chemical, material and biological sciences. An elegant perception of "**Super Smart Grid (SSG)**", a hypothetical wide area network of electric power with the unification of various national grids and renewable sources initiated in the European countries including the Northern Africa, Middle East, Turkey and the IPS/UPS system of Commonwealth of Independent States (CIS) countries. It initiates a large scale utilization of alternative energy, and as well as advocates of enhanced energy security for Europe.

Due to the proliferation and propagation of advance technologies, smart grid has been taken over by various developing and developed nations across the globe, with initiatives undertaken with the assistance of the government and non-government organizations. Huge investments have been committed by different countries to initiate and establish distributed demand side management, smart metering, substation automation, PHEVs etc. Countries like China are moreover transmission-centric, with the procurement of WAMS and PMU sensors at all generators units and substations to be established by near future. Comparing, countries like US and Europeans, are concerned about the development of Smart Grid Technology Platform for electricity network nationwide *[ref. Pazheri FR]*. An around, $100 million is being funded to build smart grid, and create Grid Modernization Commissions to assess the benefits of demand response and to recommend needed protocol standards. The Smart Grid Maturity Model (SGMM), Smart Grid Task Force (SGTF) and Smart Grid Forum are being initiated by India, for the transformation of entire power grid forward towards smarter grid *[Ref. Belijepalli]*. Of around, $370 billion is being estimated to be spent for the deployment of smart grid technology with an overall conjecture of 130 million smart meters to be installed at various consumer levels by 2030. Still huge headway investments and planning are being done by nations like Korea and Saudi Arabia. The next section discusses about the deployment of smart grid in Indian sub-continent in detail and its future perspectives.

## 2.3 Factors critical to success of study and Summary

### 2.3.1 Challenges in Implementation of Smart Grid

The key features of smart grid offers lots of advantages and future perspectives in power dominion, revitalizing the socio-economic strategies of the realms. But, in contrary the wide-spread applications of up-and-coming technologies summons vulnerabilities which may result in perilous catastrophe, like long term blackout, economic breakdown, terrorist attacks etc., if not taken care of. Table VI.1 provides a brief study on some of the challenges of smart grid technology *[Ref. Bendou F]*.

**Table VI.1**

Challenges of Smart Grid Technology.

| TECHNOLOGY | CHANLLENGES | OBLIGATIONS |
|---|---|---|
| **Self-Healing Action** | Security | Exposed to internet attacks (spams, worms, virus etc.), question of National security |
| | Reliability | Failure during natural calamities, system outages and total blackout |
| **Renewable Energy Integration** | Wind/PV generation and forecasting | Long-term and un-predictable intermittent sources of energy, unscheduled power flow and dispatch |
| | Power Flow Optimization | Transmission line congestions and huge investments |
| | Power System Stability | Decoupling causes system stability issues causes reduced inertia due to high level of wind penetration |
| **Energy Storage Systems** | Cost | Expensive energy storage systems like Ultra capacitors, SMES, CAES etc. |
| | Complexity | Complex customary design module and networks |
| | Non-flexibility | Unique designs for all individual networks not ease adaptation. |
| **Consumers' Motivation** | Security | Malware, data intercepting, data corruption, illegal power handling and smuggling |
| | Privacy | Sharing of data cause privacy invasion, identity spoofing, eavesdropping etc. |
| | Consumer awareness | Corruption and system threats like security and privacy issues |
| **Reliability** | Grid Automation | Need of strong data routing system, with secure and private network for reliable protection, control and communication |

| | | |
|---|---|---|
| | Grid Reconfiguration | Generation demand equilibrium and power system stability with grid complexity |
| **Power Quality** | Disturbance Identification | Grid disturbances due to local faults in grids, load centers or sources |
| | Harmonics Suppression | System instability during sags, dips or voltage variation such as over-voltages, under voltages, voltage flickers etc. |

With these aforementioned challenges; metrics, cost and benefits analysis of Smart Grid field projects has also been some major challenges. These includes; enabling a fair comparison of baseline performance and smart grid performance, collecting proper data at appropriate frequency and location, determining societal benefits, monetizing benefits, using appropriate assumption and estimation methods etc.

Extensive researches are being initiated by various universities towards this technology in order to overcome its multiple multi-levels challenges. Power system and design engineers are being trained, to understand and investigate about system variables and reconFig. the power grids to a smarter way. Being a corner stone in future power system network configuration, it has been anticipated that a strong and viable solution can be envisioned to contempt the energy market challenges.

### 2.3.2 Technical Challenges for Development of Smart Grid in India

A proper coordination among the generation, transmission, distribution and utilization of the power is essential for proper and reliable functioning of the grid. For a developing nation like India, possible challenges that represent the main obstacles for development of smart grid in India are as follows:

*1) Integration of RES in India:* For better implementation of smart grid share of renewable energy sources must be increased to 30% to 40% of total generating capacity which requires large investment with high technical knowledge. Renewable energies such as small hydro plants, solar PV, wind, biomass, and tidal based generations have many technical and commercial challenges viz., forecasting and dependency, reliability, grid connection requirements, power flow optimization and stability issues, reactive power compensation, involvement of power electronic devices etc. To eradicate such issues the government and power agencies has amended an optimized grid connection codes for the reliable and flexible operation of RES and integration in to classical grid. This is explained in successive section in details.

*2) Energy Storage System (ESS):* With the incorporation of RES in forthcoming times, it is desirable to integrate energy storage devices such as batteries, flywheel, electrical vehicles etc. due to the intermittent behavior of the RES and uphold the endurance of the power network.

Such increases the efficient and maximum utilization of renewable energy sources when available. Being at the prolific stage of development in India we often face issues like; complexity and non-flexibility, design considerations, high capital investment, and lack of technical conscience about ESS.

*3) Consumer Participation:* Active participation of consumers is the foremost concern for the development of smart grid. A smart grid incorporates consumers' equipment and behavior in grid design, operation and communication. A bi-directional data link enables consumers to better control of smart appliances and equipment in homes and business. Even though challenges in consumer's participation in smart grid implementations viz., lack of bidirectional communication data link between consumers and utilities, security of consumers, reliability of supply authority, awareness about the use of energy efficient smart appliance and energy management, complication in billing process and, high capital investment involved for designing smart building.

*4) Automation, Protection and Control:* Automation facilitates high level quality and reliable power for both consumer as well as utility sectors. For consumers, automation means receiving hourly electricity price signals and for utility sector, automation means automatic islanding of distribution feeder with local distributed energy sources in an emergency. In developing nation like India, million dollar investment is required with high design skills. Automation, protection and control will benefit for proper operational utilities of smart grid. Complex distribution network, lack of satisfactory sensors and actuators, communication link delay, aging of the devices etc. are few dire challenges faced by Indian power grid.

*5) Intelligent Electronic Devices (IEDs):* Intelligent Electronic Devices (IEDs) are the electronic based multipurpose meters used in existing grids. IEDs receive data from sensors and power equipment, and can issue control commands, such as tripping circuit breakers if they sense voltage, current, or frequency anomalies, or raise/lower voltage levels in order to maintain the desired level. Unlike other measurement devices, it issues challenges in IEDs like conversion from electromechanical to static metering, standardization in design, Fast data acquisitions and its management with advance state-of-art communication data wiring.

*6) Telecommunication:* The fundamental of the smart grid transformation is the use of intelligent communications networks or the implication of information and communication technology with systems as the platform that enables grid instrumentation, analysis and control of utility operations from power generation to trading, and from transmission and distribution to retail. In India such as power line carrier communication (PLCC), land line, and other wired and wireless communications are installed. The major challenges of telecommunication in smart grids are evaluation of system reliability, security and availability, collection of data, storage, design of architecture and monitoring system, physical and cyber security, threat defense and access control.

*7) Power Quality:* Proper knowledge of power quality issues and its low cost mitigation measures is required in India. The power quality problems are broadly classified into two categories viz. variations and events. As the advent of power electronic based circuits is essential part of smart grids, quality of power must be analyzed. The technical challenges of power quality like analysis of discharge of new devices connected in smart grid and its allocation, measurement of power quality indices, reduced voltage support and large problem of voltage sag, weak transmission system, lack of awareness in consumers, and high cost of mitigation methods are the foremost concerns.

*8) Reliability:* In India, due to lack of energy available, problems like blackouts and brownouts are common, which is required to reduce effectively within niche timeline. The following are possible challenges in achieving improved reliability; grid automation, grid reconfiguration, dwindling human interaction, high speed fault locators and repairing, preserving generation-demand equilibrium.

*9) Power Market Tools:* To accommodate changes in markets of retail power, market-based mechanisms are need. This will offer incentives to market participants in ways that benefit all stakeholder. In India, there is lack of co-ordination in suppliers and service providers. Following are the challenges of power market: Financial management, open access of data, development of data and communication standards for emerging market, development of market simulation tools.

*10) Demand Side Management (DSM):* DSM is widely recognized as a definitive and practical source of information. DSM is the planning, implementation and monitoring of those utility activities designed to influence customer use of electricity in ways that will produced desired changes in utility's load shape.

The challenges subjects are; smart metering, load research and dispatch, Load control and scheduling and development of software for DSM. As the existing power grid has professed aforementioned technical challenges and issues so to prevail such, smart grid is essential in India. While developing smart grid, various technical problems might occur as discussed above. The solution of these challenges is possible through a proper research initiatives under the collaboration of government and state-of-art highly equipped skill test facility. In addition, power system engineers have to now be trained more deeply about the smart grid and its related challenges, which would able to resolve these technical challenges.

### 2.3.3 Grid Connection Planning

As a result, the level of integration of distributed generation (DG) technologies, especially in distribution networks has increased. In order to counteract the impact of DG on the stability and reliability of power systems, the transmission and distribution systems operators have started to reconsider and update their national grid codes. The grid codes differed from country to country due to the different regulations, laws and different characteristics of their national power systems. These grid codes are set of technical guidelines and operation specification upon which large conventional power plants needed to comply with in order to maintain grid stability and avoid hostile grid disturbances like excessive line loading.

At distribution power system (DPS) level, grid codes were mainly used to specify and design the guidelines which the distribution network operators (DNOs) will apply in the planning and development of DPSs, with the compliance of end users (loads).In today's context, when generation had moved, also to lowest levels of the power systems (medium and low voltage levels), the loads have transformed into active ones and power systems into entities with a bidirectional energy and informational flow. When this change occurred in the DPS, the DNOs assessed normally the DG integration by conducting simple integration studies (load flow, basic power quality studies) because the amount of DG integration was small and the stipulated technical guidelines were simple or even absent.

In the last years, a harmonization work of grid codes related to DG has been carried out at international level and the results are being shaped into a set of standards and recommendations. Most of them have become part of the national policies regarding DG or reference points for developing new ones (e.g.: IEEE-1547, IEC-62109, IEC- 62477, ENTSO-E draft grid code). The grid codes elaborated at DPS level are basically regarding, frequency and voltage operation areas, active and reactive power control, voltage grid support during balanced disturbances, synthetic inertial capability or inertia emulation, oscillation damping in DPS and reactive current injection and absorption for fast acting voltage control.

### 2.3.4 Common Requirements for Grid Codes related to DG

The common grid connection requirements for RES integration being scrutinized by several countries upon which the grid codes are framed as per the nation's power grid requirement. The following table IV.1 exemplifies set of common technical connection requirement upon which operation states in which DPS is functioned.

**Table VIII.1**

**Common Grid Code Requirements (GCRs) for grid operation and connection for RESs.**

| OPERATION STATE | REQUIREMENTS | ASSETS |
|---|---|---|
| STEADY STATE OPERATION | Voltage operating range | To operate at typical grid voltage variations |
| | Frequency operating range | To operate within typical grid variations |
| | Active power control | To provide active power control to ensure a stable frequency, respond to desired range of ramp rates and prevent overloading of lines etc. |
| | Frequency control | To provide frequency regulation capability to help maintain the desired network frequency. |
| | Voltage control | To provide their own terminal voltage to a constant value by means of an AVR (Automatic Voltage Regulator) |
| | Reactive power control | To provide dynamic reactive power control capability to maintain reactive power balance and the power factor in the desired range. |
| DYNAMIC OR TRANSIENT STATE OPERATION | Low Voltage Ride through (LVRT) | To remain connected for the specific amount of time before being allowed to disconnect during voltage sag and also to support grid voltage for certain utilities during faults. |
| | High Voltage Ride Through (HVRT) | To stay on line for the given length of time during voltage rise (above upper limit) |
| | Voltage control | To inject reactive current into the grid or absorb upon desired requirement for fast acting voltage control. |
| | Inertia Emulation | To generate active power variations w.r.t the derivation of frequency in the PCC. |
| | Damping of oscillation | To be equipped with power system stabilizers in order to damp power oscillations in a predefined frequency range. |

The following table IV.2 are the important grid codes related to DG of few major countries which has been interconnecting DG under certain norms and regulations which also involve penetration of RES.

**Table VII.2**

**Grid Codes related to DG involving RESs integration of various nations.**

| COUNTRY | | GRID CODES |
|---|---|---|
| CANADA | Hydro Quebec (February, 2009) | Requirements for the Interconnection of Distributed Generation to the hydro-Quebec Medium-Voltage Distribution System |
| | Manitoba Hydro (January 2003) | Interconnection Guidelines for connecting distributed resources to the Manitoba Hyrdo Distribution System |
| Germany (June 2008) | | Guidelines for generating plants connection to and parallel operation with the medium voltage network. |
| | | |
| Ireland (March, 2011) | | EirGrid Grid Code |
| Spain (October, 2008) | | Technical requirements for wind power and photovoltaic installations and any generating facilities whose technology does not consist on synchronous generator directly connected to the grid |
| United Kingdom (June 2009) | | The Grid Code and the Distribution Code |
| India (April 2006) | | Indian Electricity Grid Code (IEGC) |
| ENTSO-E (January 2012) | | Requirements for Grid Connection Applicable to all Generators. |
| IEEE-1547 (July 2003) | | Standard for Interconnecting Distributed Resources with Electric Power System |

## 2.3.5 The Indian Power Grid

As per the IEEE 519 standard, it recommends that with maximum current distortion for $I_{SC}/I_L$ (<20) for current harmonics $\geq 35_{th}$ is 0.3%, however this requirement of 0.3% refers to "**weak**" grid. As per this, the Indian grid is regarded as weak grid. Upon such circumstances, it is highly essential to maintain the grid parameters into desired normal level in order to avoid brownouts and blackouts. In order, to maintain power system stability and avoid local impacts like voltage and frequency fluctuations etc., technical grid connection requirement and codes has been developed in conjunction with

i. Indian electricity grid code (IEGC) issued by Central Electricity Regulatory Commission (CERC).

ii. Technical standard for connectivity to the grid, Regulations 2007, issued by CEA

iii. State electricity grid codes issued by respective states of India.

With this, the interconnection rules are continuously reformulated because of the increasing wind power penetration and other new and renewable energy sources in to the grid, including PV. The main focus in the electricity grid codes has been focused on FRT analysis, where TSOs and DSOs requires wind power generators to stay connected to the grid during and after a fault in the transmission system. Another important requirement to the wind power installation is on active and reactive power control capability, to make the wind power installation able to support the control of grid frequency and voltage. In this work, a common grid code requirements has been suggested and some technical and operational issues of high penetration of wind power for Indian power system are addressed.

### 2.3.6 Proposed grid codes for wind power in India

The Indian electricity grid code for wind farms (IEGCWF) proposed in this section outlines the minimum technical grid connection requirements that new wind turbines and associate systems at the connection point to the transmission network have to provide safe and reliability operation of the system as per CEA regulations, which when enforced. The full capabilities of wind farms may not be exploited at all times.

Therefore, the connection codes should be such that it should provide the maximum power output from the wind farm without affecting the existing grid operation *[ref Singh B. Singh SN]*. The following grid behavior of the wind turbines are taken into consideration for large-scale grid integration of wind power in India:

- Majority of wind turbines use induction generators, unlike the conventional generators which are synchronous.
- Induction generator needs VAR support, for which capacitor banks are provided.
- Inadequate reactive power support will lead to drawl from grid, and affect the voltage profile at the point of common coupling (PCC).

- Wind turbine using synchronous generators don't need reactive power support but, they need to deal with other issues like harmonics.

- Grid codes set a standard operating practice for different type of generators.

- Wind turbines disconnect from the grid when voltage at PCC drops.

- Wind turbines can remain connected to the grid during a fault, only if adequate reactive power support is provided.

- Wind is variable in nature (intermittent), hence wind generation cannot be scheduled.

Henceforth, the following aspects are taken into consideration for large-scale grid integration of wind power in India:

- Active power control,
- Reactive power control,
- Fault ride through capability,
- Power Quality,
- Flickers,
- Harmonics,
- Communication requirements,
- Others (voltage unbalance, metering, modeling and validation).

*1. Active Power Control*

The wind power generating units are normally operated to maximum power using maximum power point tracking algorithm and remain connected to the network even if the system frequency deviates from specified one. Active (real) power control is used to control the system frequency by changing the power injected into the grid. The active power production from the wind farm must be controllable, to prevent overloading of the transmission lines, to avoid large voltage steps and in-rush currents during start up and shut down of wind turbine and to maintain the security and stability of the electric grid. Active power control may have been implemented;

- ✓ Depending on frequency of the system,
- ✓ To regulate in rush currents during startup of the turbine,
- ✓ During a fault, if the turbine may have to remain online to avoid generator tripping.
- ✓ During post-fault, the rate at which the power is being ramped should not cause power surges in the system

The following functions must be available for the active power control in wind based power generation.

- An adjustable upper limit to the active power production from the wind farm shall be available whenever the wind farm is in operation. The upper limit control of active power production, does not exceed a specified level and the limit shall be adjustable by remote signals. It must be possible to set the limit to any value with an accuracy of ±5%, in the range from 20% to 100% of the wind farm rated power. Also, Fig. IV.1 shows the variation of active power output of the wind farm with respect to frequency, where the shaded portion shows the IEGC specified frequency band of operation for Indian power grid.

- Ramping control of active power production must be possible to limit the ramping speed of active power production from the wind turbine in upwards direction (increased production due to increased wind speed or due to changed maximum power output limit) to 10% of rated power per minute. There is no requirement to down ramping due to fast wind speed decays, but it must be possible to limit the down ramping speed to 10% of rated power per minute, when the maximum power output limit is reduced by a control action.

- Fast down regulation should be possible to regulate the active power from the wind turbine down from 100% to 20% of rated power in less than 5 s. This functionality is required for system protection schemes. Some system protection schemes implemented for stability purposes require the active power to be restored within short time after the down regulation. For that reason, disconnection of a number of wind turbines cannot be used to fulfill this requirement.

- Immediate disconnection of the wind turbine is advised and is obligatory when the frequency breaches its IEGC limit i.e. more than 50.2 Hz (over-frequency), or else perilous effect might cause generator to damage and might trounce wind turbine due to over-speed. This causes when there is sudden elimination of the load or islanding occurs mainly due to transmission line failure.

- Automatic control of the wind turbine active production as a function of the system frequency must be possible. The control function must be proportional to the frequency deviations with a dead-band.The detailed settings can be provided by the state utilities (SU).

- During under-frequency (it shows the deficit in the generation), wind power can increase the power output without affecting the network congestion.

- In India, the system frequency has controlled by the state load dispatch centers (SLDC) in coordination with regional load dispatch centers (RLDC) at about 50 Hz, within the range of 49.5-50.2 Hz band. Wind farms must be capable of operating continuously for 49.5–50.2 Hz frequency band and allowed to be disconnected during over frequency as per the wind turbine specifications. In addition, the wind turbines can reduce power at frequency of above 50.2 Hz as detailed settings provided by the SU.

*2. Frequency Requirement*

System frequency is a major indicator of the power balance in the system. A decrease in generation with respect to the demand causes the frequency to drop below the nominal frequency and vice versa. This imbalance can be mitigated by primary control and secondary control of conventional synchronous generators. High penetration of wind turbines can have a significant impact on the frequency of the grid. Power output of the wind turbine can be regulated during high frequency. As per IEGC, the grid frequency tolerance limit is specified to be 49.5–50.2 Hz, where the wind farm should be able to withstand change in frequency up to 0.5 $Hzs_{-1}$.

*3. Reactive Power Control*

Wind turbines with induction generators need reactive power support. The reactive power control requirement is used for generating units to supply lagging/leading reactive power at the grid connection point. Wind farms should be capable of supplying a proportion of the system's reactive capacity, including the dynamic capability and should contribute to maintain the voltage profile by providing reactive power support.

Capacitor banks are the preferred method of reactive power compensation in wind farms. Reactive power drawl from the system can cause increased losses, overheating and de-rating of the lines. Doubly fed induction generators and synchronous generator based wind turbines don't have any constraints with respect to reactive power.

Requirements of the grid codes for reactive power support that the power factor is to be maintained in the specified range. Wind farms are required to balance voltage deviations at the connection point by adjusting their reactive power exchange and, moreover, by setting up predetermined power factors. Wind farms shall be capable of operating at rated output for power factor varying between 0.9 lagging (overexcited) to 0.95 leading (under-excited). Fig. IV.2 shows the operating range of wind farms at different voltage levels. The above performance shall also be achieved with voltage variation of ±10% of nominal, frequency variation of +1.6% and −0.06% and combined voltage and frequency variation of ±10%.

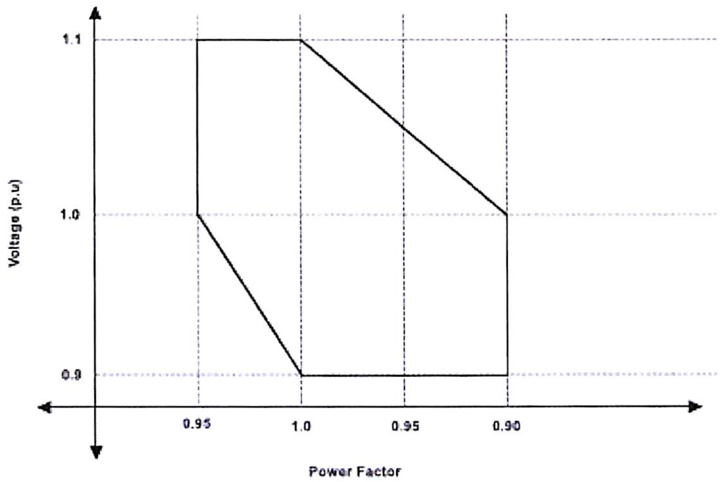



**Fig.VII.2 Operating Range of power with voltage of wind turbine in India**

Wind farms are required to have sufficient reactive power compensation to be neutral in reactive power at any operating point. In India the SLDC (and users), ensure that the grid voltage remains within the operating limits as specified in IEGC 5.2, as show in Table IV.3, and hence it is required from the wind turbine to remain connected and deliver power for the specified voltage ranges and put efforts to maintain it. Also, wind farms shall make available the up-to-date capability curves indicating restrictions to the SLDC/RLDC, to allow accurate system studies and effective operation of the state transmission system.

**Table VII.3**

**Grid voltage operating limits.**

| NOMINAL SYSTEM VOLTAGE (kV) | GRID VOLTAGE TOLERANCE VALUE | MAXIMUM VOLTAGE LIMIT (kV) | MINIMUM VOLTAGE LIMIT (Kv) |
|---|---|---|---|
| 400 | +5% to -10% | 420 | 360 |
| 220 | -9% to -11% | 245 | 200 |
| 132 | -9% to +10% | 145 | 120 |
| 110 | -12.5% to +10% | 121 | 96.25 |
| 66 | -9% to +10% | 72.5 | 60 |
| 33 | -10% to +5% | 34.65 | 29.7 |

The reactive power output of the wind farm must be controllable in one of the two following control modes according to SU specifications.

- The wind farm shall be able to control the reactive exchange with the system at all active power production levels. The control shall operate automatically and on a continuous basis.

- The wind farm must be able to automatically control its reactive power output as a function of the voltage at the connection point for the purpose of controlling the voltage.

The detailed settings of the reactive power control system will be provided by the respective SU. The wind farm must have adequate reactive power capacity to be able to operate with zero reactive exchange with the network measured at the connection point, when the voltage and the frequency are within normal operation limits. The following points are the standards being framed by the IEGC for reactive power exchange within the network;

- VAR drawl from the grid at voltages below 97 % of nominal will be penalized.
- VAR injection into the grid at voltages below 97 % of nominal will be given incentive.
- VAR drawl from the grid at voltages above 103 % of nominal will be given incentive.
- VAR injection into the grid at voltages above 103 % of nominal will be penalized.

*4. Fault Ride Through Capability (LVRT/HVRT)*

Fault-ride through (FRT) requirement is imposed on a wind power generator so that it remains stable and connected to the network during the network faults. Disconnection from grid may worsen the situation and can threaten the security standards at high wind penetration. The wind farm must be able to operate satisfactorily during and after the disturbances in the distribution/ transmission network, and remain connected to the grid without tripping from the grid for a specified period of time during a voltage drop (LVRT) or voltage swell (HVRT) at the PCC. The period and intensity of the fault ride through depends upon parameters like;

- Magnitude of voltage drop/voltage swell at the Point of Common Coupling (PCC) during the fault.

- Time taken by the grid system to recover to the normal state.

This requirement applies under the following conditions:

- The wind farm and the wind turbines in the wind farm must be able to stay connected to the system and to maintain operation during and after clearing faults in the distribution/transmission system.

- The wind farm may be disconnected temporarily from the system, if the voltage at the connection point during or after a system disturbance falls below the certain levels.

- During a fault that causes a voltage drop at the wind turbine terminals, active power demand of induction generators increases, as a result of which the reactive power will be drawn from the grid unless active power support is available at the generator terminals, which further causes instability.

The fault, where the voltage at the connection point may be zero, duration is 100ms for 400 kV and 160ms for 220 kV and 132 kV. Fig. IV.3 shows the fault clearing time and voltage limit for FRT of wind power as per IEGCWF, where region ABCDA is the restrain zone. In India, the SU and the RLDC ensures reliable operation of the grid under specified limit of voltage and fault clearing time, as shown in table IV.4. Prevalent practice shall be followed according to Regulations 2007.

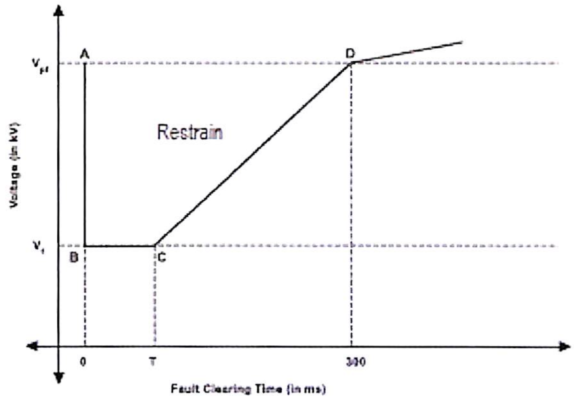



Fig. VII.3 LVRT of wind turbine as per IEGC.

**Table VII.3**

**Grid voltage operating limits.**

| NOMINAL SYSTEM VOLTAGE (Kv) | Fault clearing time (IN MS) | Vpf (kV) | Vr (kV) |
|---|---|---|---|
| 400 | 100 | 360 | 60 |
| 220 | 160 | 200 | 33 |
| 132 | 160 | 120 | 19.8 |
| 110 | 160 | 96.25 | 16.5 |
| 65 | 300 | 60 | 9.9 |

The wind turbines are required to be equipped with relay protection system which should take into account; normal operation of the system and support to network during and after the fault, and secure wind farms from damage origination from faults in the network.

Wind turbines are required to be equipped with under/over-frequency protection, under/over-voltage protection, differential protection of the generator transformer, over current and earth fault protection, load unbalance (negative sequence) protection, capacitor bank protection, tele-channel protection and backup protection (including generator over-current protection, voltage-controlled generator over-current protection, or generator distance protection).

*5. Power Quality*

It is an ability of a power system to operate loads, without damaging or disturbing them. It is mainly concerned with voltage quality at points of common coupling & ability of the loads to operate without disturbing or reducing the efficiency of the power system, a property mainly, but not exclusively, concerned with the quality of current waveform.

Assessment of power quality of wind farms IEC 61400-21: Wind Turbine Generator Systems, Part 21: "Measurement and Assessment of Power Quality Characteristics of Grid Connected Wind Turbines" describes the power quality management of a wind farm.

*6. Flicker*

Flicker, is the visual fluctuation in the light intensity as a result of voltage fluctuations (at 1-10 Hz). It is mainly caused due to; shadowing effect of the turbine which regards 1-2 Hz and switching operation causing power fluctuation at both active and reactive part. For variable wind turbines based system, it not a matter of concern.

With this, IWGC has incorporated IEC 61000-3-7 for voltage flicker limits and IEC 61000-4-15 for the guideline on measurement of flicker in the grid.

*7. Harmonics*

Harmonics are basically generated by variable speed turbines with power converters, like DFIG based WT and full variable speed wind turbine. IEC 61400-21 recommends measurement of harmonics emission only for variable speed turbines. As per IEGC, table IV.5 shows the THD at certain voltage levels. It is mandatory that the harmonic content of the supply current i.e. $I_{THD}$ should be less than 5% for supply voltage less than 69 kV and 2.5% for supply voltage greater than 69 kV as per IEEE STD-519-1992.

**Table VII.5**

**THD of voltage**

| SYSTEM VOLTAGE (kV) | TOTAL HARMONIC DISTORTION (THD in %) | INDIVIDUAL HARMONICS AT ANY PARTICULAR FREQUENCY (in %) |
|---|---|---|
| 765 | 1.5 | 1.0 |
| 400 | 2.0 | 1.5 |
| 220 | 2.5 | 2.0 |
| 132 | 3.0 | 2.0 |

*8. Communication Requirement*

Wind farms must be controllable from remote locations by telecommunication system. Supervisory control and data acquisition (SCADA) is recommended for the remote control of wind power and telemetry of the important parameters for scheduling and forecasting is obtained. Control functions and operational measurements must be made available to the SLDC/RLDC. The SU in each area specifies the required measurements and other necessary information to be transmitted from the wind farm. Information required generally from wind farms are voltage, current, frequency, active power, reactive power, operating status, wind speed, wind direction, regulation capability, ambient temperature and pressure, frequency control status and external control possibilities.

*9. Other requirements*

*Voltage Unbalance*

Voltage unbalance refers to the ratio of the deviation between the highest and lowest line voltage to the average of the three line voltage. It is susceptible and affects the generator performance as negative sequence current is generated and flows in the rotor. Table IV.6 gives the voltage imbalance limits for wind farms at desired supply voltage level.

**Table VII.6**

**Voltage imbalance limit for wind farms.**

| VOLTAGE LEVEL (in KV) | UNBALANCE LIMIT (in %) |
|---|---|
| 400 | 1.5 |
| 220 | 2 |
| <220 | 3 |

*Metering*

Recording instruments such as data acquisition system/ disturbance recorder/event logger/fault locator (including time synchronization equipment) shall be installed at each wind farms for recording of dynamic performance of the system. Agencies shall provide all the requisite recording instruments as specified in the connection agreement according to the agreed time schedule. These requirements are similar for conventional power sources and mentioned in detail in CEA (Installation and operation of meters, Regulation 2006), IEGC, and respective state electricity grid codes.

*Modelling and Validation*

Prior to the installation of a wind turbine or a wind farm, a specific test programme are conducted and must be agreed with the SU in the area regarding the capability of the wind turbine or wind farm to meet the requirements in this connection code. As a part of the test programme, a simulation model of the wind turbine or wind farm must be provided to the SU in a given format and the model shall show the characteristics of the wind turbine or wind farm in both static simulations (load flow) and dynamic simulations (time simulations). These requirements are similar to the conventional power sources and mentioned in detail in IEGC and respective state electricity grid codes.

### 2.3.7 Grid connectivity and withdrawal planning

Grid connectivity has posed a major challenge in harnessing the renewable energy as most of the renewable energy sources, particularly wind and small hydro sites are in remote areas where in transmission and distribution network is sparse. As per the provisions of Electricity Act 2003, it is the responsibility of concerned licensee or respective state utility (SU) to provide grid connectivity to the generating stations. Further, Electricity Act 2003 under Section 86(1) (e) specifically empowers state electricity regulatory commission (SERC) to take suitable measures for ensuring the grid connectivity to the renewable energy projects or wind farms. However in most of the cases, responsibility of licensee and wind farm developer in developing the evacuation infrastructure varies across the states. For wind energy projects, inter connection point is to be located and specified by the respective SU.

General connectivity conditions elaborated in Regulations 2007 must be held valid for wind farms. Therefore, it is preferred that evacuation infrastructure from generator terminal up to grid inter connection point shall be developed by the wind farm developer and beyond inter connection point the concerned licensee shall develop the network. The concerned licensee or SU shall be responsible for providing grid connectivity to the wind farms from the inter connection point, on payment of wheeling or transmission charges as the case may be, in accordance with the regulations of the respective SERC.

### 2.3.8 Operational issues

With increasing penetration of wind power, it is equally important to address concerns of grid operations. In case, information about likely wind power generation forecast is available then, it will facilitate grid operation. Accordingly, it is obligatory that Indian system that in near future should be make mandatory for all non-firm renewable energy generating sources (RES), especially wind power, shall furnish the tentative day-ahead hourly generation forecast (MWh) for the energy availability at inter connection point to the concerned RLDC/SLDC to facilitate better grid co-ordination and management like present day conventional power generation.

Further, it has been clarified that above forecasts shall be used for calculating deviation from such scheduled forecasts and must be subjected to unscheduled interchange (UI) mechanism outlined under CERC UI Regulations 2009, but with suitably selected price cap on wind power generation decided in conjunction with fixed price paid for wind power *[ref. Ackermann T]*.

Wind farm owners are in-charge of balancing his own production balance by market-based means or by developing technical capabilities. Unscheduled interchange mechanism is a best mechanism, exercised in India, can make wind power (or other non-firm renewable energy sources) semi-competitively dispatchable. In this proposed manner, wind farm owners continually get fixed return on wind power they accurately dispatched and get paid/charges for UI power. Wind farm owners can optimally schedule their generation slightly lower than actually forecasted wind power to avoid any charges. Sufficient return on wind power will ensure promotion to wind power in longer term and UI mechanism will ensure the competiveness and technological innovation. As there is huge demand–supply gap prevails in India, frequency remains mostly in lower side of range specified for UI mechanism and hence remunerate much more, for UI injection of power, compare to fixed price received by wind power in next future.

As wind penetration is forecasted to increase significantly in the short to medium term, it is essential that grid code harmonization process is to be done immediately. It will help the manufacturers to internationalize their products/services, the developers to reduce the cost and the system operators to share experience, mutually, in operating power systems *[ref. Singh B, Singh SN]*.

As a result, GCR should be harmonized at least in the areas those have little impact on the overall costs of wind turbines. In other areas, GCR should take into account the specific power system robustness, the penetration level and/or the generation technology. Harmonization in GCR will help in achieving following goals:

- ✓ For setting of proper regulations for the connection of wind power technology to the electricity grid,
- ✓ For facilitating the internationalization of manufacturers and developers, and
- ✓ For developing new standards, codes and verification procedures, interaction between GCR issuing working groups.

**2.3.8 Micro grid and Hybrid Energy System**

Adding renewable energy resources into the existing bulk generation power system can be accomplished through a smarter power grid when the integration includes complex, end-to-end control strategies and consumer incentives to participate. Successful application of distributed generation requires an enterprise level system perspective which views generation and associated loads as an integrated and autonomous subsystem or a "**Microgrid**". A Microgrid is a localized, scalable, and sustainable power grid consisting of an aggregation of electrical and thermal loads and corresponding energy generation sources. It includes; distributed energy resources (including both energy storage and generation), control and management subsystems, secure network and communications infrastructure, and assured information management. When renewable energy resources are included, they usually are of the form of small wind or solar plants, waste-to-energy, and combined heat and power systems.

Microgrid perform dynamic control over energy resources enabling autonomous and automatic selfhealing operations. During normal operations, peak load, or grid failure the Microgrid can operate independently from the larger grid and isolate its internal assets and associated loads without affecting the larger grid's integrity. A technical complexity for Microgrid is the sensing, monitoring and resultant control of distributed energy resources.

Microgrid will need to perform complex system control functions such as;

- ✓ Dynamically adding or removing new energy resources without modification of existing components,

- ✓ Automating demand response, autonomous and self-healing
- ✓ Operations connect to or isolate from the transmission grid in a seamless fashion, and
- ✓ Manage reactive and active power according to the changing need of the loads.

Micro grid will fundamentally need to interoperate with legacy bulk power systems and their associated data and network infrastructure. Microgrid deployments can take several forms and sizes, such as a utility run metropolitan area grid, industrial park, college campus or a small energy efficient community.

Once Microgrid controls are operational at a local level on the distribution grid, they become resources for the larger bulk renewable generators.

### 2.3.9 Micro grid control arrangement

The independent role of specific Microgrid and the varying specific control needs of the attached resources require deployment of a control system that considers a hierarchy of control objectives.

- ✓ At the grid level, optimization and overall grid stability goals are paramount.
- ✓ At the device level, efficient energy production and device optimization are key.
- ✓ At the load level, efficient energy consumption, cost and reliability are the critical elements.

This broad set of requirements creates an implicit Microgrid control hierarchy. It indicates that a single controller cannot effectively make decisions for all attached elements and draws the conclusion that a distributed control system supporting multiple and cooperative goals must be provided. Two critical areas arise as primary control logic requirements for orchestrating a Microgrid;

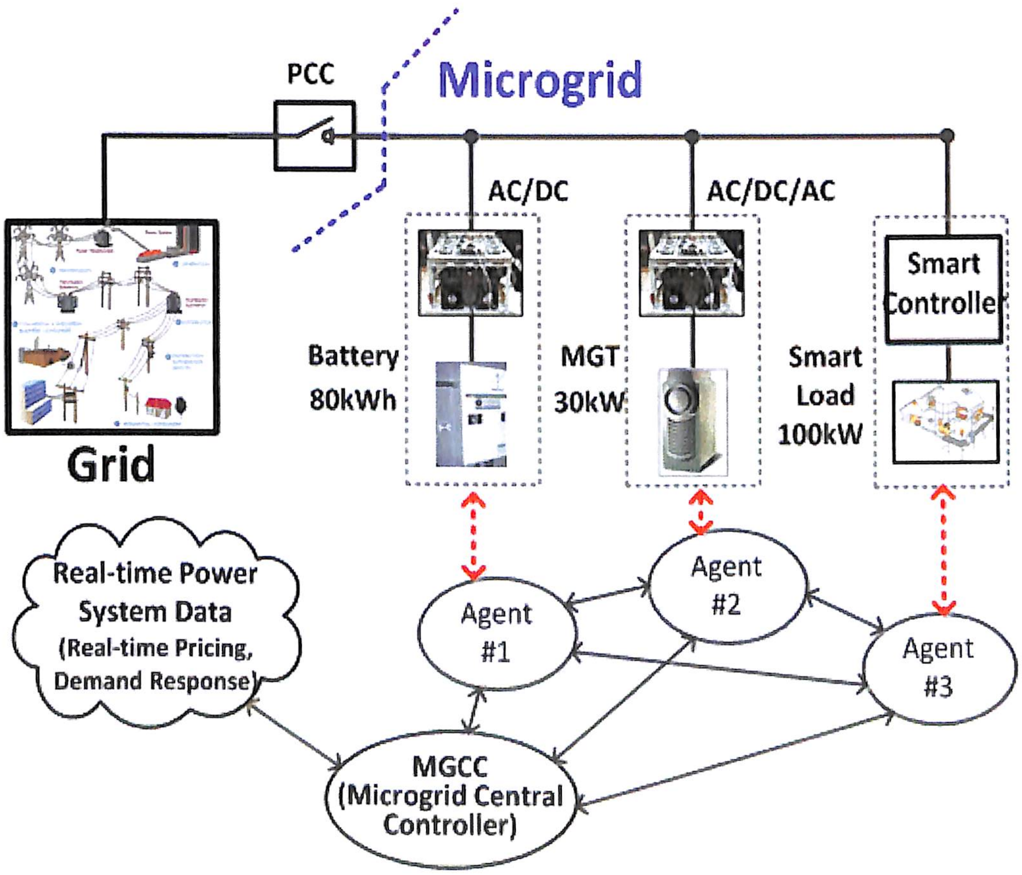
1- Control logic managing power stability of the grid else Analog-centric, and
2- Control logic managing the digital information and automation layer of the grid else Digital-centric.

| ANALOG CENTRIC CONTROL | DIGITAL CENTRIC CONTROL |
|---|---|
| Voltage stability | Demand Response |
| Frequency stability | Distributed Generation |
| Rotor-Angle stability | Energy storage |
| Transient Stability | Energy Metering |
| | Energy Forecasting |
| | Energy Market Trading |
| | System Monitoring |

The analog-centric control power distribution and transmission infrastructure monitors and balances the stability of power. It also regulates dynamic price and performance attributes of the distributed energy generation as well as information reflecting the energy consumption, cost, environmental and reliability desires of the distributed loads. It also includes analyzing and orchestrating voltage level consistency, voltage frequency stability and the underlying power signal phase relationships.

Whereas, the digital centric control computes the need for power and where to procure it based on price, reliability and grid situational awareness. It also scrutinize cyber security, distributed information management, process automation, workflow orchestration and advanced resource forecasting for smart and reliable operation of a grid.

**Microgrid Agent Control System (MGAS) framework**



As discussed earlier, integrating renewable and variable resources will require new and novel control systems technology. Integration of DER will require control logic that addresses both the unique characteristics of the DER units as well as provide capability to coordinate control in a highly distributed environment. To address this need, Microgrid design has been developing is an agent based, cooperative control system. In this capacity, we have been developing the Microgrid Agent Control System (MGAS), shown in Fig. V.1. MGAS is a modular platform for performing distributed Microgrid control.

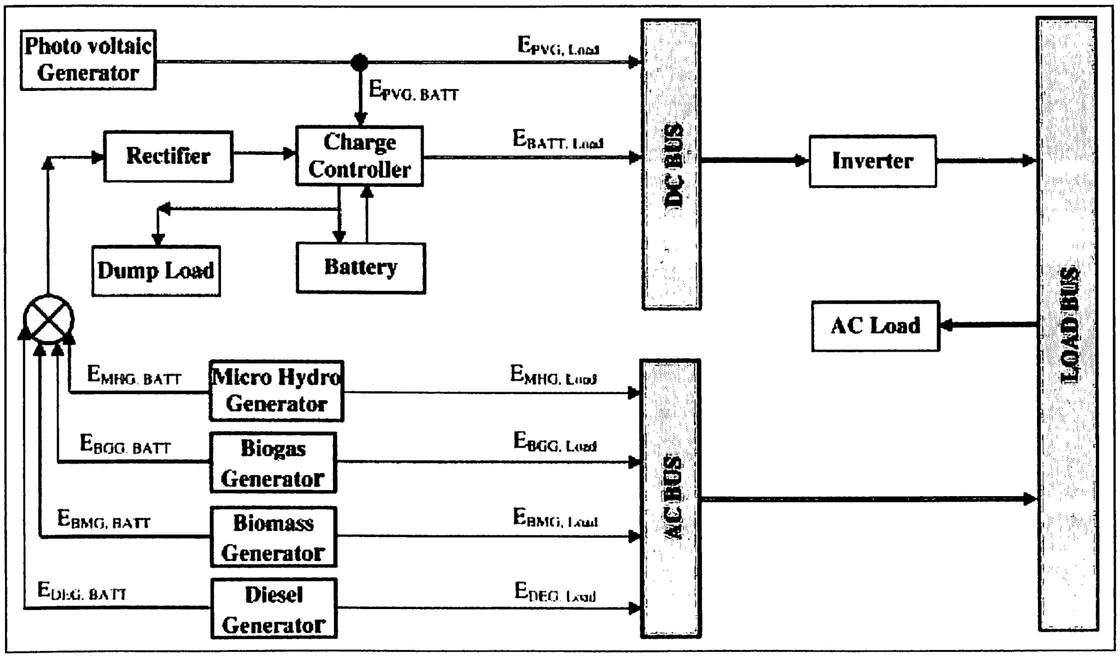
It is specifically designed to support a variety of Microgrid classes via its service oriented design and hierarchy of agent families. MGAS services consist of cooperative agents that compose distributed energy resource control and automation as well as Microgrid switching and self-healing operations. MGAS agents collaborate as a cooperative control system to execute distributed control protocols and services for automated demand management, energy storage and energy generation. MGAS applies the OpenADR standard for DR control signals, IEEE 1547 for interconnect and the IEC Common Information Model (CIM) standard to exchange information metadata. FIPA compliant agent communication protocols and lifecycle management technology are also applied to facilitate standards based agent interoperability. This collaborative and semi-autonomous agent architecture enables true distributed control and mitigates single point of failure risk. The primary system goal of MGAS is to create an adaptive and intelligent control system enabling collaboration and cooperation between DER nodes. Three core families of agent behaviors are established: Grid-Level Agents, Site-Level Agents and Device-Level Agents. From these three primary sets of behaviors a variety of agent types are sub-cast and implemented. The three core behaviors are inherited by all sub-cast agents and serve to promote common mechanisms of decision behavior and functionality.

### 2.3.10 Concept of Hybrid Energy System

The renewable resources in absolutely stand-alone mode do not perform reasonable due to reliability issues subjected to asymmetrical behavior and disturbance in weather conditions. As in such cases, the generators are supported by another generating technology and/or storage devices consist of two or more distributed generation system like; wind-PV, wind-diesel etc., to supply a common load. Such a technology is called Hybrid energy.

Hybrid connection of different resources and/or storage devices improves the reliability of the system, as well as is technically and economically sustainable a more ethical approach is to congregate all such technology into Micro Grid. Smart Micro Grid are to create perfect power system with smart technology, redundancy, distributed generation and storage, cogeneration or combines heat and power, improve voltage profile, cost reduction, reduction in carbon credits, smart regulation of appliances and load etc.

Fig. V.2 gives an idea of hybrid energy system with several different AEDGs split DC and AC buses with centralized and de-centralized control system.



### 2.3.11 Energy Storage System

As mentioned before, renewable energy sources, such as wind and PV, are intermittent in nature because of the dependence on weather conditions (and the time of the day) and therefore require storage of surplus energy to match with the energy demand curve on the grid. As mentioned before, to avoid expensive grid energy storage, the smart grid concept can be used, where smart metering can condition the demand curve (demand-side energy management) to match with the available generation curve by offering lower tariff rate.

In contrary, suitable energy storage devices can be incorporated with these DG system to store energy and then discharge be providing power back to the network which when the RES power generation sources are out. The following are few major energy storage devices which are preferred to be used in the energy storage facility and an optimized research are made on it for efficient and reliable operation.

- ✓ Pumped storage in hydroelectric plant
- ✓ Battery storage
- ✓ Flywheel (FW) storage
- ✓ Superconducting Magnet Energy Storage (SMES)
- ✓ Ultra-capacitor (UC) storage
- ✓ Vehicle-to-Grid (V2G) storage
- ✓ Hydrogen gas ($H_2$) storage, and
- ✓ Compressed Air Energy Storage (CAES)

- **Pumped storage in hydroelectric plant**

In this method, hydro-generators are used as motor pumps to pump water from "tail" to "head" and store at high level using the off-peak grid period. During the peak demand, the head water runs the generators to supply the demand. It is possibly the cheapest method of energy storage but is applicable only with proper site facilities. Otherwise, it may be expensive. The typical cycle energy efficiency may be 75%, and cost may be less than \$0.01/kWh. Currently, there is over 90 GW of pumped storage facility around the world. A new concept in this method is to use wind turbines or solar cells to directly drive water pumps for energy storage.

- **Battery storage**

It has been the most common form of energy storage for the grid. In this method, electrical energy from the grid is converted to dc and stored in a battery. Then, the stored energy is retrieved through the same converter system to feed the grid. Although very convenient with high cycle efficiency (typically 90%), battery storage is possibly the most expensive (typically > \$0.1/kWh). Lead–acid battery has been used extensively, but recently, NiCd, NaS, Li-ion, and flow batteries (such as *vanadium redox*) are finding favor. For example, General Electric (GE) installed 10-MVA lead–acid battery storage in the Southern California Edison grid in 1988. The world's largest battery storage was installed by ABB in Fairbank, Alaska, in 2003 that uses NiCd battery with a capacity of 27 MW for 15 min. Flow batteries have fast response and can be more economical in large-scale storage.

- **Flywheel (FW) storage**

In FW storage, electrical energy from the grid is converted to mechanical energy through a converter-fed drive system (operating in motoring mode) that charges a FW, and then the energy is recovered by the same drive system operating in generating mode. The FW can be placed in vacuum or in $H_2$ medium, and magnetic bearing can be used to reduce the energy loss. Steel or composite material can be used in FW to withstand high centrifugal force due to high speed. FW storage is more economical (\$0.05/kWh) and has been used, but mechanical storage has the usual disadvantages. Recently, wind turbines have been used with direct coupling to FW system to achieve better efficiency.

- ### Superconducting Magnet Energy Storage (SMES)

In this method, grid energy is rectified to dc, which charges SMES coil to store energy in magnetic form ($0.5LI^2$). Then, energy is retrieved by the reverse process. The coil is cooled cryogenically so that dissipation resistance tends to be zero, and the energy can be stored indefinitely. Either liquid helium (0K) or high-temperature superconductor (HTS) in liquid nitrogen (77 K) can be used. The cycle efficiency can be higher than 95%. SMES storage is yet very expensive.

- ### Ultra-capacitor (UC) storage

A UC (also called super capacitor or electrical double layer capacitor) is an energy storage device like an electrolytic capacitor (EC), but with energy storage density (Wh or $0.5CV^2$/kg) as high as 100 times higher than that of EC. UCs are available with low-voltage rating (typically 2.5 V) and capacitor values up to several thousand farads. The units can be connected in series–parallel for higher voltage and higher capacitance values. However, the Wh/kg of UC is low compared to that of a battery (typically 6:120 ratio for a Li-ion battery). The power density (W/kg) of UC is very high, and large amount of power can cycle through it without causing any deterioration. In the present state of technology, UCs are yet expensive for bulk grid energy storage.

- ### Vehicle-to-grid (V2G) storage

This a new concept for bulk energy storage assuming that a large number of battery EVs are plugged in the grid. A plugged-in EV can transmit electricity to the grid during peak demand and then charge the battery during off-peak hours. V2G technology can be used, turning each vehicle with its 20–50-kWh battery pack into a distributed load balancing device or emergency power source. However, the main disadvantage is that the battery life is shortened by charge–discharge cycles.

- **Hydrogen ($H_2$) gas storage**

$H_2$ gas can be used as bulk energy storage medium and then used in FC or burned as a fuel in IC engine. This idea has generated the recent concept of hydrogen economy, i.e., $H_2$ as the future clean energy source.

As mentioned before, $H_2$ can be generated easily from abundantly available sporadic sources like wind and PV and stored as compressed or liquefied gas with high density amassable fuel. It can be generated also from hydrocarbon fuels with underground sequestration of undesirable $CO_2$ gas. The overall energy efficiency of $H_2$ storage cycle may be 50% to 60%, which is lower than battery or PSP.

- **Compressed Air Energy Storage (CAES)**

CAES is another grid energy storage method, where off-peak or renewable generated electricity is used to compress air and store underground. When electricity demand is high, the compressed air is heated with a small amount of natural gas and then burned in turbo expanders to generate electricity. CAES system has been used in Europe. The idea of using wind turbines to compress air directly is floating around.

The development and implementation of the electrical energy storage system could drive groundbreaking changes in the design and operation of the electric power system. Such facilitates peak load issues, electrical stability, power quality disturbances elimination etc. Power plants are also nowadays equipped with such systems.

Energy storage system is the combination of advanced power electronics incorporated with the grid playing a major role in both technical and financial benefits. Table IX.1 summarizes the following benefits.

**Table IX.1**

**Benefits of Energy Storage Systems.**

| | |
|---|---|
| **TECHNICAL BENEFIT** | Grid voltage support |
| | Grid frequency support |
| | Grid Angular (Transient)Stability |
| | Load levelling |
| | Spinning Reserve |
| | Power Quality Improvement |
| | Power Reliability |
| | Rode through Support |
| | Unbalanced load compensation |
| **FINANCIAL BENEFIT** | Revenue increased of Bulk storage Arbitrage |
| | Revenue increase of Central Generation Capacity |
| | Revenue increase of Ancillary Services |
| | Revenue increase for transmission access |
| | Reduced demand charges |
| | Reduces Reliability-related Financial losses |
| | Increase revenue from RES |

## Chapter 3: Research Design, Methodology and Plan

Various publication, research papers, government standards and date include both present historical information are used for this dissertation.

### 3.1 SOURCES OF DATA

1. Global Wind Energy Council (GWEC), European Renewable Energy Council (EREC), Green Peace (2012), Energy revolution, A Sustainable World Energy
2. Central Electricity Authority. Technical standard for connectivity to the grid, regulations 2007; 2007
3. Central Electricity Regulatory Commission. Indian Electricity Grid Code (IEGC) 2006, December; 2005
4. Central Electricity Authority, 2010.
5. Ministry of Power, Government of India
6. Ministry of New and Renewable Energy.
7. Power Grid India Corporation Limited,
8. http://en.wikipedia.org/wiki/SuperSmart_Grid
9. Indian Energy Vision 2050: The future lies in the Smart Grids: http://www.cmrindia.com.
10. Rural Electrification Corporation of India Limited,

## Chapter 4 : Interpretation of Results

Due to the consequence of cutting edge technology, buzzwords like energy conservation and emission reduction, green energy, sustainable development, safety factor, reduction of T&D losses, optimal utilization of assets, have turn out to be the core of discussion. As India is struggling to meet its electricity demands, both in terms of Energy and Peak Load, Smart Grids can help better manage the shortage of power and optimize the power grid status in the country. A "**Smart Grid**" is a perception of remodeling the scenario of the nation's electric power grid, by the convergence of information and operational technology applied to electrical grid, allowing sustainable option to the customers and upgraded security, reliability and efficiency to utilities *[ref. J.P. Conti]*. The elite vision of Smart Grid (SG) Technology allows energy to be generated, transmitted, distributed and utilized more effectively and efficiently.

Demand Side Management (DSM) is an essential practice for optimized and effective use of electricity, particularly in the developing countries like India where the demand is in excess of the available generation. Such kind of non-technical losses can be overcome by electricity grid intelligence *[ref. Balijepalli]*, which focuses on advanced control and communication protocols integrated with the utility providing a complete package for the requirement of "Smart Grid".

With the introduction of the Indian Electricity Act 2003, the APDRP was transformed to restructured APDRP (R-APDRP) which has improvised the operation and control, and has attempted a seamless integration of generation (including distributed energy resources (DER), transmission and distributed system through usage of intervening information technology (IT) that uses high speed computers and advance communication network, and employing open standard with vendor-neutrality is deemed a cornerstone for embracing the up-and-coming conceptualization of Smart Grid for India scenario.

A vivid study of the power scenario has been illustrated each classified rendering to the timeline in brief. Introducing with the power strategy management in the past, the whole system was monitored and controlled using telephonic medium which was purely a blue-collar job. The system was solely dependent on a single generation unit or the interconnected substations. On further progress in science and technology, the system is monitored round the clock using advance data communication protocols. As well the substation has the islanding facility with immediate power backups to maintain the grid stable.

India as a developing country, the scenario of the power system changes in exponential basis. Moreover the system is expected to be more reliable and flexible with its advancement in data communication and data analysis facility. Fig. V.1 illustrates about the advancement and it immediate results during its implementation in future. The conclusive approach for the Indian Smart Grid would be visualized accordingly, with latest technological advancement and extensive features as shown in Fig. V.2.

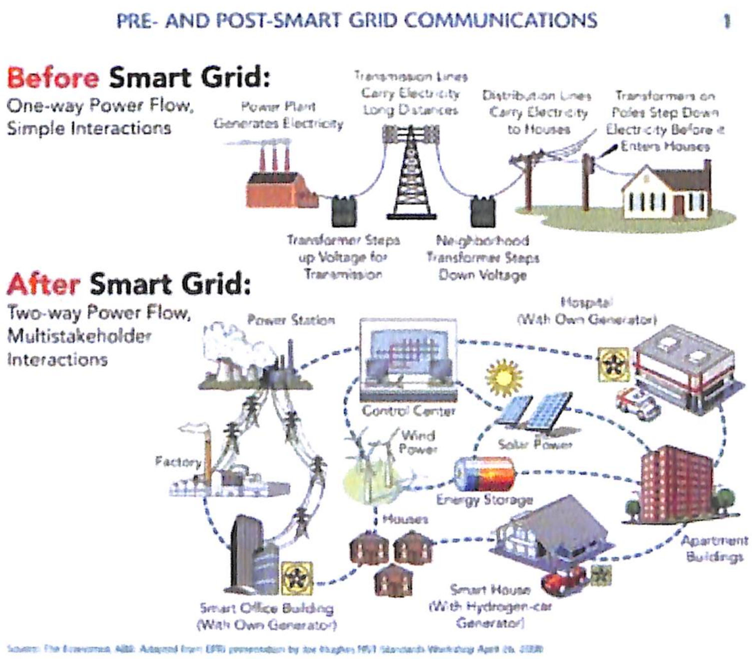



**Fig. V.1. Smart Electricity System**

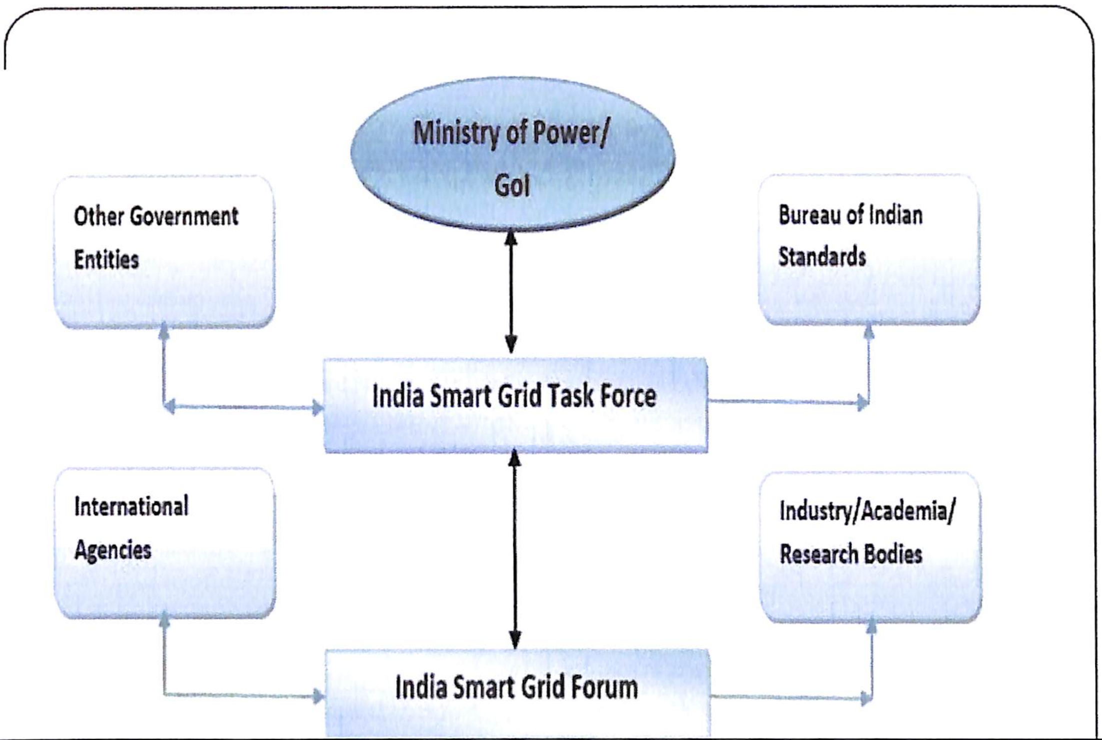



**Fig. V.2. Hierarchy of Indian Smart Grid**

## 4.1 Smart Grid Initiatives in India

As it has been acknowledged earlier that, Smart Grid Technology has a widespread overview of transforming the Indian power grid from technology based standard to performance based standard. The Ministry of Power (MoP) participated in the SMART 2020 event with "The Climate Group" and "The Global e-Sustainability Initiative (GeSI)" in October 2008 which aimed to highlight the reports relevant to key stakeholders in India. Unfortunately, the possible "way forward" has not yet been drilled out and is still a question mark for the Government. But to facilitate demand side management distribution networks has been fully-augmented and upgraded for IT enabling, which has enhanced the grid network with amended customer service. Table V.1 provides a brief analysis of some of the initiative which has been taken under the supervision of many government and private bodies and allies.

In the view of multitude that could be accrued, it is suggested that there should be ample Government regulatory support and policy initiatives to move towards Smart Grids. India is in its nascent stage of implementing various other controls and monitoring technology, one of such is ADA. Further researches are being carried out in some of the elite institutes in the country in collaboration with some of the various multinational companies and power sectors across the nation.

| SMART GRID INITIATIVES IN INDIA | REGION / LOCATION OF IMPLEMENTATION | REGION / LOCATION OF IMPLEMENTATION | REGION / LOCATION OF IMPLEMENTATION |
|---|---|---|---|
| Power Grid Corporation Of India Limited (PGCIL) | Northern Region (NR-I and NR-II) | PMUs with GPS system, PDC at NRLDC, smart load control, on-line condition monitoring, data communication using fibre link | M/s SEL group |
| | Western Region (WR-1 and WR-II) | Intelligent monitoring and control of the interconnected electric power grid using Wide Area Monitoring (WAM) | TCS, IIT Mumbai, Tata Power Project funded by CSIR under NMITLI |
| Crompton Greaves Limited (CGL) | NA | Integrated SCADA solution, Smart bay control, Smart protection IEDs, Smart Metering solution, Smart load break switches etc. | Govt. of India |
| North Delhi Power Limited (NDPL) | North And West Delhi | SCADA controlled grid station, automatic meter infrastructure, GSM based street lightning, GIS platform | Tata Power, GE SmartGrid Technologies and Govt. of Delhi |

| | | | |
|---|---|---|---|
| | | with fault management system | |
| | North And West Delhi | Development of SGMM, hi-tech automation control and monitoring, integration of grids, improvise market strategy | IBM, IUN Coalition |
| Bangalore Electricity Supply Company (BESCO) | 8 Districts Of Karnataka | T&D Loss reduction, ensuring reliable and quality power with least interruption, quick turnaround, intelligent grid monitoring | KPTCL |

**Table V.1**
Smart Grid Initiatives in India by Various Organizations.

Due to advent of advance information and communication technology (ICT) and proliferation of green energy, it's liable that Smart Grid technology transforms to more superior and advanced form. Some the newly innovated prospects like renewable energy integration, rural electrification and micro grid are to be featured in it *[ref. Belijapalli]*.

- ***Renewable Energy Integration***

Present-day environmental awareness, resulting from coal fired power station, has fortified interest in the development of the modern smart grid technology and its integration with green and sustainable energy.

Table V.2 provides and brief analysis of the renewable energy development in India which has been planned according to Five year Plans by the Indian Government and the Ministry of New and Renewable Energy (MNRE) *[ref: Indian Renewable Energy Status report, DIREC2010]*. With the perception of renewable energy, the energy converges to; reduction in carbon footprints, cleaner environment, plug-in EV, decentralized power which increases the quality of living standard and enhances the power system quality along with the stability of the grid network.

**TableV.2**

**Installed capacity of renewable energy in Indian according to five year plan**

| RENEWABLE ENERGY RESOURCES | 2007-2012 (in GW) | THROUGH 2012 (in GW) | THROUGH 2022 (in GW) |
|---|---|---|---|
| WIND | 10.5 | 17 | 40 |
| HYDRO | 1.4 | 3.5 | 6.5 |
| BIOMASS | 2.1 | 3 | 7.5 |
| SOLAR | 1 | 1.5 | 20 |
| TOTAL | 15 | 25 | 74 |

But in contrary to that the power quality also bids some of the potential challenges such as; voltage regulation, power system transient and harmonics, reactive power compensation, grid synchronization, energy storage, load management and poor switching action etc. These problems are mainly visualized for major renewable energy sources like wind and solar energy. Other energy sources like biomass, hydro and geothermal sources have no such significant problem on integration of grid.

Integration of renewables with the Smart Grids makes the system more reliable and flexible in economic load dispatch, not only in a specified location but in a wide area, even between the nations. Nordic countries have practiced such grid integration among its neighboring nations and still future implementations are being focused on. However, forecasting approaches, design algorithm and other models are being developed by many research analysis teams and are to be established in many regions

across the nationwide. Fig. V.3 below represents a brief analysis of solicitation of renewables in smart grid technology in its whole network of power system engineering.

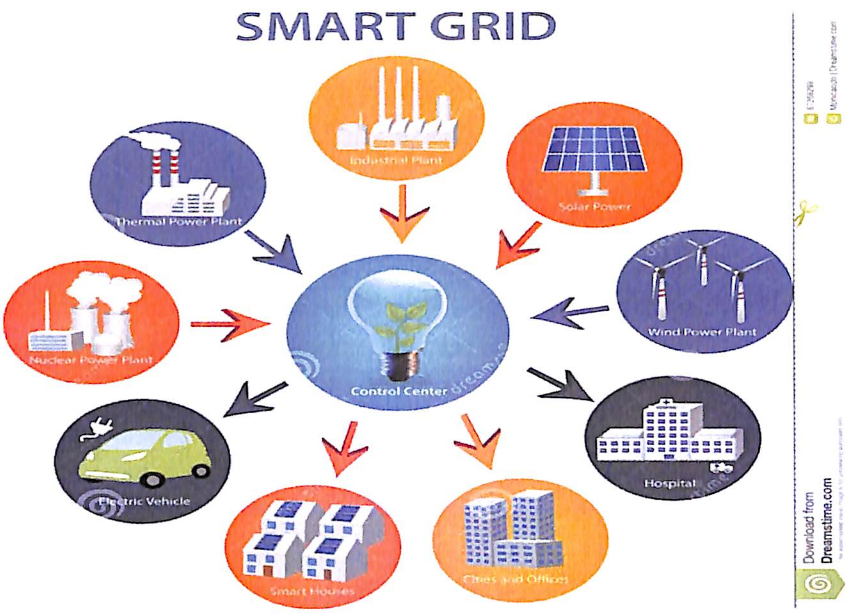



**Fig. V.3. Renewable in Smart Grid Technology.**

The volatility of fossil fuels has opened the ground for new and renewable energy sources. With the inherent unpredictability, the wind and the photo voltaic cell should be supported by upcoming technologies like Micro Grid and ICT. Such emerging technologies will play a major role in sustainable standard of living with economical insolence. Large scale implementation of the renewables need to have motivating government policies and well established standards. Proper financial support is the governing factor for a generation deficient and developing country like India.

- ***Rural Electrification***

Technologies are advancing day-by-day, Smart distribution technologies allowing for increased levels of distributed generation have a high potential to address rural electrification needs and minimize the erection costs, transmission losses and maintenance costs associated with large transmission grids. Rural Electrification Corporation Limited (REC) is a leading public infrastructure finance company in India's power sector which finances and promotes rural electrification projects across the nation, operating through a network of 13 Project offices and 5 Zonal offices. Along with the government of India has launched various programs and schemes for the successful promotion and implementation of rural electrification. One such major scheme is *Rajiv Gandhi Gramen Vidyutkaran Yojana (RGGVY).* Other schemes like, *Pradhan Mantri Garmodaya Yojana (PMGY), Three phase feeders-single phasing and Smart metering, Kutir Jyoti Program (KJP), Accelerated Rural Electrification Program (AREP), Rural Electricity Supply Technology Mission (REST), Accelerated Electrification of one hundred villages and 10 million households, Remote Village Renewable Energy Programme (RVREP)* and *Grid-connected Village Renewable Programme (GVREP) [ref: www.recindia.nic.in].*

Some of them have got a remarkable success but some of them got trapped in for their own interest due to various non-technical issues *[ref: M. Vijay]*. Some of the key features of such projects are; to achieve 100% electrification of all villages and habitation in India, provide electricity access to all households, free-of-cost electricity to BPL households, DDG system, smart based metering, promote fund, finance and facilitate alternative approaches in rural electrification, single light solar lightning system for remote villages and its hamlets. Table-3 provides a detail analysis of various rural electrification initiatives taken under the guidance of govt. of India.

**Table V.3**

Rural Electrification schemes implemented by Govt. of India.

| RURAL ELECTRIFICATION SCHEMES | YEAR OF IMPLEMENTATION | OBJECTIVES OF THE SCHEME | GOVERNING BODY |
|---|---|---|---|
| *Rajiv Gandhi Grameen Vidyutikaran Yojana (RGGVY)* | 2005 | To achive 100% electrification of all villages and habitation in India to provide electricity access to all households, to provide free-of-cost electricity connection to BPL households | Rural Electrification Coorporation (REC) |
| Three phase feedersingle phasing and | NA | Reliable service that meets the needs of agriculture, | Govt. of India |

| | | | |
|---|---|---|---|
| Smart card metering | | household supply, irrigation facility etc | |
| *Pradhan Mantri Gramodaya Yojna (PMGY)* | 2000-2001 | NA | Rural Electrification Corporation (REC) and State Electricity Board |
| *Kutir Jyoti Program (KJP)* | 1988-89 | Provide single point light connection, provide electricity access under-developed villages | Govt. of India, later merged with RGGVY under REC |
| *Minimum Needs Program (MNP)* | NA | Targeted states with less than 65% RE and provide 100% loan for last mile connectivity | Govt. of India, later merged with RGGVY under REC |
| *Accelerated Rural Electrification Program (AREP)* | 2003-2004 | Electrification of non-electrified villages/electrification of hamlets/dalit bastis/ tribal villages and electrification of households in the villages through conventional and nonconventional source of energy | State utilities, Govt. of India, later merged with RGGVY under REC |
| *Rural Electricity Supply Technology Mission (REST)* | 2002 | Identify and adopt technological solutions, promote fund, finance and facilitate alternative apporach to RE, coordinates with various ministries, apex institutions and research organizations to facilitate meeting national objectives, etc. | Govt. of India, later merged with RGGVY under REC |
| *Grid-connected Village Renewable Energy* | 2007-2012 | Development of solar thermal system and biogas plant | Planning Commision of India, Govt. of India |

| | | | |
|---|---|---|---|
| *Programme (GVREP)* | | | |
| *Accelerated Electrification of one hundred villages and 10 million households* | 2004-2005 | Merging interest subsidy scheme AREP and KJP, 40% capital subsidy was provided for RE projects and balance amount as a soft term loan through REC | Govt. of India, later merged with RGGVY under REC |
| *Remote Village Renewable Energy Programme (RVREP)* | 2007-2012 | Decentralized renewable electricity system, remote village solar lightning programme (RVSLP) | Planning Commision of India, Govt. of India |

The present rural electrification scenario in the nation is still uncertain, and is yet to be put on more exploration and verified by the Ministry of Power (MoP) and Ministry of New and Renewable MNRE).

Over 500,000 thousand of India's 600,000 thousand villages are deemed to be electrified. As in such case, the Indian Government and Indian businesses sector would need to invest on more such projects and schemes, for low-footprint technologies, renewable sources of energy, smart metering and resource efficient infrastructure.

- ***Micro Grid***

The renewable resources in absolutely stand-alone mode do not perform reasonable due to reliability issues subjected to asymmetrical behavior and disturbance in weather conditions. As in such cases, the generators are supported by another generating technology and/or storage devices consist of two or more distributed generation system like; wind-PV, wind-diesel etc., to supply a common load. Such a technology is called Hybrid energy. Hybrid connection of different resources and/or storage devices improves the reliability of the system, as well as is technically and economically sustainable a more ethical approach is to congregate all such technology into Micro Grid. There are some similarities between Smart Grid and Micro Grids or smart Micro Grids. But, the scale, the type of decision makers involved and the impending rate of growth are different for both. Smart Grid are realized at the utility and national grid level, concerning large transmission and distribution lines, while the smart Micro Grid integrates various DG technologies into electricity distribution networks and have faster implementation *[ref. Balijepalli]*. Smart Micro Grid are to create perfect power system with smart technology, redundancy, distributed generation and storage, cogeneration or combines heat and power, improve voltage profile, cost reduction, reduction in carbon credits, smart regulation of appliances and load etc.. India has just initiated their effort in this direction with two small Micro Grid projects as described in Table V.4, with brief analysis of the projects along with the technology used, installed capacity and its remarks. These projects are supported by the public-private partnerships.

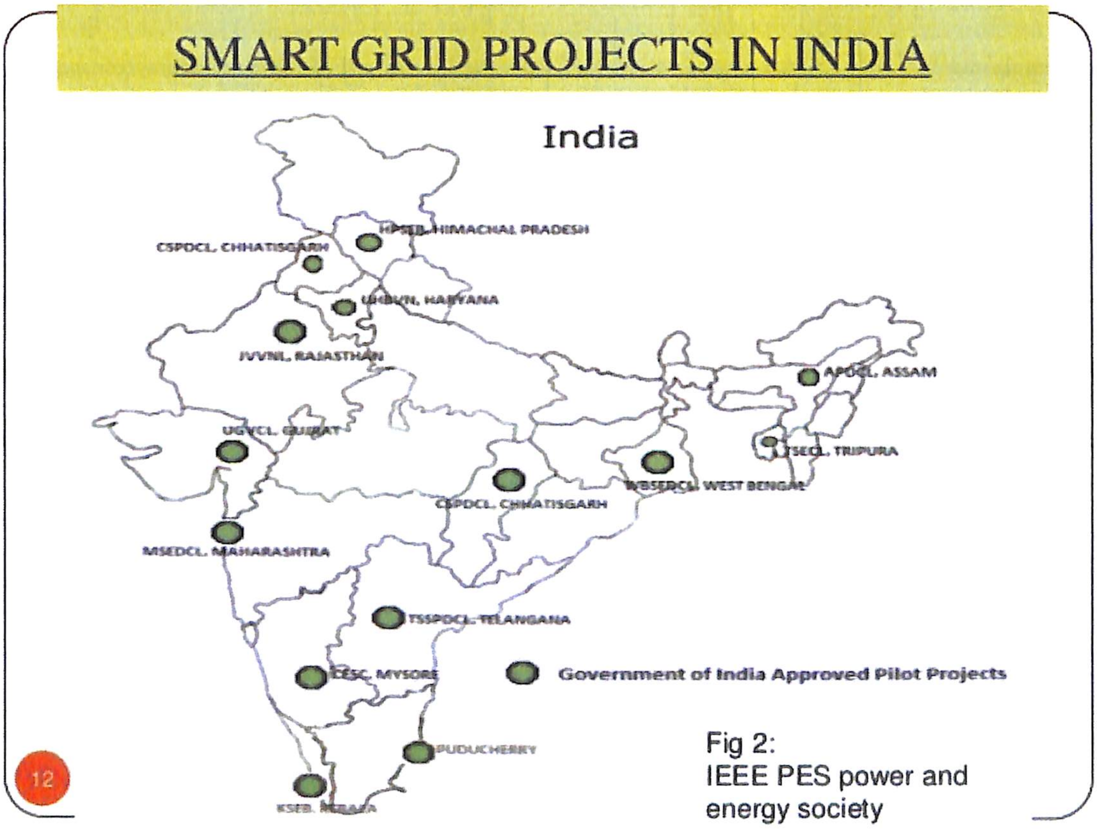



Fig 2:
IEEE PES power and energy society

## CHAPTER – 5 : CONCLUSION AND SCOPE FOR THE FUTURE WORK:

### 5.1. Summary and Conclusions.

As the report only had pulled the grid connection requirement for wind power generation, which has been planned to stretch upon to the study of photovoltaic (PV) and its grid connection planning in Indian scenario. Also, few more work related to micro grids and hybrid energy with energy storage system is premeditated to complete by near future.

India's energy generation and consumption are on high growth rate. Climatic change concerns due to emission combined with resource and infrastructure constraints are dampers. With nearly 40 % of its 1.22 billion population deprived of grid electricity, present 186 GW installed power capacity may have to be doubled by the end of this decade to meet energy need of its growing population and expectations of a high GDP growth economy. An overview of Indian Power Market along with brief analysis about the power system units is described. Power market in India is generally characterized by the poor demand side management and response for lack of proper infrastructure and awareness.

Smart Grid Technology can intuitively overcome these issues. In addition to that, it can acknowledge reduction in line losses to overcome prevailing power shortages, improve the reliability of supply, power equality improvement and its management, safeguarding revenues, preventing theft etc.. Integration of RES is expected to play significant influence on the operation of the power system for sustainable energy in future. Grid codes are set up to specify the relevant requirements for efficient and secure operation of power system for all network users and these specifications have to be met in order to integrate wind turbine into the grid. Several technical and operational issues with increased power penetration has discussed for emerging Indian power system.

In addition, Micro-grid are creating new smart grid technology requirements in the areas of automation, management and control of alternative energy sources with energy storage devices. The call for dynamic and distributed control methodologies has been discussed using MGAS framework in the above report.

With this, the report may guide future policies which to lead Indian power system to take several steps to implement Smart grid with RES integration.

The thesis presents a discussion on Indian Power Strategy along with its pitfalls in various technical and non-technical themes, with an organized approach to evolve the conceptualization of Smart Grid. Model architecture as well as India's Smart Grid initiatives taken by the government and many private bodies, are presented in the thesis. Further, various prospects of sustainable energy and off-grid solutions, Rural Electrification (RE) and evolution of Micro Grid along with various policies and regulatory affairs of India is also presented here. Currently, the nation ranks to be 4th largest in installed power generation capacity using RES and 3rd largest in investment and implementation of smart grids, which will be a trend setter for emerging economies to pursue "green" and sustainable energy. In this connection, the thesis should act as advocate to bring forth the significance and fortification of Smart Grid philosophy and implanting it on the basis of proposed ideology in Indian subcontinent.

## 5.2. SCOPE FOR THE FUTURE WORKS.

Upon the finalizing of the entire study, the further research perspective would deliberately act as an advocate to discover the rank and strategy of nation's development in power and energy with respect to current and future energy demand.

## BIBLIOGRAPHY AND REFERENCES.


1. Ackermann T, editor. Wind power in power system. England: John Wiley & Sons, Ltd.; 2005
2. Akerman, J. (2005): Sustainable air transport on track in 2050. Transportation Research Part D, 10,111-126.
3. Bossart, S.J.; Bean, J.E.; , "Metrics and benefits analysis and challenges for Smart Grid field projects, *Energytech, 2011 IEEE* , vol., no., pp.1-5, 25-26 May 2011
4. Balijepalli, V.S.K.M.; Khaparde, S.A.; Gupta, R.P.;, "Towards Indian Smart Grids" , Proc. Of T*ENCON 2009 - 2009 IEEE Region 10 Conference,* vol., no., pp.1-7, 23-26 Jan. 2009.
5. Balijepalli, V.S.K.M.; Khaparde, S.A.; , "Smart and sustainable energy systems for developing countries: An Indian perspective," *IEEE Power and Energy Society General Meeting, 2011* , vol., no., pp.1-8, 24-29 July 2011
6. Central Electricity Authority. Technical standard for connectivity to the grid, Regulations 2007 and amendments 2013.
7. Central Electricity Regulatory Commission. Indian Electricity Grid Code (IEGC) 2006, December; 2005
8. Central Electricity Regulatory Commission. Terms and conditions for tariff determination from renewable energy sources regulations, 2009, May; 2009.
9. Central Electricity Authority, 2010. [Online] Available : http://www.cea.nic.in/
10. C. Martinez, M. Parashar, J. Dyer, and J. Coroas, "Phasor Data Requirements for Real Time Wide- Area Monitoring, Control and Protection Applications," CERTS/EPG, EIPP-Real Time Task Team, Tech. Rep., 2005
11. DLR (2011): Vehicles of the Future, Preliminary Report.
12. Document from official website of *Ministry of New and Renewable Energy in India*, "Conceptual framework of REC mechanism in India," [Online] http : //mnes.nic.in/pdf/MNRE REC Report.pdf. Nov. 2009.

13. Eyring, V., Köhler, H., Lauer, A., Lemper, B. (2005): Emissions from International Shipping: 2. Impact of Future Technologies on Scenarios until 2050, Journal of Geophysical Research, 110, D17305.
14. "*Electricity Act '2003"*, Govt. of India, New Delhi, 2003
15. Epri Intelligrid, Distribution Operations - Overview of Advanced Distribution Automation. [Online].available: http://www.intelligrid.info.
16. Fulton, L. and Eads, G. (2004): IEA/SMP Model Documentation and Reference Case Projection, published by WBSCD.
17. Feltes, J.W.; Gemmell, B.D.; Retzmann, D.; , "From Smart Grid to Super Grid: Solutions with HVDC and FACTS for grid access of renewable energy sources," *Power and Energy Society General Meeting, 2011 IEEE* , vol., no., pp.1-6, 24-29, 2011
18. Fangxing Li; Wei Qiao; Hongbin Sun; Hui Wan; Jianhui Wang; Yan Xia; Zhao Xu; Pei Zhang; , "Smart Transmission Grid: Vision and Framework," *Smart Grid, IEEE Transactions on* , vol.1, no.2, pp.168-177, 2010
19. Fang, X.; Misra, S.; Xue, G.; Yang, D.; , "Smart Grid — The New and Improved Power Grid: Survey," *Communications Surveys & Tutorials, IEEE* , vol.PP, no.99, pp.1-37,2011
20. Gungor, V.C.; Sahin, D.; Kocak, T.; Ergut, S.; Buccella, C.; Cecati, C.; Hancke, G.P.; , "Smart Grid Technologies: Communication Technologies and Standards," *Industrial Informatics, IEEE Transactions on* , vol.7, no.4, pp.529-539, 2011
21. G. K. Venayagamoorthy, "Potentials and Promises of Computational Intelligence for Smart Grids," *IEEE Power General Society General Meeting,* Calgary, AB, Canada, 2009, pp. 1-6.
22. Hashmi, M.; Hanninen, S.; Maki, K.; , "Survey of smart grid concepts, architectures, and technological demonstrations worldwide," *Innovative Smart Grid Technologies (ISGT Latin America), 2011 IEEE PES Conference on* , vol., no., pp.1-7, 2011
23. *Restructuring and Power Technologies (DRPT), 2011 4th International Conference on* , vol., no., pp.1586-1589, 2011

24. International Electrotechnical Commission (IEC). Wind turbine generator systems. Part 21. Measurement and assessment of power quality characteristics of grid connected wind turbines, IEC 61400-21; 2001.
25. ICAO (2008): Committee on Aviation Environmental Protection (CAEP), Steering Group Meeting, FESG CAEP/8 Traffic and Fleet Forecasts.
26. ICCT (2011): Reducing Greenhouse Gas Emissions from Ships – Cost Effectiveness of Available Options.
27. Indian Renewable Energy Status Report, Background Report for DIREC 2010, NREL/TP-6A20- 48948, October 2010
28. Jadhav, G.N.; Dharme, A.A., "Technical challenges for development of smart grid in India," *Advances in Engineering, Science and Management (ICAESM), 2012 International Conference on* , vol., no., pp.784,788, 30-31 March 2012.
29. J. P. Conti, "Let the grid do the thinking," *IET Power Engineer*, pp. 34– 37, April/May 2006.
30. Long Zhou; Fang-Yuan Xu; Ying-Nan Ma; , "Impact of smart metering on energy efficiency," *Machine Learning and Cybernetics (ICMLC), 2010 International Conference on* , vol.6, no., pp.3213-3218, 2010
31. Ministry of Power, Government of India Website. [Online] Available : http://powermin.nic.in, Nov. 2009
32. Ministry of New and Renewable Energy. Online available: www.mnes.nic.in.
33. Mashhour, E.; Moghaddas-Tafreshi, S.M.; , "A review on operation of micro grids and Virtual Power Plants in the power markets," *Adaptive Science & Technology, 2009. ICAST 2009. 2nd International Conference on* , vol., no., pp.273-277, 2009
34. Mohd, A.; Ortjohann, E.; Schmelter, A.; Hamsic, N.; Morton, D., "Challenges in integrating distributed Energy storage systems into future smart grid," *Industrial Electronics, 2008. ISIE 2008. IEEE International Symposium on* , vol., no., pp.1627,1632, June 30 2008-July 2 2008
35. M. Vijay, "Improving Electricity Services in Rural India," Working paper series, Centre on Globalization and sustainable development, The Earth, Institute at Columbia University, Dec. 2004.

36. Mohn, T.; Piasecki, R., "A Smarter Grid Enables Communal Microgrids," *Green Technologies Conference (IEEE-Green), 2011 IEEE* , vol., no., pp.1,6, 14-15 April 2011
37. [Online] "A Report on Transmission and Distribution in India" , Power Grid India Corporation Limited, 2011, Available: http://powergridindia.com
38. [Online] Indian Energy Vision 2050: The future lies in the Smart Grids: http://www.cmrindia.com.
39. [Online] The Climate Group (http://www.theclimategroup.org).
40. [Online] northen region load despatch center. available: http://www.nrldc.org."
41. [Online] westren region load despatch center. available: http://www.wrldc.com."
42. [Online], Available: http://www.cglonline.com/
43. [Online], Available: http://www.ndpl.com/
44. Pradeep, Y.; Thomas, J.; Sabari, C.L.; Balijepalli, V.S.K.M.; Narasimhan, S.R.; Khaparde, S.A.; ,
"Towards usage of CIM in Indian Power Sector," *IEEE Power and Energy Society General Meeting 2011* , vol., no., pp.1-7, 24-29 July 2011.
45. Pazheri, F.R.; Khan, H.; Ahamed, I.; , "Smart grid implementation across the globe: A survey," *Innovative Smart Grid Technologies - India (ISGT India), 2011 IEEE PES* , vol., no., pp.1-5, 2011
46. Power Grid Corporation of India, 2011. [Online] Available: http://powergridindia.com
47. Raoot, M.G.; Pentayya, P.; Khaparde, S.A.; Usha, S.;, "Complexities in integrating IPPs in Indian power system," IEEE *Power and Energy Society General Meeting, 2010*, vol., no., pp.1-9, 25-29 July 2010.
48. R. Bedard, G. Hagerman, M. Previsic, O. Siddiqui, R. Thresher, and B. Ram, Final summary report: Project definition study— Offshore wave power feasibility demonstration project, Electric Power Research Institute, Palo Alto, CA, Tech. Rep. E2I EPRI Global WP 009-US Rev 2, Sept. 22, 2005.
49. Rural Electrification Corporation of India Limited, [Online], Available : http://recindia.nic.in/ downloads/rggvy_brochure.pdf

50. Singh B, Singh SN. Wind power interconnection into power system: a review on grid code requirements. The Electricity Journal 2009; 22(June (5)):54–63.
51. Steimer, P.K.; , "Enabled by high power electronics - Energy efficiency, renewables and smart grids,"*Power Electronics Conference (IPEC), 2010 International*, vol., no., pp.11-15, 2010.
52. Sooriyabandara, M.; Ekanayake, J.; , "Smart Grid - Technologies for its realisation," *Sustainable Energy Technologies (ICSET), 2010 IEEE International Conference on*, vol., no., pp.1-4, 2010
53. Schainker, R.B.; , "Executive overview: energy storage options for a sustainable energy future," *Power Engineering Society General Meeting, 2004. IEEE* , vol., no., pp.2309-2314 Vol.2, 2004
54. Shiban Kanti Bala, B.Chitti Babu, Shyamal Bala;, "A Review on development of Smart Grid Technology in India and its Future Perspective,"
55. Shafiullah, G.M.; Oo, A.M.T.; Jarvis, D.; Ali, A.B.M.S.; Wolfs, P.; , "Potential challenges: Integrating renewable energy with the smart grid", *Proc. Of IEEE 20th Australasian Universities Power Engineering Conference (AUPEC), 2010*, vol., no., pp.1-6, 5-8 Dec. 2010
56. Singh B, Singh SN. Wind power interconnection into power system: a review on grid code requirements. The Electricity Journal 2009;22(June (5)):54–63.
57. S.A. Khaparde, "Infrastructure for Sustainable Development using Renewable Energy Technologies in India" in Proc. *IEEE Power Engineering Society General Meetin.*, pp. 16, Jun 2007
58. TOSCA (2011): Technology Opportunities and Strategies toward Climate-friendly transport (Reports).
59. Taqqali, W.M.; Abdulaziz, N.; , "Smart Grid and demand response technology," *Energy Conference and Exhibition (EnergyCon), 2010 IEEE International* , vol., no., pp.710-715, 2010
60. Technology Roadmap, Smart Grid, International Energy Agency (IEA), http://www.iea.org/papers/2011/smartgrids_roadmap.pdf, pp. 6, 2011
61. Technology Roadmap, Smart Grid, International Energy Agency (IEA), http://www.iea.org/papers/2011/smartgrids_roadmap.pdf, pp. 15, 2011

62. "The Green Grid: Energy Savings and Carbon Emission Reductions Enabled by a Smart Grid," EPRI Palo Alto, CA: 2008.
63. V.S.K. Murthy Balijepalli, S.A. Kharparde, R.P. Gupta, Yemula Pradeep, "SmartGrid Initiatives and Power Market in India" Proc. Of *IEEE Power and Energy Society General Meeting*, pp.1-7, Jul. 2010.
64. V.Teja, et all; , "Wide-Area Monitoring, Protection, and Control of Future Electric Power Network," *Proc. Of IEEE* , vol., no., pp. 80-93, January 2011.
65. W.Breuer, D.povh, D.Retzmann, Ch. Urbanke, M.Wienhold ;„"Propects of Smart Grid Technologies for Sustainable and Secure Power Supply", 20th World Energy Congress and Exhibition, Rome, Italy, 2007
66. Zhenhua Jiang; Fangxing Li; Wei Qiao; Hongbin Sun; Hui Wan; Jianhui Wang; Yan Xia; Zhao Xu; Pei Zhang; , "A vision of smart transmission grids," *Power & Energy Society General Meeting, 2009. PES '09. IEEE* , vol., no., pp.1-10, 2009

DISSERTATION FOR THE Degree of MBA in Power Management.

DISSERTATION TOPIC:
SMART GRID AND ITS DEVELOPMENT IN INDIAN SCENARIO

Submitted By.
Qamar Inam
(SAP ID:500049534)
Academic Year: Oct 2015 session

Supervised By.
Mr. L. Sreenivasan



CONTENTS:

Dissertation by: Qamar Inam
Dissertation Topic: Smart Grid and its Development in Indian Scenario

UPES Centre for Continuing Education

CONTENTS:

EXECUTIVE SUMMARY (1/3):

- Estimated World wide population will be escalated by a factor of 1.4 billion in a next decade
- Power consumption expectancy of around 27,000 TWh will be increased due to population growth.

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CONTENTS:

EXECUTIVE SUMMARY (2/3):

- Lack of asset, outdated network, fuel cost resulted in inefficient and unstable electric system.
- Quality of Service and continuity of supply is required for efficient power system.

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Dissertation Topic: Smart Grid and its Development in Indian Scenario

CONTENTS:

EXECUTIVE SUMMARY (3/3):

- It is recommended to introduce SG (Smart Grid) at various levels in the Indian Power system.
- New technologies like WAMS, PMUs, DER enriches the modern power system

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Dissertation Topic: Smart Grid and its Development in Indian Scenario

Chapter 1: Introduction.

- Fossil deadlock
- Climatic change threat
- Global negotiation
- Climate change and security of supply
- Energy Efficiency

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Dissertation Topic: Smart Grid and its Development in Indian Scenario

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## 1.2 Background (1/2)

- The economic growth of a nation heavily depends of electric power supply.
- By 2050, around 92% of electricity power generation would be by renewable energy fired power station.

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## 1.2 Background (2/2)

- Renewable technologies to slightly increase the cost of electrical generation in India.
- In the long run, efficiency gains and increase the use of renewable energy.

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## 1.3 Purpose of the Study.

- Implement renewable solution.
- Respect the natural limits of the environment.
- Phase out dirty, unsustainable energy sources.
- Create greater equity in the use of resources.
- Decouple economic growth from consumption of fossil fuels.

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## 1.4 Research Hypothesis (1/2).

- Curbing Indian Energy Demand.
- Controlling Indian Power Demand.
- Reducing Indian Heating Demand.
- Development of Indian Industry Energy Demand.
- Electricity generation.

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Dissertation Topic: Smart Grid and its Development in Indian Scenario

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## 1.4 Research Hypothesis(2/2).

- Future costs of electricity generation.
- Future investment in power generation.
- Fuel costs savings.
- Heating supply.
- Future investments in the heat sector.
- Primary Energy consumption.
- Development of CO2 emission.

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## Chapter 2: Literature Review (1/7)

### 2.1 Review Area Broad

- Renewable Energy In India.
- Wind Power.
- Solar Power (PV).

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## Chapter 2: Literature Review (2/7)

Indian Power Grid, Power Market and Reforms

- Indian Power Grid.
- Indian Renewable Energy Guidelines.

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Dissertation Topic: Smart Grid and its Development in Indian Scenario

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## Chapter 2: Literature Review (3/7)

2.2 Review Area Narrow

- Global outline of smart Grids.
- Smart Grid Technology.
- Advancements in Smart Grid Technology.

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## Chapter 2: Literature Review (4/7)

2.3 Factors critical to success of the study.

- Challenges in Implementation of Smart Grid.
- Technical Challenges for development of Smart Grid in India.
- Grid connection Planning.
- Common Requirements for Grid code related to DG.

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## Chapter 2: Literature Review (5/7)

2.3 Factors critical to success of the study.

- The Indian Power Grid.
- Proposed Grid codes for Wind power in India.
- Grid connectivity and withdrawal planning.
- Operational issues.
- Micro grid and hybrid Energy System.

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Dissertation Topic: Smart Grid and its Development in Indian Scenario

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## Chapter 2: Literature Review (6/7)

2.3 Factors critical to success of the study.

- Micro grid control arrangement.
- Concept of Hybrid Energy system.

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Dissertation Topic: Smart Grid and its Development in Indian Scenario

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## Chapter 2: Literature Review (7/7)

- Energy storage system
  - Pumped storage in hydroelectric plant
  - Battery storage
  - Flywheel FW storage
  - Superconducting Magnet Energy Storage (SMES)
  - Ultra capacitor storage
  - Vehicle to grid (V2G) storage
  - Hydrogen gas (H2) storage
  - Compressed Air Energy Storage (CAES)

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Dissertation Topic: Smart Grid and its Development in Indian Scenario

Chapter 3: Research Design, methodology and Plan.

- Central Electricity Authority.
- Central Electricity regulatory commission.
- Power Grid corporation of India.
- Ministry of Power GOI.
- Global Wind Energy council (GWEC).

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Chapter 4: Interpretation of Results.

- Smart Grid initiatives in India.
- Renewable Energy Integration.
- Rural Electrification.
- Micro Grid.

## Chapter 5: Conclusion and scope of Future Work.

- Summary and Conclusion.
- Scope for the future works.

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# THANK YOU