# "MODELLING AND ANALYSIS GRID CONNECTED PV SYSTEM"

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**Dehradun**
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# "MODELLING AND ANALYSIS GRID CONNECTED PV SYSTEM "

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Master of Technology
(Energy System)

By

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April, 2013

# CERTIFICATE

This is to certify that the work contained in this thesis titled "**Modelling and Analysis Grid Connected PV System**" has been carried out by Nikhil Kr. Singh under my/our supervision and has not been submitted elsewhere for a degree.

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# ABSTRACT

A grid-connected photovoltaic (PV) system is introduced in this thesis along with under varying load condition and fault conditions. Based on this, a number of the schemes are introduced. Increasing demand and investment in renewable energy give rise to greater development of high penetration solar energy. Compared to the nonrenewable energy resources, photovoltaic (PV) system is an important phenomenon that uses the solar energy to produce electricity. It is considered as an important renewable energy that has a great potential and development of solar power are increasingly fast compared to its counterparts of renewable energies. Such systems can be either stand-alone system or utility grid connected. However, the disadvantage of solar energy is that PV solar power generation depended on weather. Thus, the battery energy storage is necessary to help get a stable and reliable output from PV generation system for varying loads and improve both steady and dynamic behaviors of the entire PV generation system. The project presents detailed modeling of the grid-connected PV/Battery hybrid generation system components, in Simulink / MATLAB software. There are multiple ways to attach PV arrays with the power grid. The topology of a multistring three-stage PV module with an inverter and converters are developed in this project report, which is more suitable for medium power applications. However, the output of solar PV arrays varies due to change of solar irradiation in different fields and change in weather. Therefore, the maximum power point tracking(MPPT) algorithm is implemented in converter to ensure PV arrays to operate at maximum power point. Different algorithms are employed to control the converter. Then the central inverter is controlled by decoupled current control algorithm and connected with the utility grid. Besides, the current control of the inverter is independent of maximum power point control of the

converter. Finally, system performance and transient responses are inspected under the disturbance conditions in whether or system disturbance. And system stability is evaluated when solar irradiation change or system fault happens. The system is simulated in MATLAB. Simulation results presented here validate the component models and the chosen control schemes.

More use of static power converter and switched mode power supplies injects harmonic current into the power system. It is advisable that PV system can be controlled to compensate the harmonic current as well as for supply the active power in the system. The harmonic current is removed by using time-domain current detection method, which is much easier to apply and doesn't need any transform comparing with the instantaneous power theory.

This project focus on fault condition analysis in a grid connected Photo-voltaic system. The grid connected PV system is operated under different level of solar irradiation on the different part of earth, corresponding to the different Direct Current (DC) voltage level. The output current of the Voltage Source Inverter (VSI) at different level of solar irradiation are monitored and analyzed. The result shows the impact of various solar irradiations on the system stability and the necessity of fast and flexible.

# ACKNOWLEDGEMENT

At the very outset of great pleasure & privilege I would like to extend my sincere gratitude to all those who have provided their assistance and co-operation during the seminar work **"MODELLING AND ANALYSIS GRID CONNECTED PV SYSTEM ".**

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**DATE:**-04/22/13 **Nikhil Kumar Singh**

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# INTRODUCTION

## Motivation

In the last few decades, the demand for renewable energy has increased significantly due to the disadvantages of conventional fossil fuels and greenhouse gas effect. Among variant types of renewable energy resources , solar energy and wind energy have become the most spectecular and attractive because of invention in power electronic technique for generation of electricity. Photovoltaic sources are used as a regular manner in many applications because they have the quality of being maintenance free and pollution free. In the past few years, solar energy demand has increased rapidly due to the following reasons:

1) increasing potential and productivity of solar cells

2) production technology improvement

3) economies of scale.

According to European Photovoltaic Industry Association, at the end of 2012,total set up PV capacity in the world has reached over 70 GW with an increase of 72% compared to 2011.Europe still heads the market with over 55 GW of total power installed. Italy, first time topped the PV market in 2012 with 10GW of newly set up Capacity with an impressive 290% increment.

The high uses of PV technology was encouraged by regular increase of energy price generated in coal ,diesel and gas power plant. PV system have been needed to decrease costs in order to fulfill the necessity of population and compete on energy market but on the same time to provide reliability. Usually reliability of a PV system is attached with inverter topology and the main parts.

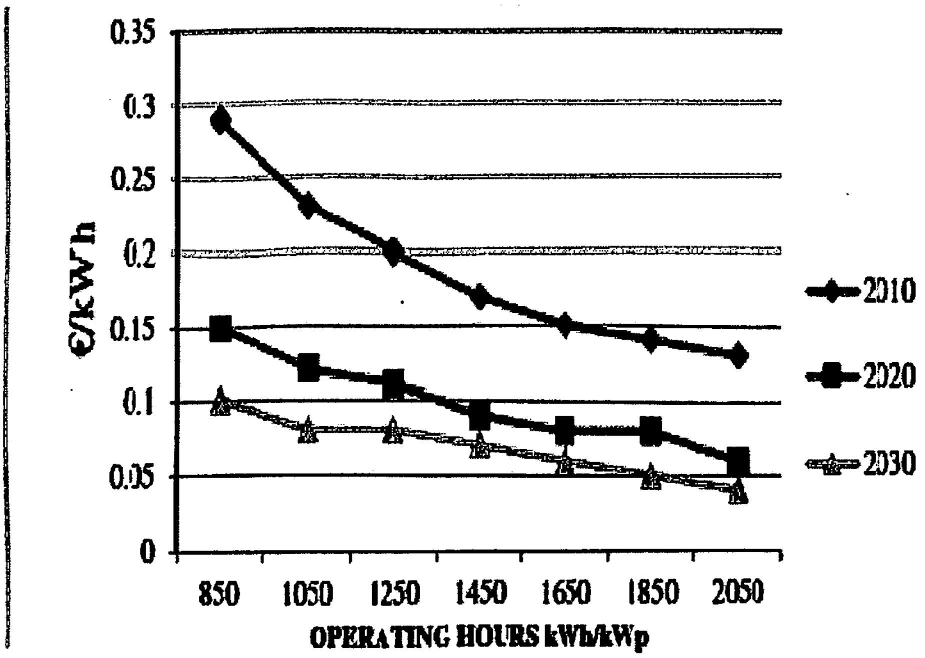



Fig.-1 Levelised cost of electricity for large PV ground-mounted systems

At the same time, more PV modules have been joined in series and will be hooked up to utility grid in many countries. The largest PV power plant has capacity more than 100MW all over the world. But, the output of PV arrays is significantly effected by solar irradiation and weather. High initial cost and limited life time of PV panels make it more hard to produce as much power from them as possible. Therefore, maximum power point tracking (MPPT) algorithms should be inserted in DC/DC converter to get maximum power efficiency of PV arrays. Several algorithms have been acquired to achieve MPPT technique.

The fast inflation and formulation of PV system into the lower parts of grid built up several concerns for grid reinforcement. This is the point, grid Operators had to command strict operational rules in order to keep the LV grid under control and to correspond the behavior of all distributed generators attached to it in terms of accuracy, efficiency and prices.

PV array can be use as a standalone system but in this type power system has disadvantage from the effect of complete and partial shading, which is mostly created by clouds, forests and commercial and domestic buildings. Under partially shaded condition, the IV characteristics of the PV array become compound with multiple peaks. These multiple peaks are produced due to non-uniform insolation level that holds on a partially shaded PV array surface or PV modules surface. The PV array efficiency is become lesser due to these non uniform insolation level.

As the efficiency of PV system is increasing in a rapid manner, the effect of PV modules on power grid can't be overlooked. They can generate problems on the grid like flicker, increase of harmonics, and total stability of the power system. To both increase the capacity of PV arrays and carry on power quality, it's essential to meet with the technique requirements of the PV system, such as fault ride through proficiency and harmonic current addition. Especially when a large scale PV module is attached to the grid, the effects on the grid may be quite effective. Therefore, the system activity and system stability under fault conditions should be checked when PV modules are attached with power grid.

The increased number of grid connected PV system with the use of inverters gave rise a lot of problems pertaining the stability , efficiency and safety of grids. The main problems are:

- **Voltage Rise Problem**

  The attachment of large PV system in the LV network increases generation of active power taking to increase in the rise of voltage along the feeders. At the moment the voltage rise does not exceed the 2% limit compelled by old grid code but now a days this limit has been increased by 3%.

- **50.2 Hz Problem**

  When the grid frequency swings and surpasses 50.2 Hz an instantaneous shutdown is required from the grid connected generators to skip from risks which can arrive in operation of network. If power fluctuation is higher than the already defined power of primary control, the system will not be able to stabilize and control the grid frequency. To come out from this problem we should use the frequency dependent active power control.

- **Increased Harmonics**

As the of PV system tends to an increase in harmonic content at the connection point. Each PV system connected to utility grid inserts harmonics. More PV systems are connected the more harmonic will increase. If one or more non linear loads are present, the total harmonic distortion can go far above allowable limit.

- **Increased Voltage Unbalance**

The qualities of installed PV system such as their location and power generation capacity can take to an increase in the voltage unbalance. This effect most of the power quality in the LV residential networks due to sudden location of PV installation and their single phase grid connection. The voltage of three phases is different because the PV systems are installed suddenly along the feeders and with different ratings. When the difference in magnitude between these phases is high then voltage unbalance increases.

- **Anti-islanding**

Islanding occurs when the PV generator is disconnected from the grid, but persists to supply power locally. The islanding problem mainly appears in Low Voltage Networks, Therefore it is suggested for the generation units to disconnect the power supply within a narrow frequency band such as 49 to 51 Hz.

# CHAPTER-2

## Literary Review

Development and improvement in PV technology in balance of system components, as well as experience gained from thousands of grid connected PV system installation, the cost of PV Energy and efficiency have improved to the point where a large off-grid market is blooming and the on-grid market is nearly economic. More attachment of PV modules with utility grid may lead to some operational difficulties in the electric network.

Many previous works deal with diffusion of PV system into power grid. Status in recognising and reviewing photovoltaic (PV) codes and standards (C&S) was presented in . Related electrical activities for grid-connected, high-diffusion PV systems with utility distribution grid interconnection were also analyzed. It included recognising topics and concerns not yet in the scope of already inserted Codes & Standard documents, recognising Codes & Standard-related ongoing work and approaches, and to give recommendations related to Codes & Standard necessity.

Currently, interconnection Codes & Standard in the US had been created based on passive support of PV systems in the grid. As higher levels of PV systems were attached into the electric power system, these PV systems could play an active role in both the technical and business operations of the utility grid and in the customer facility and loads management. Therefore, addressing grid-integration technical and business issues was a necessary issues for the long-term aspects of the distributed PV industry, and in particular, that was adversed for high penetration.

The main technical issues of large scale PV generations on power grid were: electricity quality, power flow control ,voltage and frequency stability, new technology for simulation and test of power system environment, codes and standards revising or implementing of grid operation and distributing. Several fields were advised to meet the practical and research requirements:

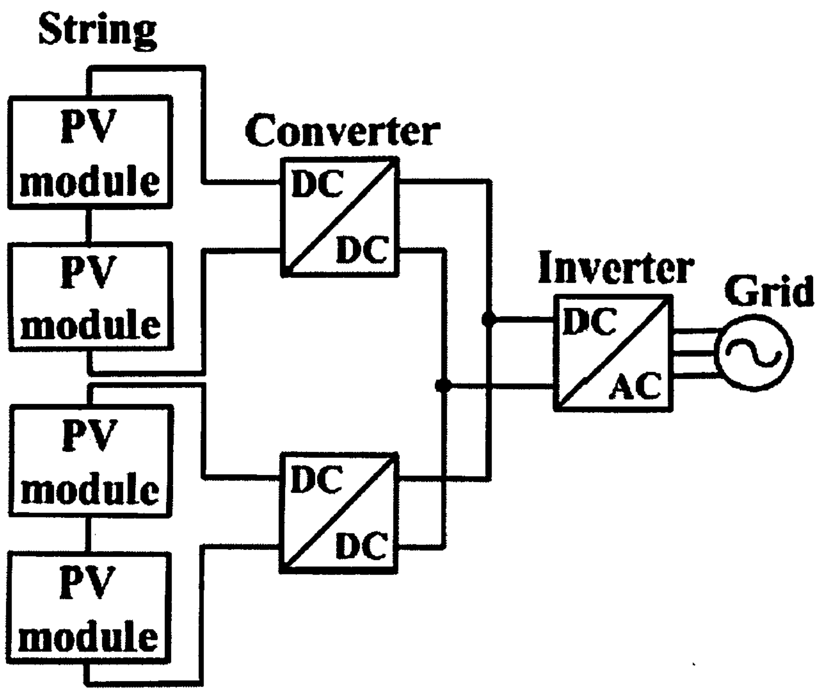
1) modeling analysis of PV systems
2) control startegy of grid-connected PV systems

Various models and technologies were examined, simulated and tested for the objective of evaluating the grid-connected PV system performance. In a 3 MW PV system with the distribution system was modeled in Matlab / Simulink. The modeled PV system based on the equivalent circuits of the PV cell accepted the number of series and parallel connections of PV cells and the changes in the temperature and irradiation level. The oscillation of voltage and current presents after the initiation of the fault. In all fault types, the PV array was not operating at maximum power point (MPP). The output power of the PV array in the case of the three-phase fault was the smallest, while the output power of the PV array in the case of the single line-to-ground fault was the largest.

An experimental setup was induced using an off-the-shelf grid-connected inverter to calculate the event of a fault happened on a distribution feeder. The experimental results had shown that, without opposing the specified criteria in the standard, the grid-connected inverter took time to search an islanding condition and prevent energizing. It also showed that higher insertion level of the PV grid-connected systems resulted in higher fault current which unavoidably had effects on the protective devices. To effectively find islanding, feed forward compensation came into existence. This detection scheme came into operation when frequency, voltage, total harmonic distortion (THD), or impedance at the point of common coupling (PCC) exceeded the set thresholds due to opening of the breaker on the grid-side. The islanding detection capability was increased if any of these quantities were used as a feed-forward signal in the control scheme. And the detection was based on the evaluation of voltage.

A new control strategy of inner current-control loop and an outer dc-link voltage control loop was accepted. The current-control strategy allowed dc-link voltage regulation and enabled power-factor control. Moreover, the current-control easily decoupled dynamics of the PV system from those of the distribution network and the loads. The dc-link voltage-control scheme allowed the control and maximization of the real-power output of the PV system. And the effect of the control strategy was checked through digital time-domain simulation studies conducted on a detailed switched model of the whole system. In addition, a model analysis or sensitivity analysis was conducted on a linearized model of the system to characterize the dynamic properties of the PV system,to calculate robustness of the controllers, and to recognise the nature of interactions between the PV system and the network. DC bus model was inserted in multistring PV system, and distribution network was also presented on grid side. Decoupled current control was applied in the voltage source inverter (VSI) to control the power inserted into the network. The transient responses of the system were studied under disturbance conditions such as sudden change of solar irradiation, fault in the distribution network and fault in the DC bus. To depreciate the huge increase in DC link voltage under fault condition, the storage system was introduced . The storage system cosist of a storage capacitor, resistor and inductor in series. And the storage system controller was structured to absorb the solar power under fault conditions. Then a multilevel inverter was advised since it offered great advantages such as lower THD, improved output waveform, lower Electromagnetic Interference (EMI) and others, compared with two-level inverter for the same switching frequency. Two symmetrical triangular carriers were applied to produce the switching decisions for the nine-switch three-level inverter.

More nonlinear loads like rectifier circuits and switched mode power supplies result in insertion of harmonic currents into electric power distribution network. Installation of active filter could be one of the solutions to avoid the harmonic. On the other hand, photovoltaic (PV) systems can be controlled to work as an active power filter (APF), as well as supplying power to grid. A high performance harmonic current reduction control scheme had been established .Its aim was to reduce the harmonic current that passed through a power conditioning system (PCS) by outputting harmonic voltage equal to the one that consisted in the grid. The control scheme did not utilize grid current and had low interference with the existing current control and fault through capability. Extraction algorithm for the harmonic voltages allowed the voltage source inverter (VSI) in the PV generation system to output harmonic voltages that were very close to the harmonic voltage of the grid.




PV system with a multi-string inverter

Fig.-2

# CHAPTER-3

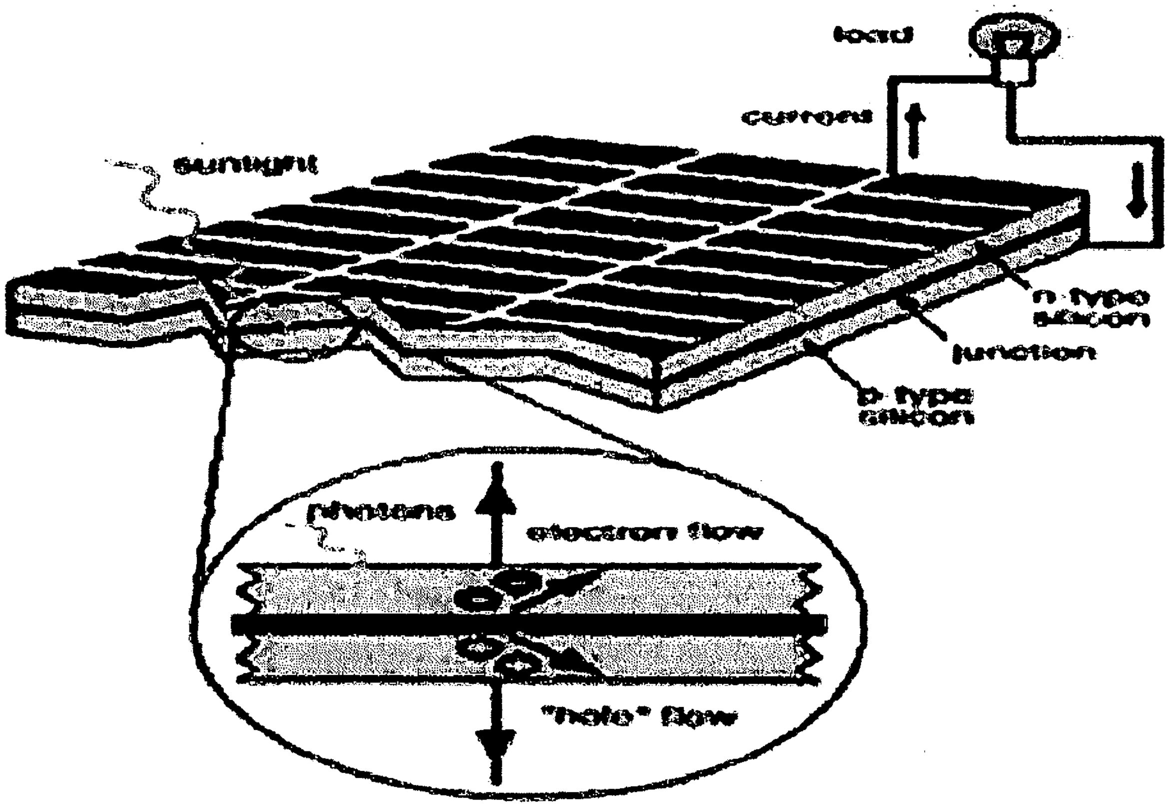
# THEORETICAL DEVELOPMENT

## PHOTOVOLTAIC SYSTEM AND TYPES

Photovoltaic (PV) are solid-state, semi-conductor type equipment that produce electricity When moved to light. The word photovoltaic's actually mean "electricity from light." Many handmade calculators run off power from room light, which would be one example of this thing. Larger power applications for this are also possible.

## Working of Photovoltaic

Photovoltaic are the direct change of light into electricity at the atomic level. Some Materials possesses a character known as the photoelectric effect that forces them to absorb Photons of light and release electrons. When these free electrons are attached Electric current flows that can be used as electricity.

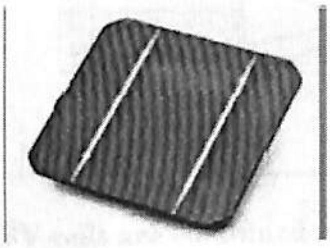



Working Principle of a PV Cell
Fig.-3

The diagram above shows the operation of a basic photovoltaic cell, also called a Solar cell. Solar cells are made of the same kinds of semiconductor materials, such as Silicon, used in the microelectronics industry. For solar cells, a thin semiconductor wafer is specially made to form an electric field, positive on one side and negative on the other. When light energy incident on the solar cell, electrons are released from the Atoms in the semiconductor material. If electrical conductors are attached to the positive and negative sides, producing an electrical circuit, the electrons can be received in the form of an electric current -- that is, electricity. This electricity can then be used to power a Load.

## Photovoltaic cell

A photovoltaic cell or photoelectric cell is a semiconductor device that chsnges light to electrical energy by photovoltaic effect. If the energy of photon light is greater than the band gap then the electron came out and the flow of electrons creates current. However a photovoltaic cell is different from a photodiode. In a photodiode light incidents on n channel of the semiconductor junction and gets converted into current or voltage signal but a photovoltaic cell is always forward biased.

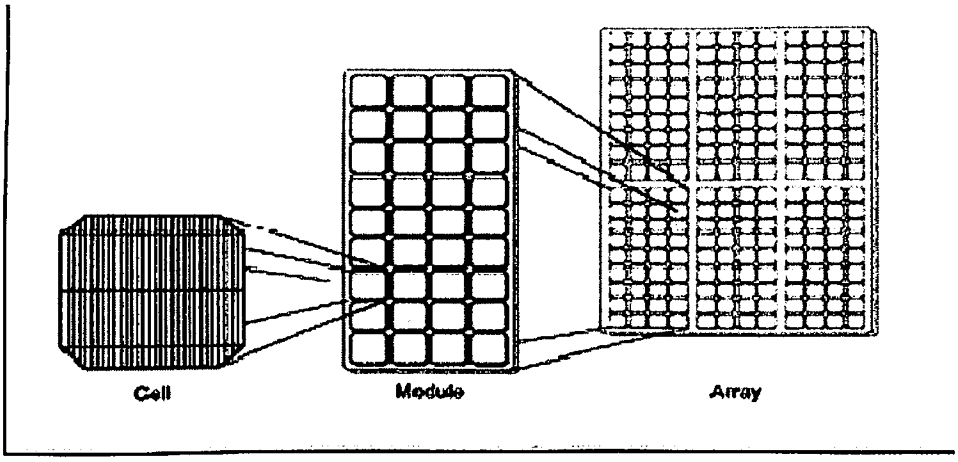


Photovoltaic cell
Fig.-4

## Photovoltaic module

PV cells are the basic building blocks of PV modules. For mostly all applications, the one half volt produced by a single cell is not enough. Therefore cells are attached together in series to gain the voltage. Some of these series strings of cells may be attached in parallel to increase the current as well. Modules come in different standard sizes and can also be custom-made by the manufacturer. These modules comprises of a series of interconnected PV cells, laminated

Between glass and a black sheet and to keep within a rigid aluminum frame. PV modules are usually the most cost effective solution and can be combined to form an array of the correct size for your building and electricity demand.




**PV cells are combined to create PV modules, which are attached to create PV array**

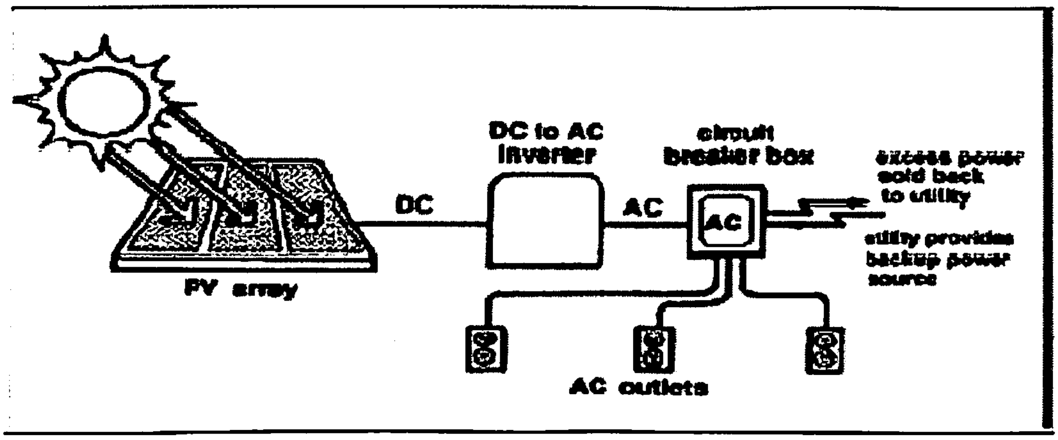
Fig.-5

## Types of Photovoltaic systems

PV technology was 1st inserted in space, by providing electricity to satellites. On the basis working operation PV systems operate in four basic forms.

### 1.Grid connected PV systems-

These systems are connected to bigger electricity network. The PV system is attached to the utility grid using a high quality inverter, which changes DC power from the solar array into AC power that fulfills to the grid's electrical requirements. During the day, the solar electricity produced by the system is either used rapidly or sold to electricity supply companies. In the evening , when the system is not able to supply immediate power , electricity can be brought back from the network.




Grid connected PV systems
Fig.-6

**2.Standalone systems-**

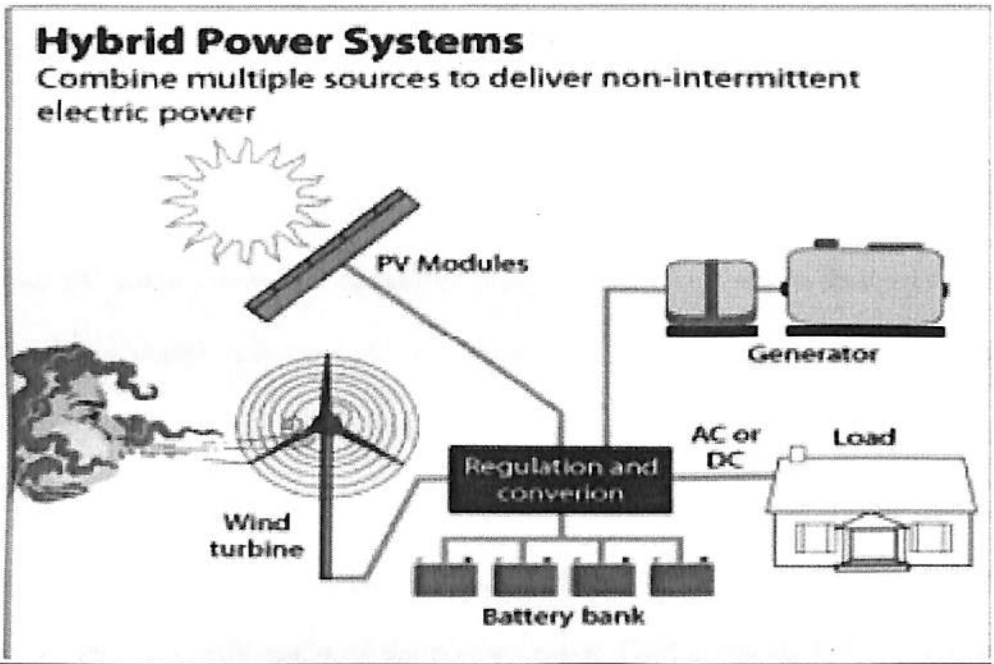
The PV systems which are not connected to the electric utility grid are known as off grid PV systems and also called 'stand-alone systems'. Direct systems use the PV power regularly as a rapid manner as it is generated, while battery storage systems can conserve energy to be used at a later time, either at night or during cloudy weather. These systems are used in isolation of electricity grids, and may be used to power radio repeater stations, telephone booths and street lighting. PV systems also give invaluable and acceptable electricity in developing countries like India, where conventional electricity grids are not reliable or non-existent.


Stand-alone PV systems

Fig.-7

## 3.Hybrid system-

A hybrid system combines PV with other forms of power generation mainly a diesel generator. Biogas is also used. The other form of power generation is usually a type which is able to modulate power output as a function of requirement. More than one form of renewable energy may be used like wind and solar. The photovoltaic power generation is able to reduce the use of non renewable fuel.




Hybrid system
Fig.-8

**4.Grid tied with battery backup PV system-**

Solar energy stored in batteries can be utilized at night time. By the use of net metering, unused solar power can be sold back to the grid. With this type of system, we can have power even if electricity has gone .

# Grid connected PV system

As day by day the interest of electricity is increasing and that's why pollution also increased. Grid tied PV system is more acceptable than other PV system. In this type of system, battery is not used, so initial cost of Grid connected PV system comes down and therefore we use grid connected methodology. If generated solar energy is attached to the conventional grid, it can fulfill the demand from morning to afternoon that is the particular time range when the SPV system can fed to grid. Grid connected photovoltaic power generation system has the gain of more effective utilization of generated power. Grid connected PV systems is made through the use of inverter, which changes DC power produced from PV modules to AC power used for ordinary power supply for electrical equipments.

Inverter technology is very important to have trustworthy and safety grid interconnection operation of PV system. The accepted model of PV grid connected system cannot only feel photovoltaic generation, but also surpasses current harmonics, comes down the reactive power, remove voltage upss or downs and other power quality difficulties.

An accepted and well known maximum power point tracking (MPPT) algorithm is applied to boost the efficiency of PV generation. To make the control simple, the synchronous frame method is inserted in designing the inverter. The form of a faster internal current control loop and a slower external voltage control loop is used in order to gain a good dynamic response.

Grid connected PV generation is one of the major development work of photovoltaic operations. At the same time, with the development of the power electronics industrialization growth, a large no. of nonlinear loads has come into existence. Harmonics and reactive current from nonlinear load increases that the power quality problems become more concerned. PV grid connected generation operates during the day and has to prevent at night. This impacted the steady state of power system and the utilization of equipment. Therefore in order to increase the utilization, the PV system can be structured to also provide the function of power quality managements.

## The proposed grid-connected PV system

The proposed system is composed of PV generation and energy storage system and the power quality includes compensator. Solar energy is changed into electricity through PV array. Then the voltage across PV array is amplified with a unidirectional dc/dc boost converter so as to trace the maximum power point of PV array easily. After that, the dc/ac inverter converts dc power into ac power which is inserted into the utility grid or directly supplied to domestic and some small commercial loads. At the same time the system can give a large voltage compensation when the grid voltage ups or downs because it is equipped with large capacity storage devices. PV array also gains the stability of its power compensation. When the grid voltage increases in a irregular manner, the batteries are charged in quick time, accepting energy from the grid, thereby the grid voltage ups is kept under control. In the same way, when the grid voltage drops irregularly, the batteries remove energy quickly to grid, suppressing the voltage ups. As Compared to the regular photovoltaic generation devices, it can not only insert active power into grid, also has the objectives of reactive power reduction and harmonic repression, removing grid voltage drops and swells. In addition, the system can work as shunt active power filter and UPS in the absence of sunshine or the weak sunshine.

## MAXIMUM POWER POINT TRACKING (MPPT) TECHNIQUE

Maximum Power Point Tracking, is an electronic system that starts the Photovoltaic modules in a manner that allows the modules to generate all the power they are acceptable of. MPPT is not a mechanical tracking system that "physically moves" the modules to point them more exposed at the sun. MPPT is a fully electronic system that varies the electrical operating point of the modules so that the modules are able to give Maximum available power. Extra power extracted from the modules is then made available as increased battery charge current. MPPT can be used as a mediator with a mechanical tracking system, but the two systems are completely differ from each other.

A typical solar panel converts only 30 to 40 percent of the incident solar irradiation into electrical energy. Maximum power point tracking technique is used to improve the efficiency of the solar panel. According to Maximum Power Transfer theorem, the output power of a circuit is maximum when the Thevenin impedance of the circuit (source impedance) matches with the load impedance. Hence our difficulty of tracking the maximum power point reduces to an impedance matching problem.

In the source side we are utilizing a boost convertor attached to a solar panel in order to gain the output voltage so that it can be used for different applications like motor load. By correcting the duty cycle of the boost converter appropriately we can relate the source impedance with that of the load impedance.

## Different MPPT techniques

There are different methodologies used to trace the maximum power point. Most popular techniques of MPP are:

1) Perturb and observe (hill climbing method)

2) Incremental Conductance method

3) Fractional short circuit current

4) Fractional open circuit voltage

5) Neural networks

6) Fuzzy logic

The choice of the methodology rely on the time complexity the algorithm takes to trace the MPP, insertion cost and the ease of insertion.

### 1) Perturb & Observe

Perturb & Observe (P&O) is the very easy to understand. In this we utilize only one sensor, that is the voltage sensor, to get the PV array voltage and so the cost of insertion is less and hence easy to assign. The time difficulty of this algorithm is very less but on connecting very close to the

MPP it doesn't stop at the MPP and keeps on moving on both the directions. When preturbing happens on both the directions the algorithm has stretched very close to the MPP and we can set an exact error limit or can use a wait function which ends up increasing the time complexity of the algorithm.

However the method does not consider of the rapid change of irradiation level (due to which MPPT changes) and considers it as a change in MPP due to perturbation and ends up computing the wrong MPP. To escape from this problem we can use incremental conductance method.

## 2)Incremental Conductance

Incremental conductance method utilizes two voltage and current sensors to feel the output voltage and current of the PV array.

At MPP the slope of the PV curve is 0.

$$(dP/dV)_{MPP}=d(VI)/dV$$

$$0=I+VdI/dV_{MPP}$$

$$dI/dV_{MPP} = - I/V$$

The left hand side is the sudden conductance of the solar panel. When this instantaneous conductance is equal to the conductance of the solar then MPP is reached. Here we are getting both the voltage and current together. Hence the mistake due to change in irradiance is deleted. However the complexity and the cost of implementation increase.

As we go down the list of algorithms the problem & the cost of utilization goes on increasing which may be reliable for a highly difficult system. This is the reason that Perturb and Observe and Incremental Conductance method are the most commonly used algorithms.

## 3)Fractional open circuit voltage

The non linear relationship between $V_{MPP}$ and $V_{OC}$ of the PV array, under moving irradiance and temperature levels, has given rise to the fractional VOC method.

$$V_{MPP} = k_1 \, Voc$$

where $k_1$ is a constant of proportionality. Since $k_1$ depends upon the characteristics of the PV array, it commonly has to be utilized before by telling $V_{MPP}$ and $V_{OC}$ for the specific PV array at different irradiance and temperature levels. The factor $k_1$ has been measured between 0.71 and 0.78. Once $k_1$ is known, $V_{MPP}$ can be computed with VOC measured periodically by keep shutting down the power converter. However, this tells some disadvantages, including temporary loss of electricity.

## 4)Fractional short circuit current

Fractional short circuit current reveals the conclusion from the fact that, under varying atmospheric circumstances, $I_{MPP}$ is near about linearly related to the $I_{SC}$ of the PV array.

$$I_{MPP} = k_2 \, I_{sc}$$

Where $K_2$ is proportionality constant. In the fractional VOC technique, $k_2$ has to be explained according to the PV array in use. The constant $k_2$ is generally showed the value between 0.78 and 0.92. Computing $I_{SC}$ during operation creates problems. Normally an additional switch has to be added to the power converter to periodically short the PV array so that $I_{SC}$ can be computed using a current sensor.

## 5)Fuzzy Logic Control

Microcontrollers have made using fuzzy logic control famous for MPPT over last some years. Fuzzy logic controllers have the advantages of working with imperfect inputs, not needing an perfect mathematical model, and to control nonlinearity.

## 6) Neural network

Another technique of inserting MPPT which are also well adapted for microcontrollers is neural networks. Neural networks mainly have three layers: input layer, output layers, haidden layers. The number of nodes in every layer vary and are user-dependent. The input variables in input layer can be PV array parameters like $V_{OC}$ and $I_{SC}$, atmosphere data or whether condition like irradiance and temperature, or any union of these. The output is usually one or several reference signals like a duty cycle signal used to move the power converter to start with or close to the MPP.

## Characteristics of different MPPT techniques

**TABLE-1**

| MPPT Technique | Convergence speed | Implementation Complexity | Periodic tuning | Sensed parameters |
|---|---|---|---|---|
| Perturb Observe | Varies | Low | No | Voltage |
| Incremental Conductance | Varies | Medium | No | Voltage,Current |
| Fractional VOC | Medium | Low | Yes | Voltage |
| Fractional ISC | Medium | Medium | Yes | Current |
| Fuzzy logic Control | Fast | High | Yes | Varies |
| Neural network | Fast | High | Yes | Varies |

. The voltage-current characteristic equation of a solar cell is given as:

$$I = I_{PH} - I_S \left[\exp\left(q\left(V+IR_S\right)/kT_C A\right)-1\right]-\left(V+IR_S\right)/R_{SH}$$ (1

Where:

$I_{PH}$ = A light-generated current or photocurrent

$I_S$ = dark current during cell saturation

q ($=1.6\times10^{-19}$C) = An electron charge k (=1.38x10⁻ = A Boltzmann's constant

23J/K)

| | |
|---|---|
| $T_C$ | = The cell's working temperature |
| A | = An ideal factor |
| $R_{SH}$ | = A shunt resistance |
| $R_S$ | = A series resistance |

The photocurrent mainly relys on the solar insolation and cell's working temperature which is described

$$I_{PH} = [I_{SC} + K_I (T_C - T_{Ref})] \lambda \quad (2$$

Where:

$I_{SC}$ = The cell's short-circuit current at a 25°C and 1 kW $m^{-2}$

$K_I$ = The cell's short-circuit current temperature coefficient

$T_{ref}$ = The cell's reference temperature

$\lambda$ = The solar insolation in kW $m^{-2}$

On the other hand, the cell's saturation current varies with the cell temperature which is described as:

$$I_S = I_{RS} (T_C/T_{Ref})^3 \exp [qE_G (1/T_{Ref} - 1/T_C)/kA] \quad (3$$

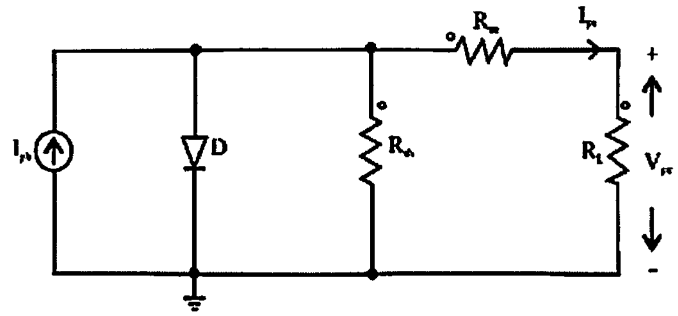



Fig. 9: Single PV cell

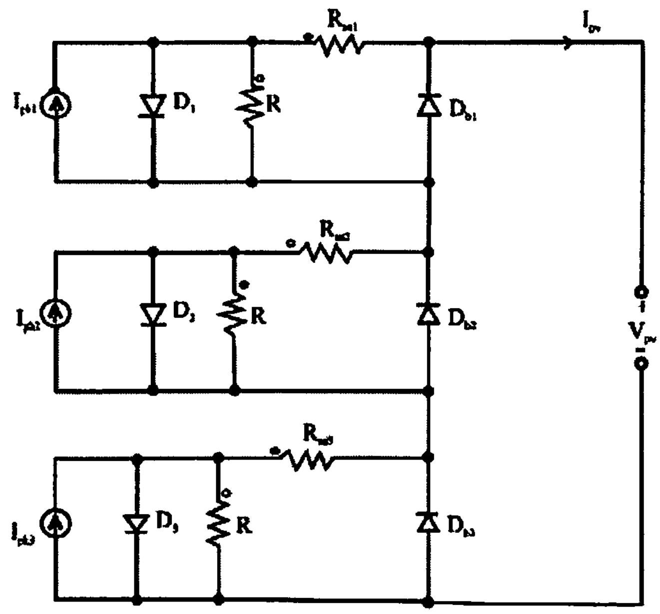



Fig.-10 Series connected PV Array with bypass diodes

Where:

$I_{RS}$ = The cell's reverse saturation current at a reference temperature and a solar radiation

$E_G$ = The bang-gap energy of the semiconductor used in the cell

**PV array model:** Since a typical PV cell generates <2 W at 0.5 V nearly, the cells must be connected in series-parallel configuration on a module to generate enough high power.

A PV array is a group of many PV modules which are electrically connected in series and parallel circuits to generate the required current and voltage. The corresponding circuit for the solar module are kept in parallel and series is shown in Fig.10. The corresponding circuit for the solar module and maximum power point algorithm is inserted to MATLAB. The equivalent circuit is discussed on the following equation:

$$I = N_P I_{PH} - N_P I_S [\exp (qV/N_S kT_C A)-1] \quad (4$$

**PROPOSED INVERTER TOPOLOGY**

The proposed inverter topology is comprises of PV array, DC-DC boost converter, five-level H-bridge inverter, grid-connected (Fig.-11).

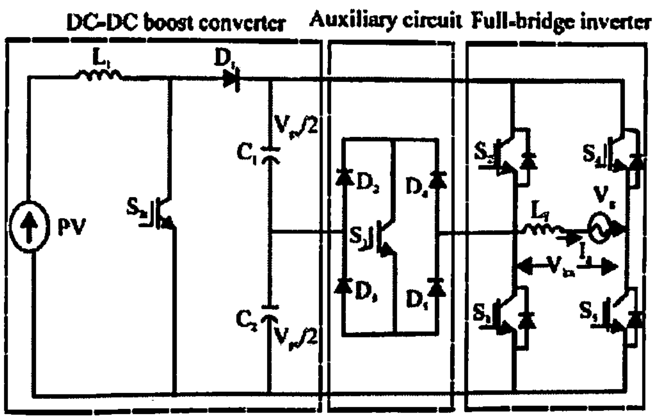



Fig.11: Proposed inverter topology

The PV array generated dc supply through solar energy, its low level dc output. In low level dc output step up high level voltage through DC-DC boost converter with dc bus capacitors. The step up ratio of boost converter is 1:2. The five-level inverter is utilized to change of DC to AC voltage. The inveter is attached to grid-system i.e., utility feeder through filtering inductor. The current inserted in grid must be sinusoidal with low harmonic distortion. The load is presumed as resistive and inductive load.

## MODULATION TECHNIQUE AND PROPOSED INVERTER's OPERATION

A sinusoidal PWM is used, it is one of the most efficient method. The suggested PWM modulation method is shown in Fig.-11. Two reference signals $V_{ref1}$ and $V_{ref2}$ and triangular carrier signal $V_{carrier}$ were used to generate the PWM switching signals. The modulation index $M_a$ is kept between 0-1. The output voltage is origined by comparison of the two reference signals and the carrier signals can be renoted as fourier series coefficient:

$$V_0(\theta)=A_0+\sum_{n=1}^{\infty}(A_n\cos n\theta+B_n\sin n\theta) \quad (5$$

n-even number, so $A_o= 0, B_n= 0$

$$V_0(\theta)=\sum_{n=1,3}^{\infty}(A_n\cos n\theta) \quad (6$$

$$A_n=\frac{4V_{pv}}{n\pi}\sum_{m=1}^{p}[(-1)^m\sin(n\alpha_m)] \quad (7$$

Where:

m = Apulse number

$\alpha$ = The phase angle displacement

In this report, two reference modulation techniques is inserted into the sinusoidal PWM technique to generate PWM switching signals for full-bridge inverter switches and auxiliary switch.

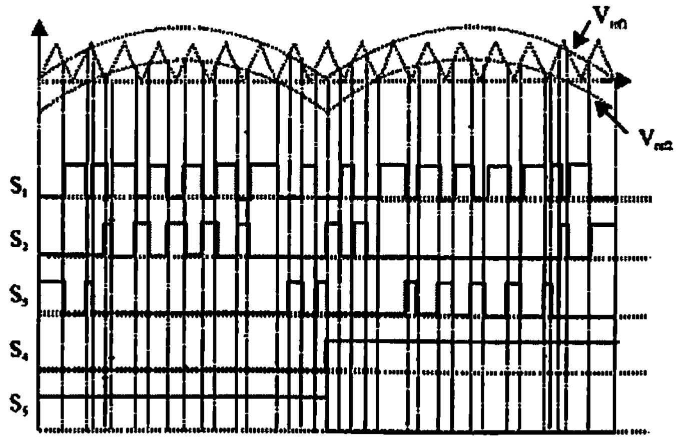



Fig. 12: Switching pattern for the single-phase five level inverter

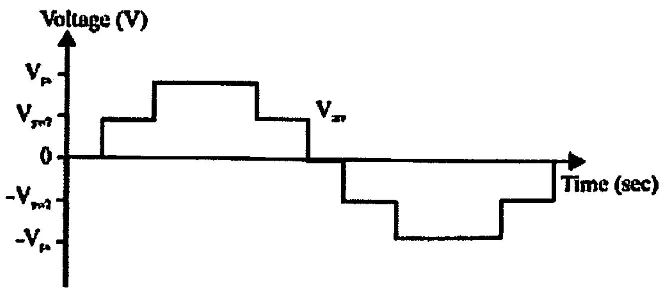



Fig. 13: Ideal five-level inverter output voltage $V_{inv}$

Table 2: Output voltage of inverter during $S_1$-$S_5$ switch on and off

| $S_1$ | $S_2$ | $S_3$ | $S_4$ | $S_5$ | $V_{inv}$ |
|---|---|---|---|---|---|
| ON | OFF | OFF | OFF | ON | $+V_{pv}/2$ |
| OFF | ON | OFF | OFF | ON | $+V_{pv}$ |
| OFF | OFF | OFF | ON | ON | - |
| | or | or | or | or | 0 |
| | ON | ON | OFF | OFF | - |
| ON | OFF | OFF | ON | OFF | $-V_{pv}/2$ |
| OFF | OFF | ON | ON | OFF | $-V_{pv}/2$ |

The applied inverter is generated five-level output voltage i.e., 0, $+V_{pv}/2$, $+V_{pv}$, $-V_{pv}/2$ and $-V_{pv}$. The auxiliary circuit comprises of four diodes and switch $S_1$, it is generated half level of PV supply voltage i.e., $+V_{pv}/2$, $-V_{pv}/2$. The five-level inverter output voltage $V_{inv}$ is shown in Fig.-12 and 13. Table-2 shows the level of $V_{inv}$ during $S_1$-$S_5$ switch ON and OFF.

## PROPOSED CONTROL SYSTEM AND ALGORITHM

The proposed inverter is inserted into grid-connected PV system. So the power is inserted to the grid, it is necessary to keep the power factor at near unity. As the irradiance level is not consistent throughout the day, the amount of electric power is produced by the solar modules is always changing with weather conditions. To remove this problem, Maximum Power Point Tracking (MPPT) is used to avoid whether condition. The perturb and observe method is used to generate maximum power from the PV modules.

Table 3: Rule base with five membership functions

| Δω/Δω | NB | NS | ZO | PS | PB |
|---|---|---|---|---|---|
| NB | NB | NB | NB | NS | ZO |
| NS | NB | NS | NS | ZO | NS |
| ZO | NB | NS | ZO | PS | PB |
| PS | NS | ZO | PS | PS | PB |
| PB | ZO | PS | PB | PB | PB |

The feedback controller used in this application utilizes the FUZZI- PI algorithm there is separate inverter topology to controlled. In the proposed inverter current is inserted into the grid, grid current $I_g$ is gained and feed back to a comparator which compares it with the reference current $I_{ref}$. $I_{ref}$ is got by realizing the grid voltage and converting it to reference current and multiplying it with constant m. This is to confirm that grid current $I_g$ is in phase with grid voltage $V_g$ and always at near-unity power factor. All the algorithm are developed in C++ language and implemented it to MATLAB version. The PI algorithm:

$$u(t)=K_p e(t)+K_i\int_0^t e(\tau)d\tau \quad (8$$

Where:

u (t) = Control signal

e (t) = Error signal

t = Continuous-time-domain variable

$\tau$ = Calculus variable of integration

$K_p$ = Proportional-mode control gain

$K_i$ = Integral-mode control gain

$K_d$ = Derivative-mode control gain

The following steps includes in the process of fuzzy logic controller design:

**Fuzzification:** The process of showing suitable linguistic variables as inputs.

**Decision making:** The suitable control action to be carried out needs to be based on practical manner.

**Defuzzification:** The process of changing fuzzified outputs into steady values. A fuzzy logic controller initially converts the firm errors and changes in error variables into fuzzy variables. Then they are mapped into linguistic labels. Membership functions are connected with each label as shown in the Table 3.

The linguistic labels are divided into seven groups: negative large, negative medium, negative small, zero, positive small, positive medium, positive large. Each of the inputs and output consist of membership functions with all seven linguistics.

## SIMULATION RESULTS

The output voltage of the PV array is 115 V and the voltage is applied DC-DC boost converter from PV array.

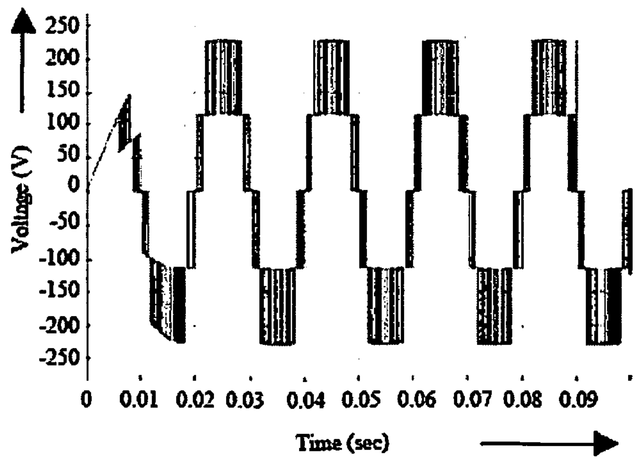



Fig. 14: Proposed inverter output voltage

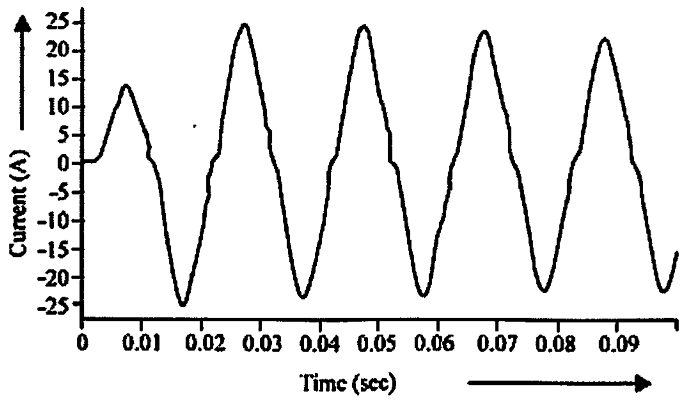



Fig. 15: Grid current

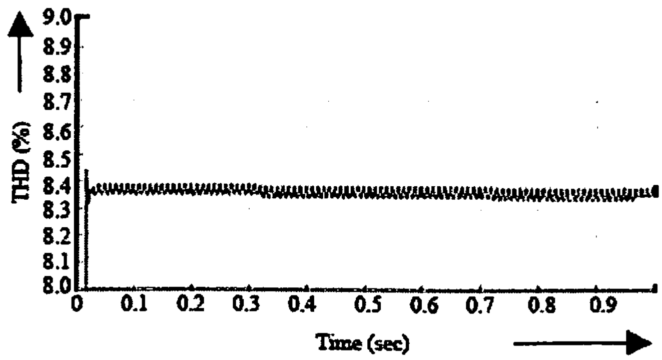



Fig. 16: THD in FUZZY PI control scheme

Researchers are getting output voltage from DC-DC boost converter 230 V and here five-level inverter inverts DC supply to AC supply. The output voltage and frequency of the inverter are 230 V and 50 $H_z$ respectively. The output of simulation five-level as shown in Fig.-14. The grid current is nearly a pure sine wave form as shown in Fig.15. The variable grid current is, dependent on load of grid. The total harmonic distortion can be checked and calculated in PI and

FUZZY PI current control scheme. The FUZZY-PI current controller produced low harmonic distortion and improved sudden step response compare to PI current controller as shown in Fig.-16 and 17. The power factor can be computed using mathematical judgement. The power factor is near unity(0.96).

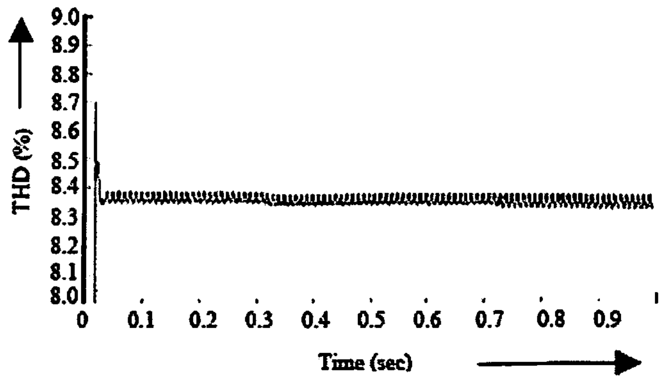



Fig. 17: THD in PI control scheme

# CHAPTER-4

# Experimental Procedure

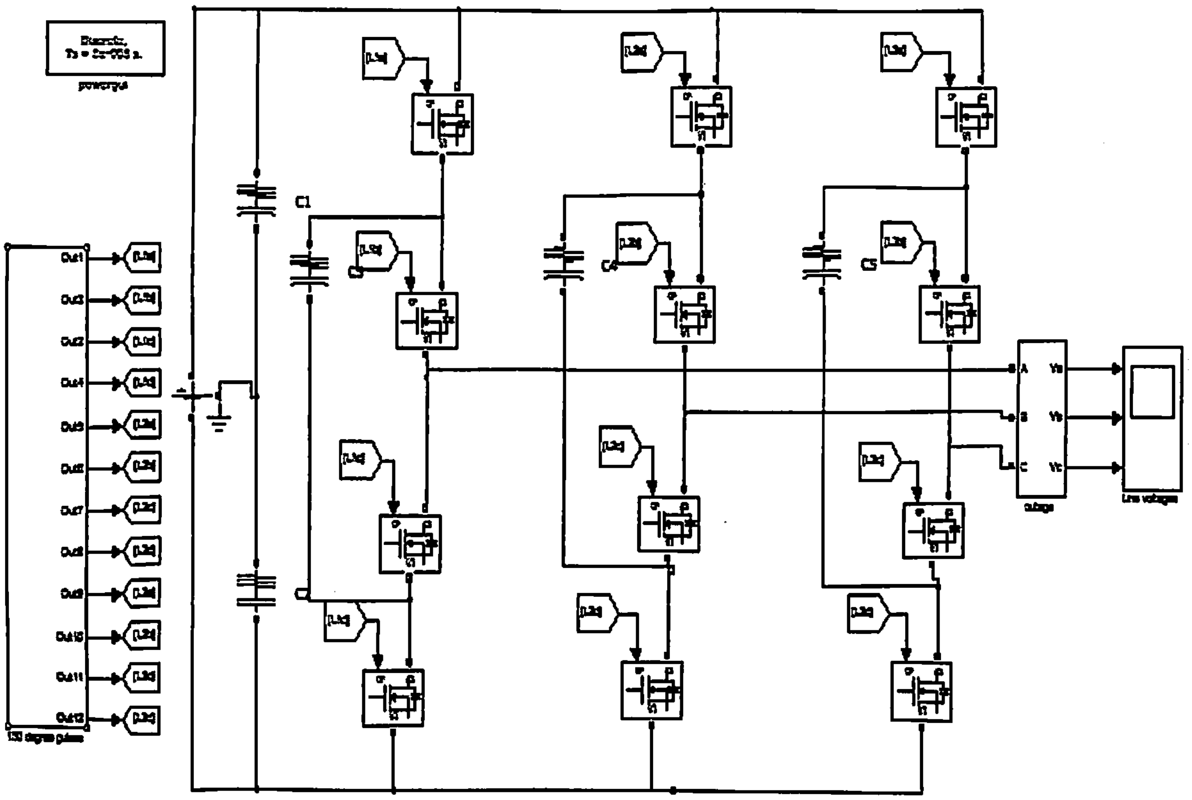



**Fig.-18 Complete Model of grid connected PV system**

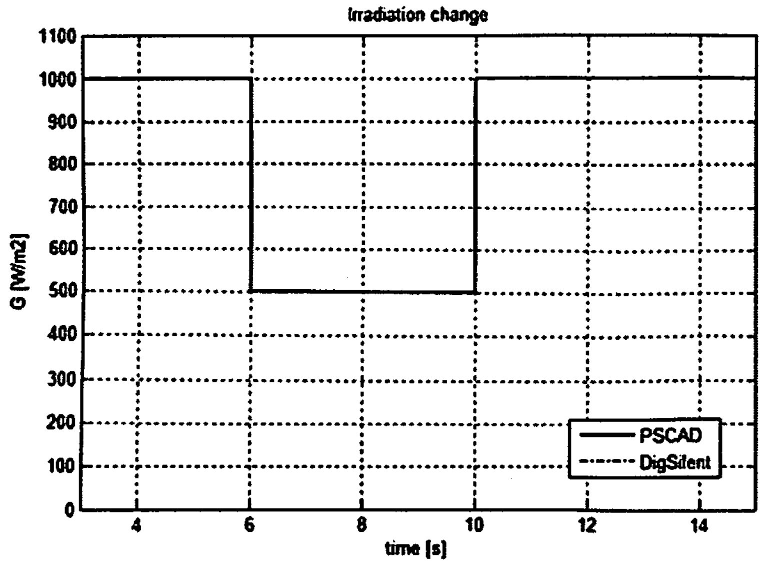



**Fig.-19 Irradation change during different time interval**

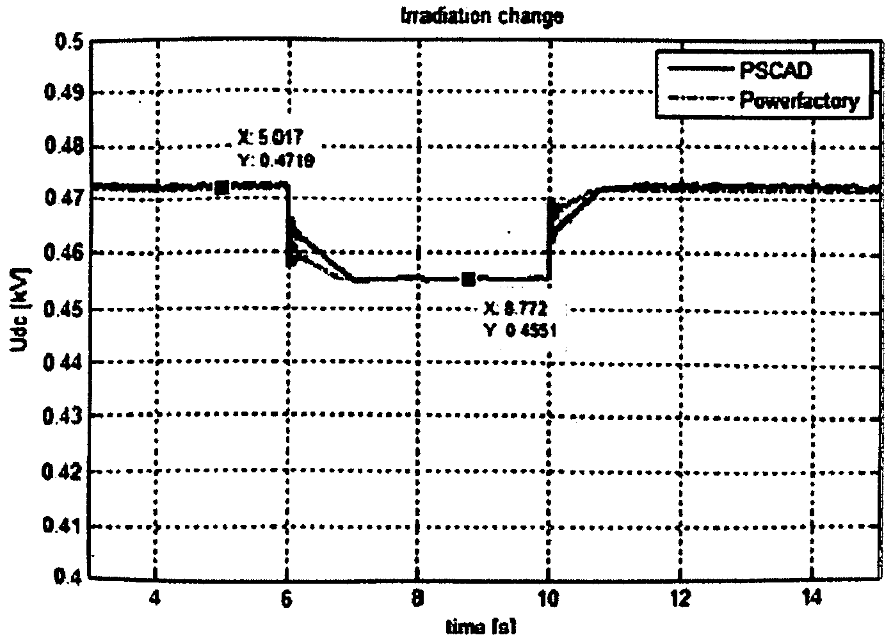



**Fig.-20 DC Voltage of PV system**

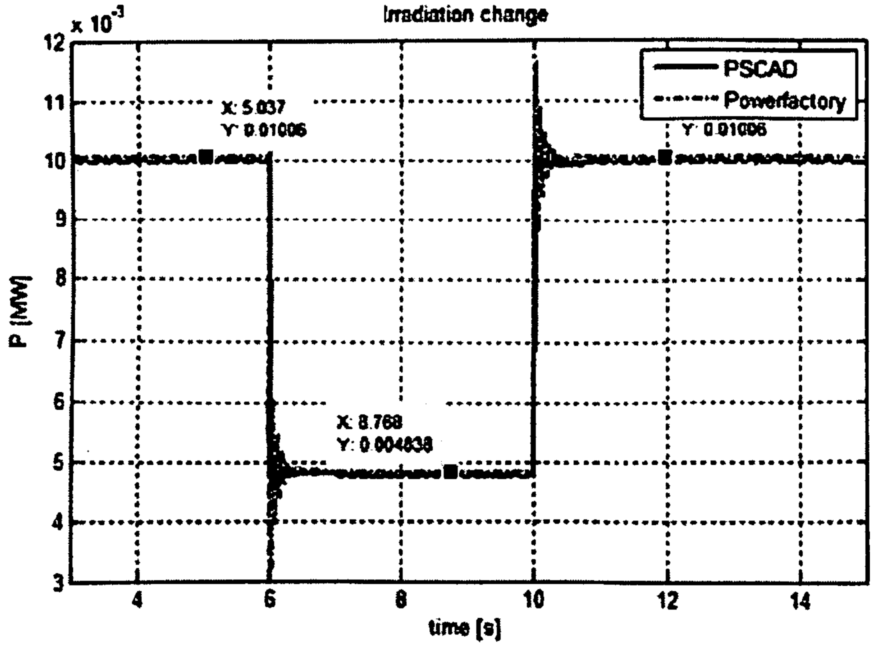



**Fig.-21 Active Power of PV system**

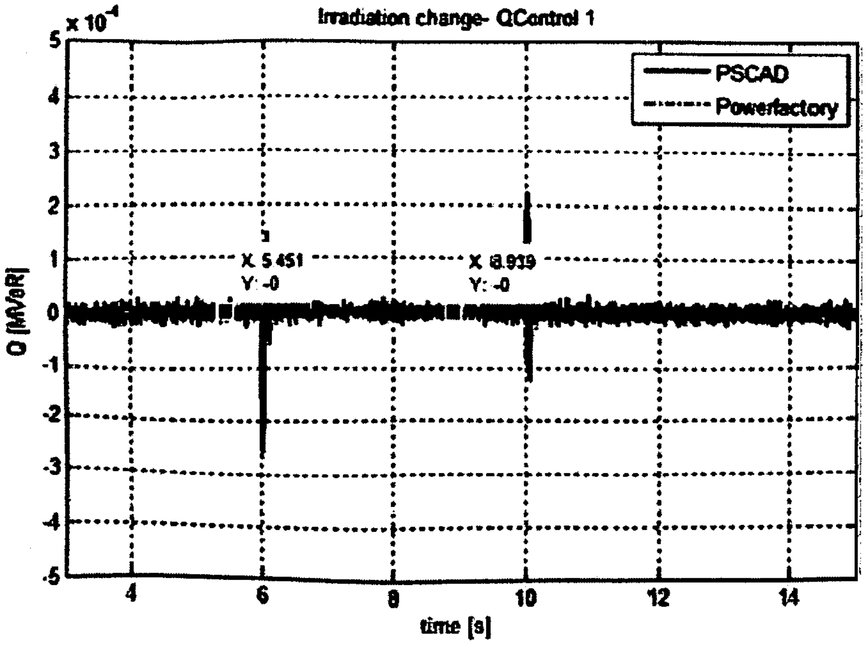


**Fig.-22 Reactive Power of PV System**

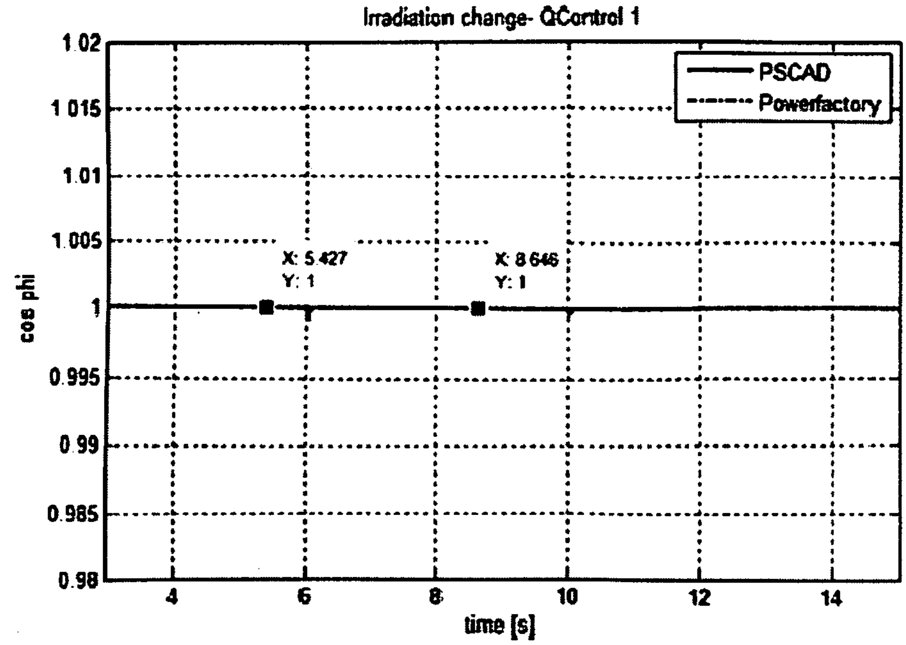



**Fig.-23 Power factor of the PV system**

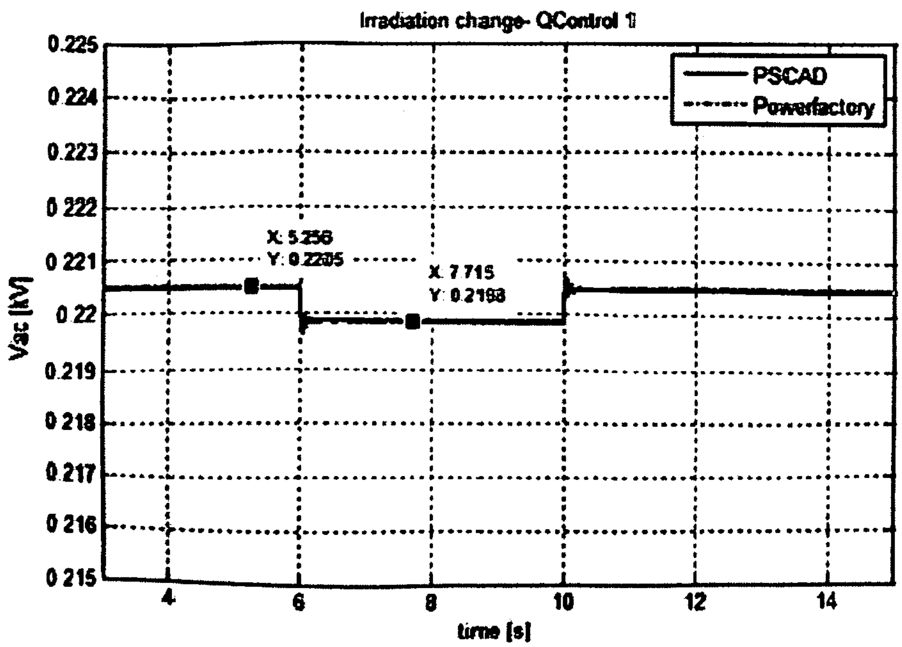



**Fig.-24 AC Voltage at terminal L-2**

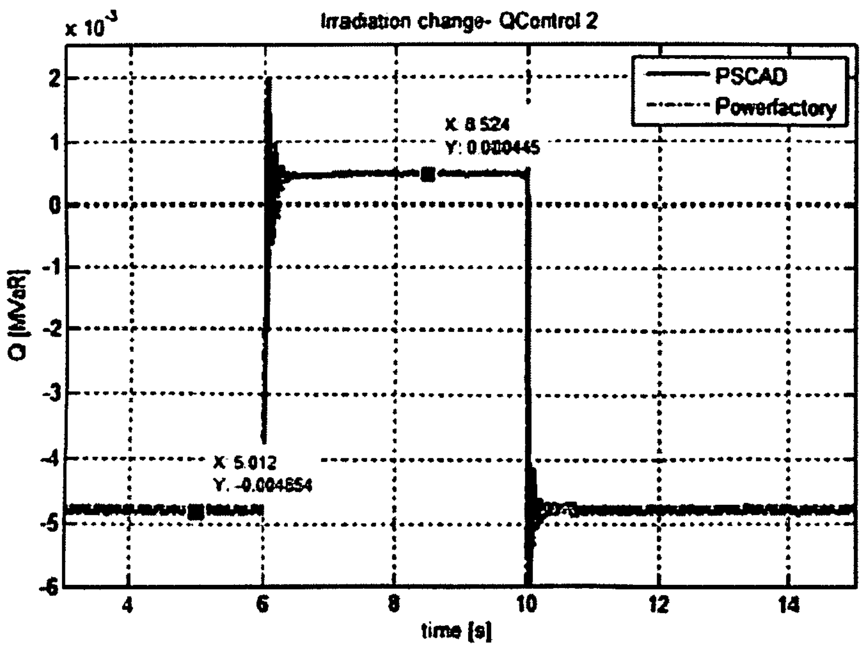



**Fig.-25 Reactive Power of the PV System**

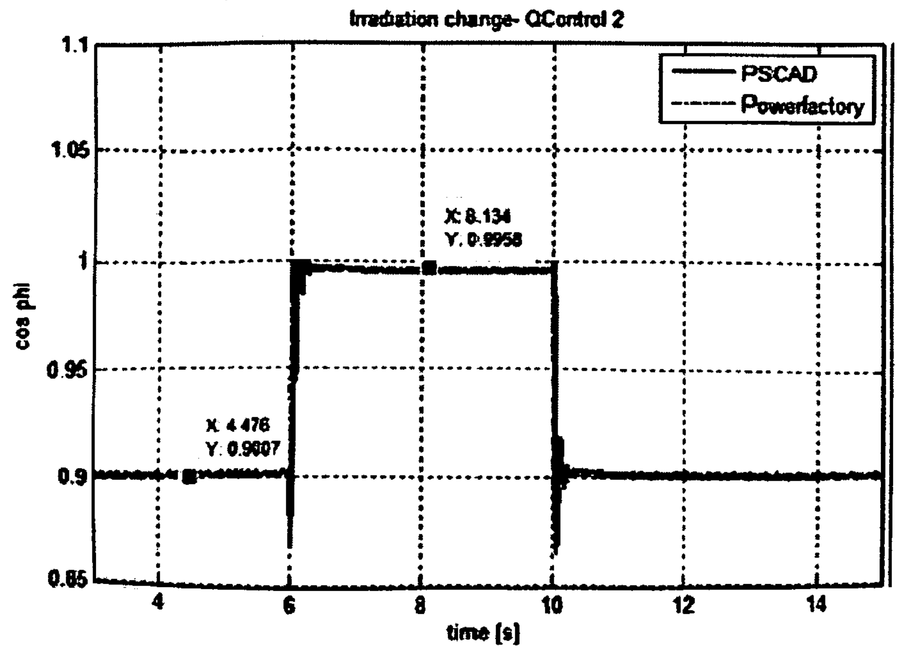



**Fig.-26 Power Factor of the PV System**

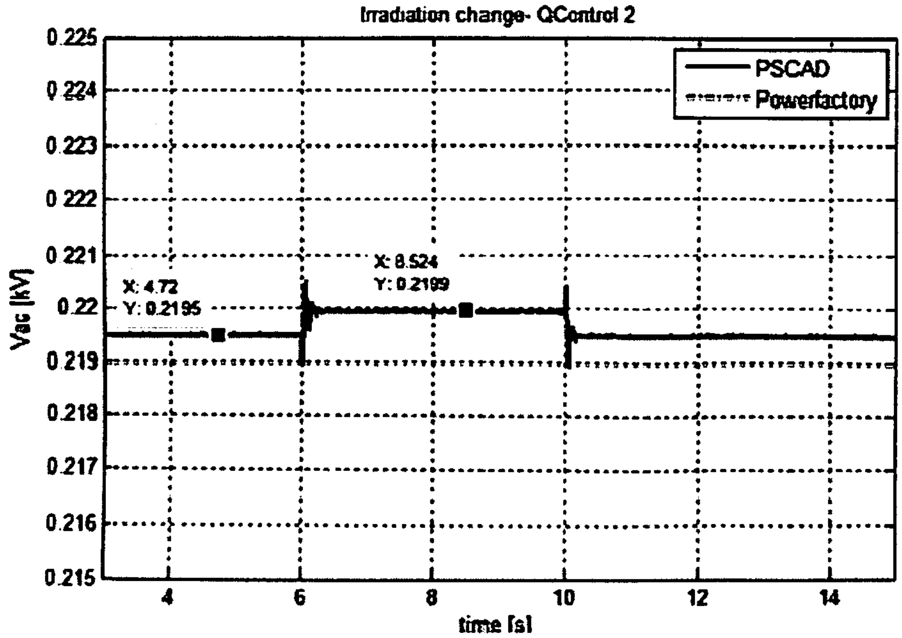



**Fig.-27** **AC Voltage at terminal L-2**

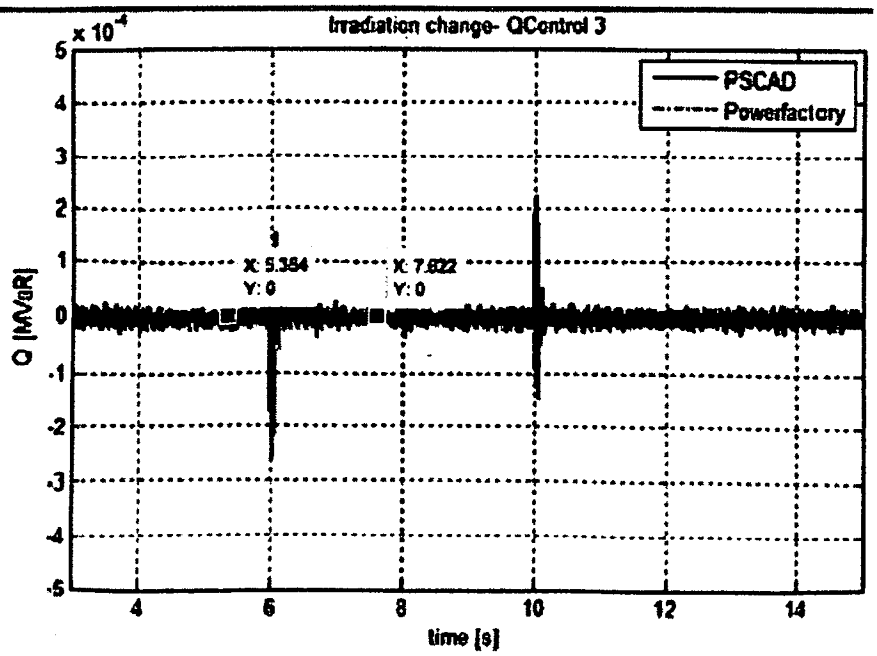



**Fig.-28** **Reactive Power output of PV system**

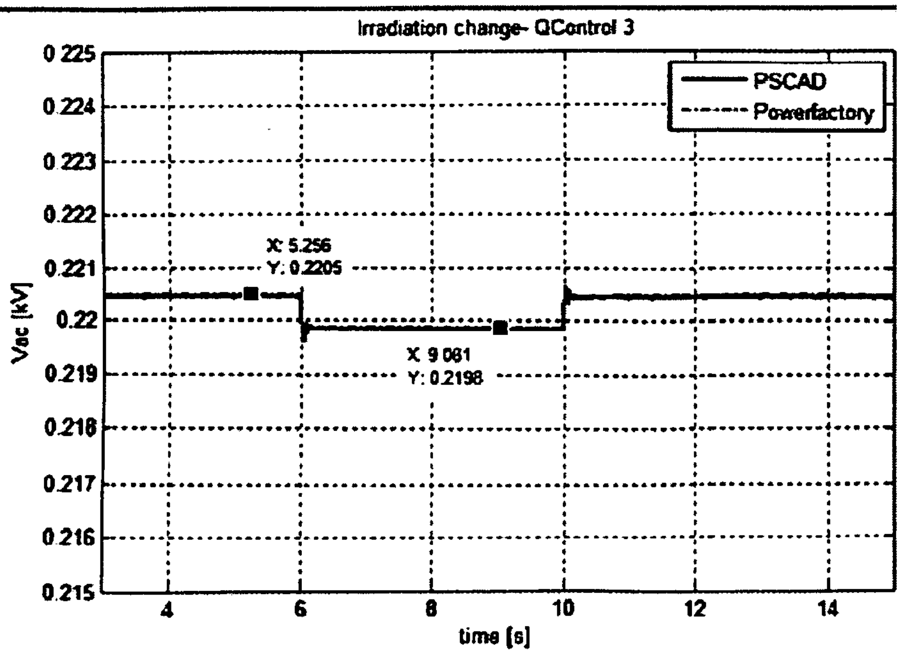



**Fig.-29 AC Voltage at terminal L-3**

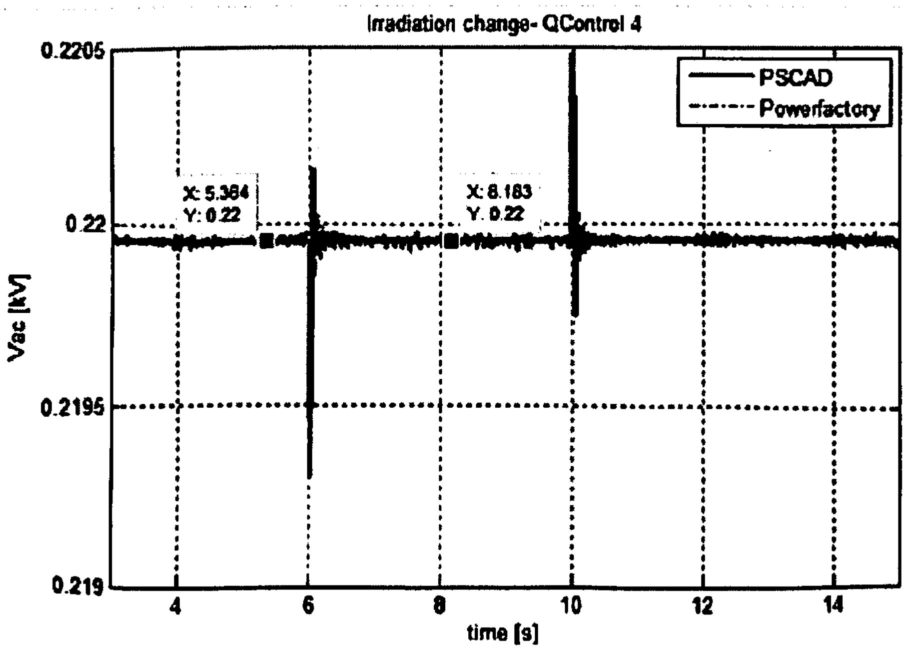



**Fig.-30 AC Voltage at terminal L-4**

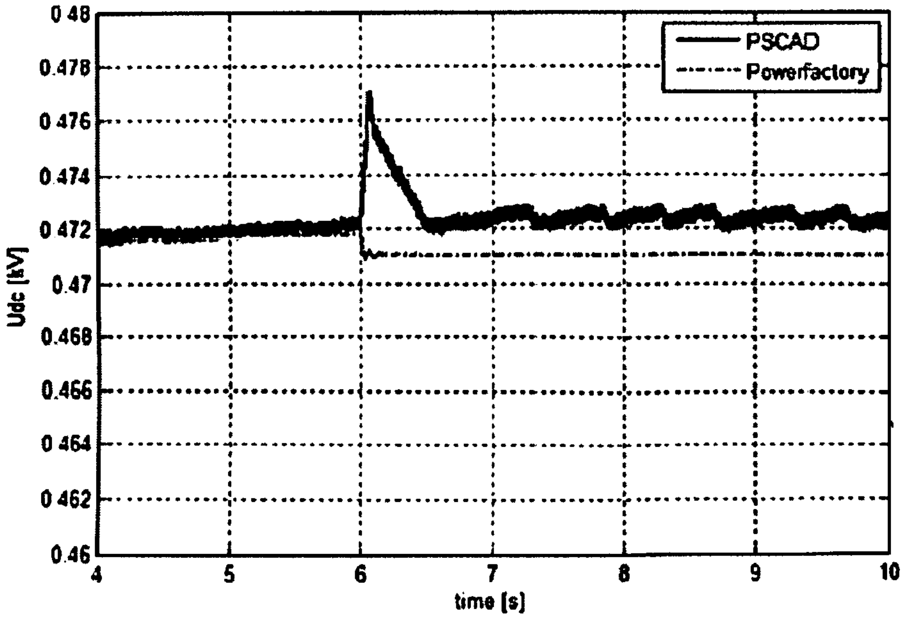



Fig.-31 DC Voltage of PV system

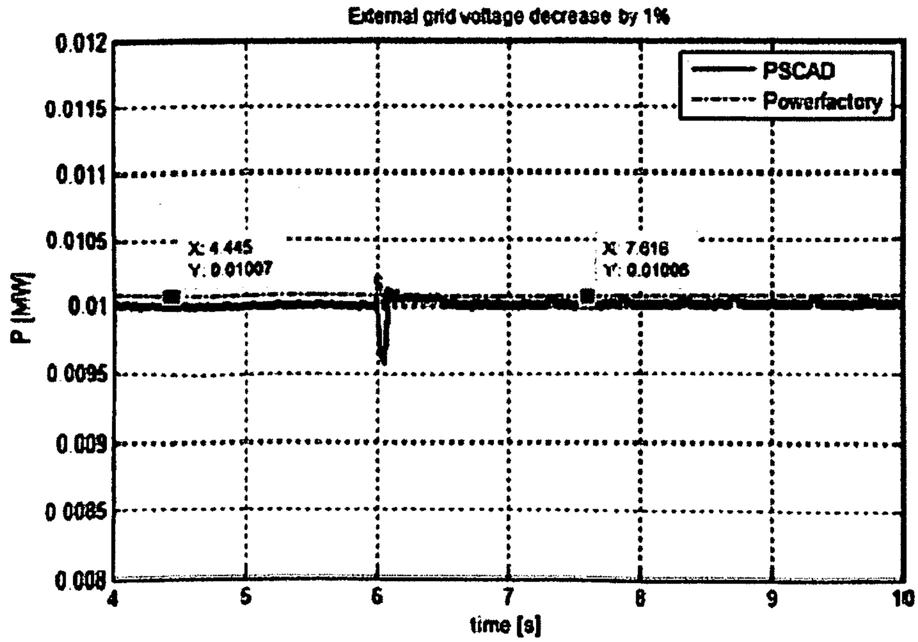



Fig.-32 Active Power of PV System

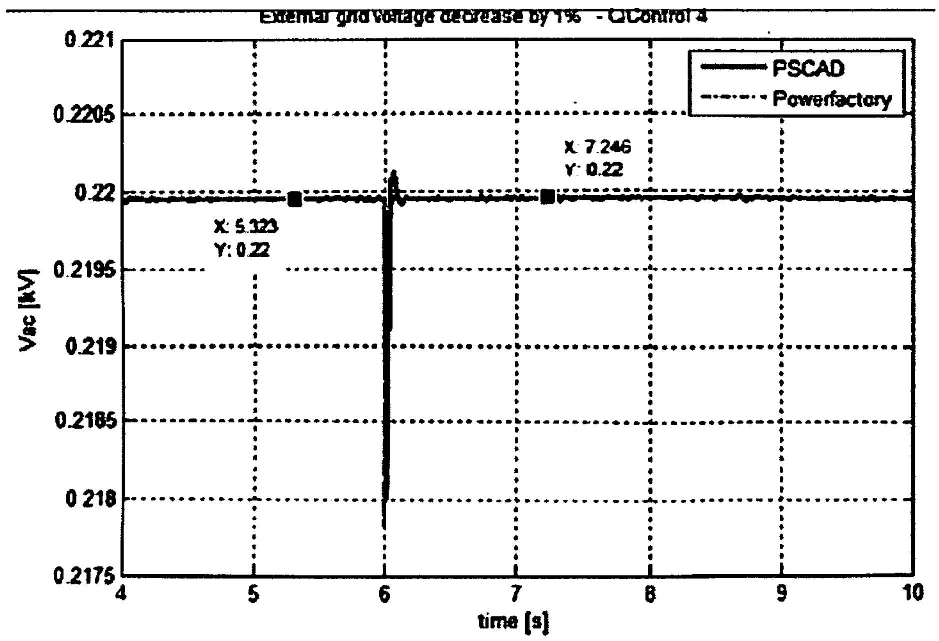



**Fig.-33 AC Voltage at terminal L-2**

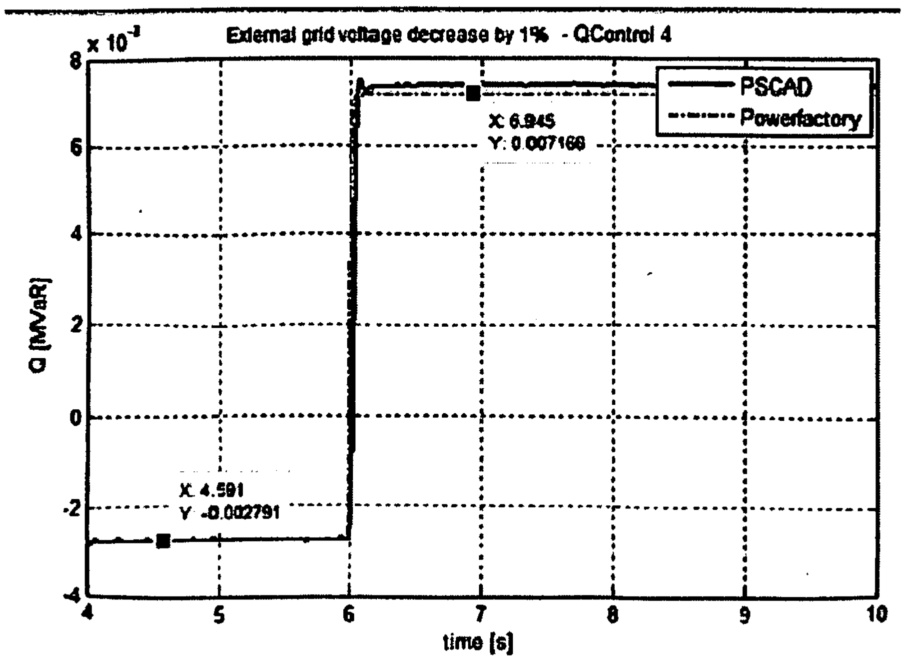



**Fig.-34 Reactive Power of PV System**

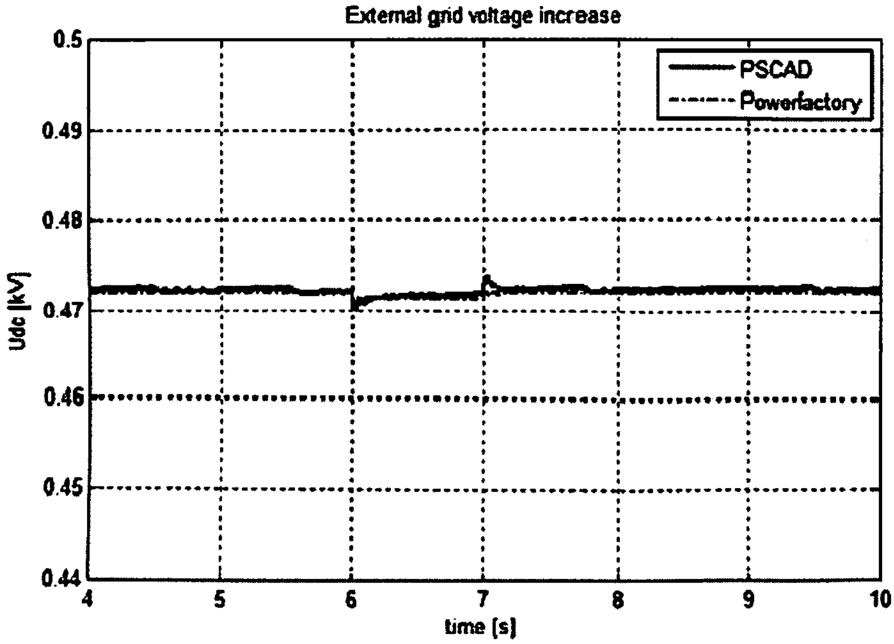



**Fig.-35** **DC Voltage of PV System**

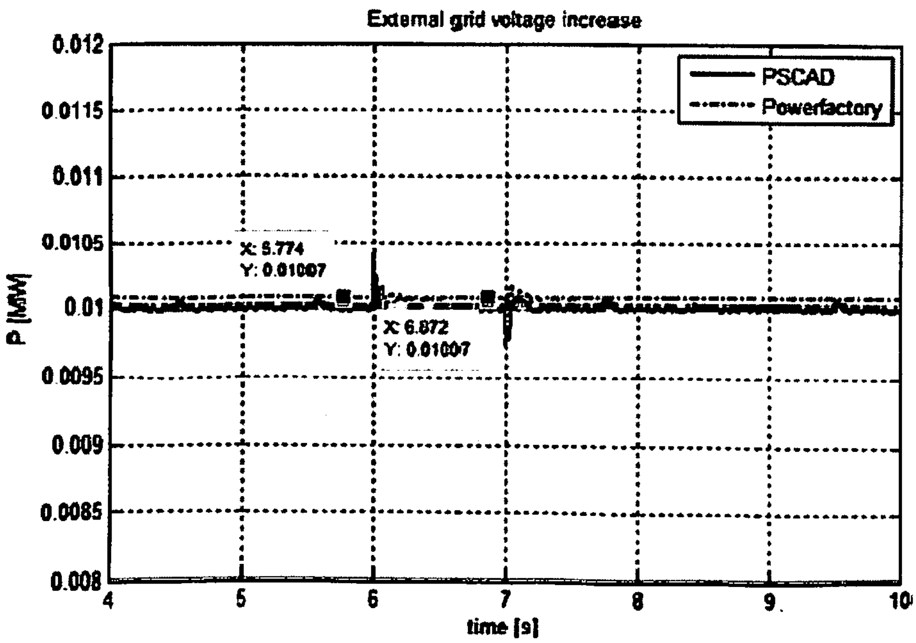



**Fig.-36** **Active Power of PV System**

44

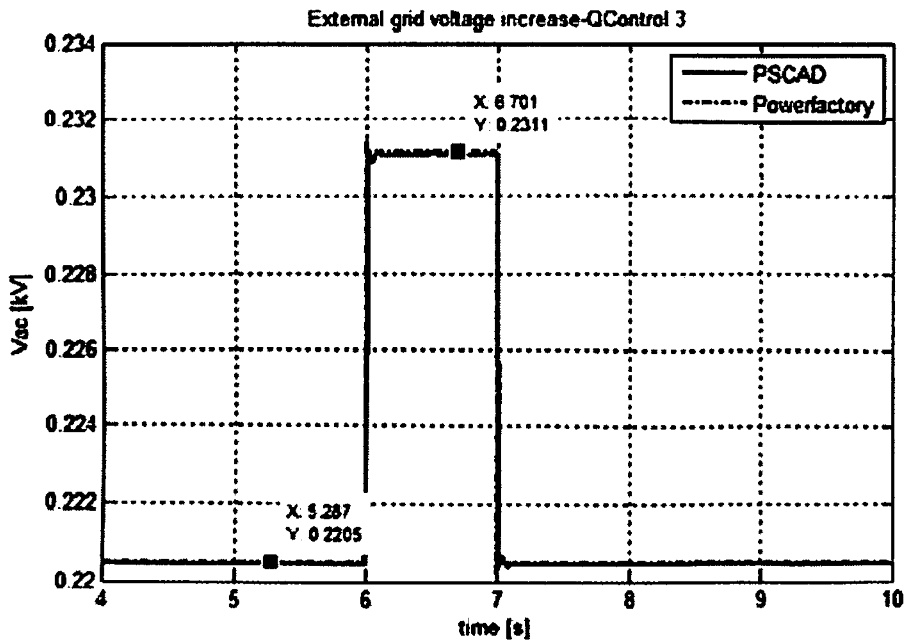



**Fig.-37** **AC Voltage at terminal L-2**

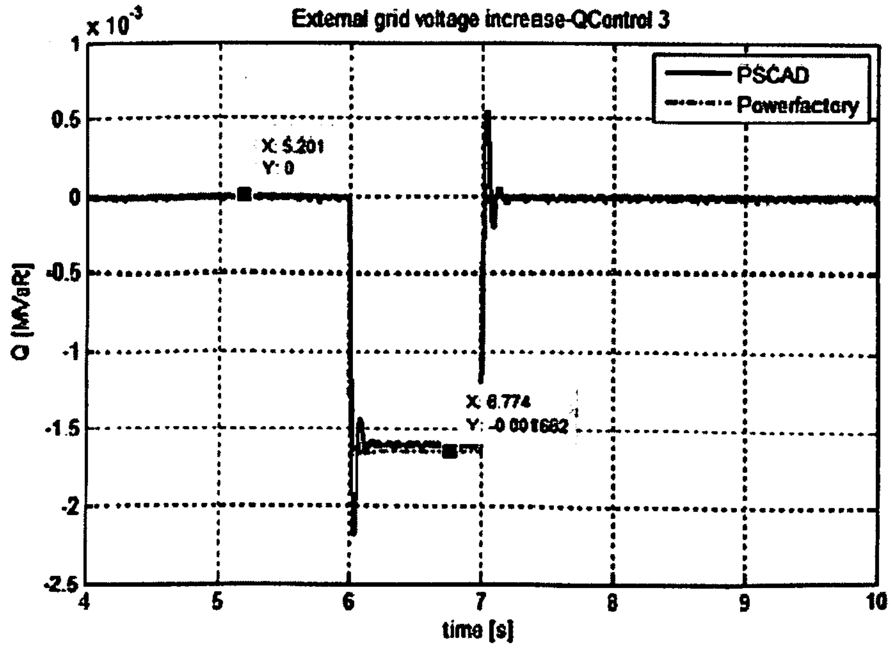



**Fig.-38** **Reactive Power of PV System**

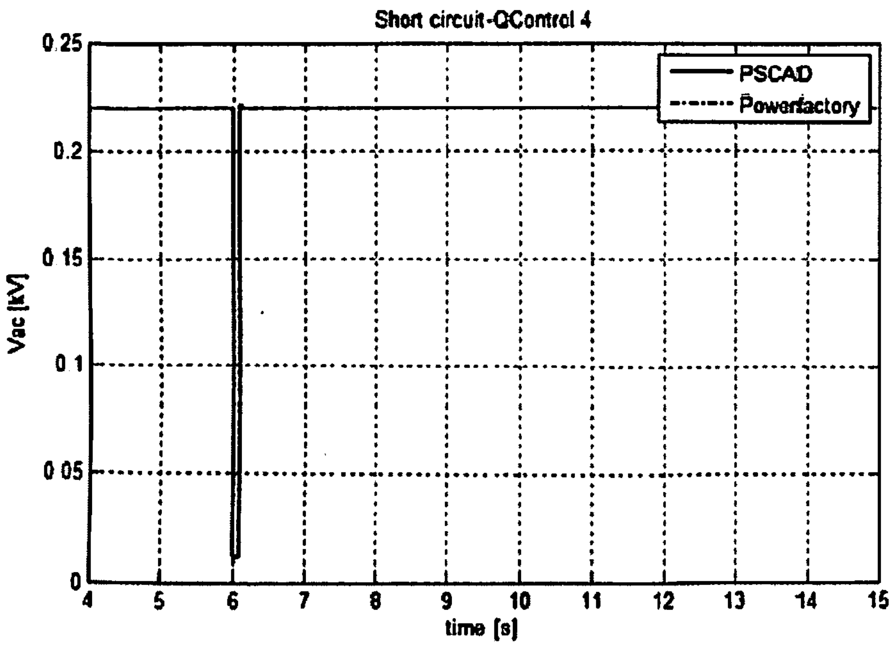



Fig.-39 AC Voltage at terminal L-2

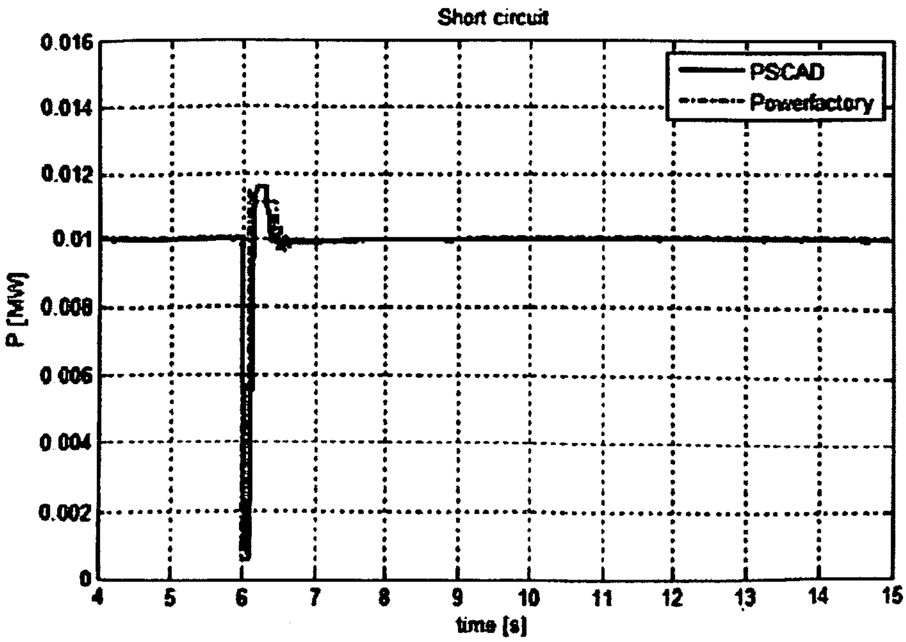



Fig.-40 Active Power of PV System

46

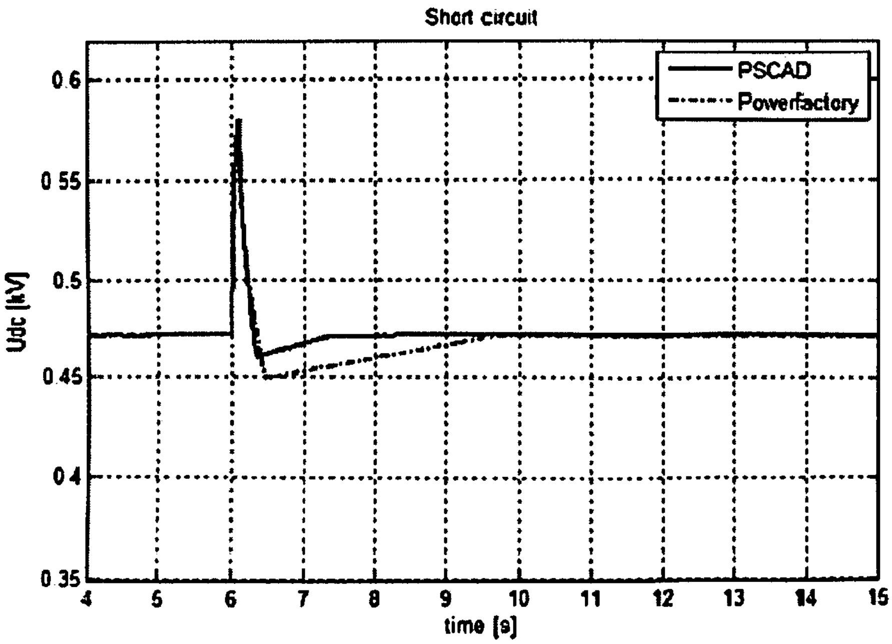



**Fig.-41 DC Voltage of PV System**

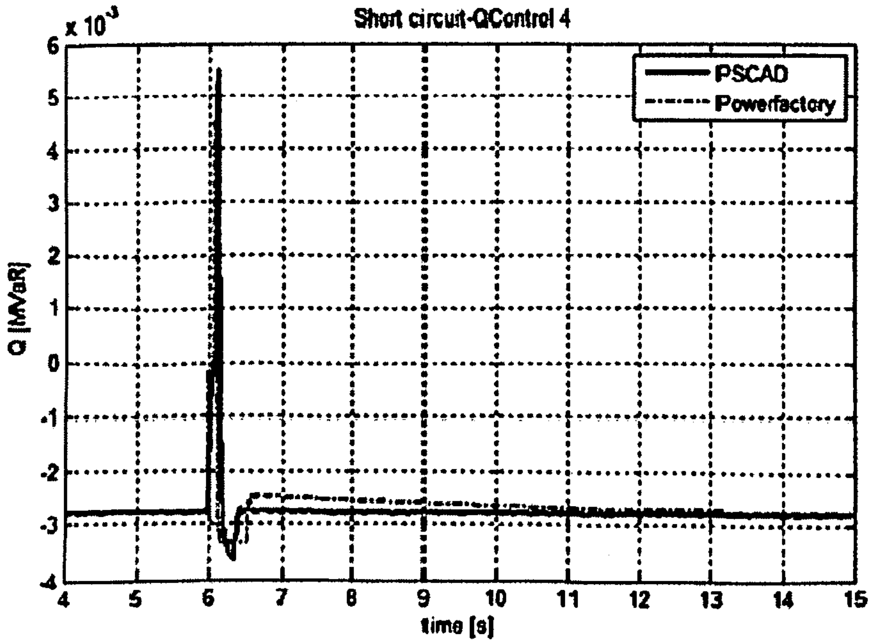



**Fig.-42 Reactive Power of the PV System**

47

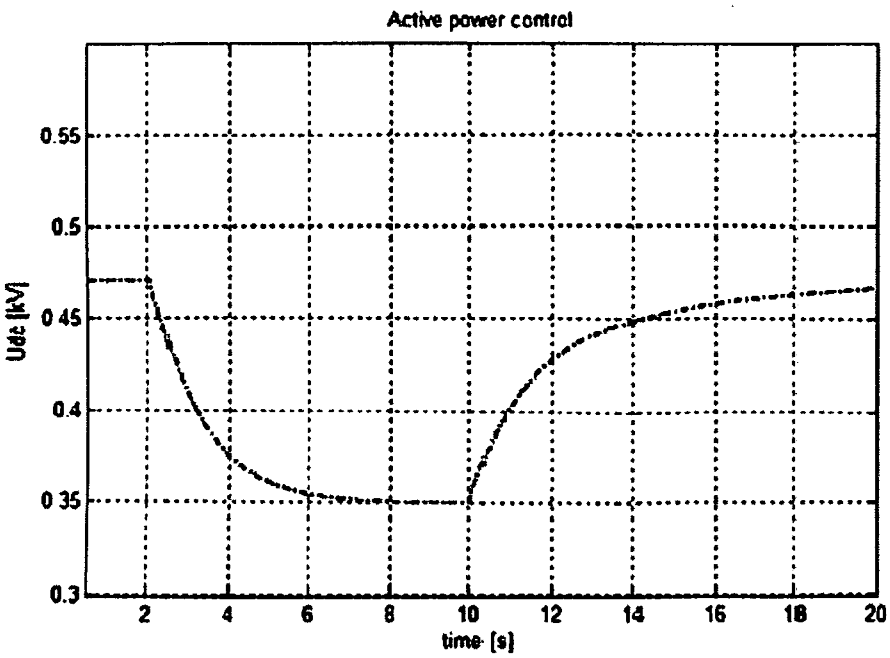



**Fig.-43 DC Voltage during active power control**

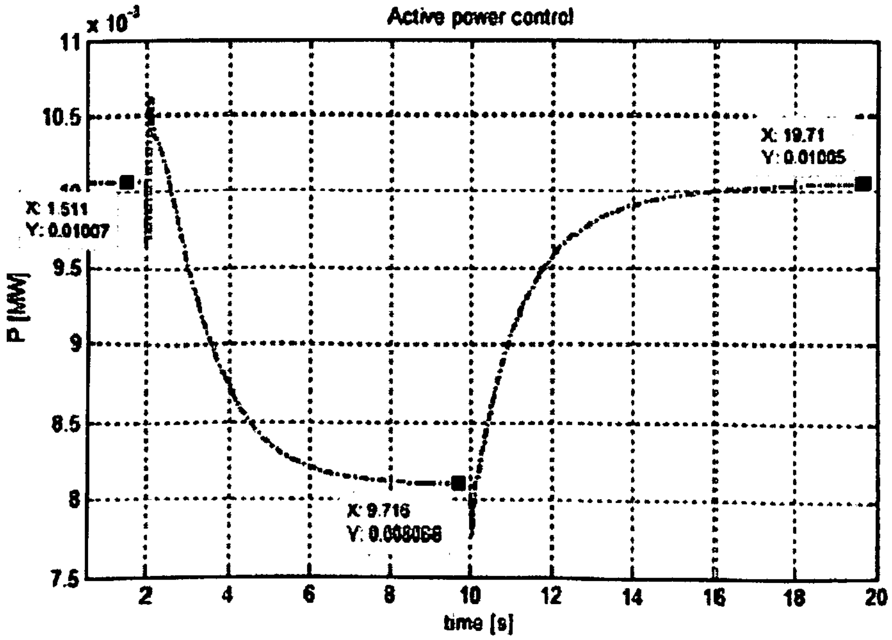



**Fig.-44 Active Power of the PV System**

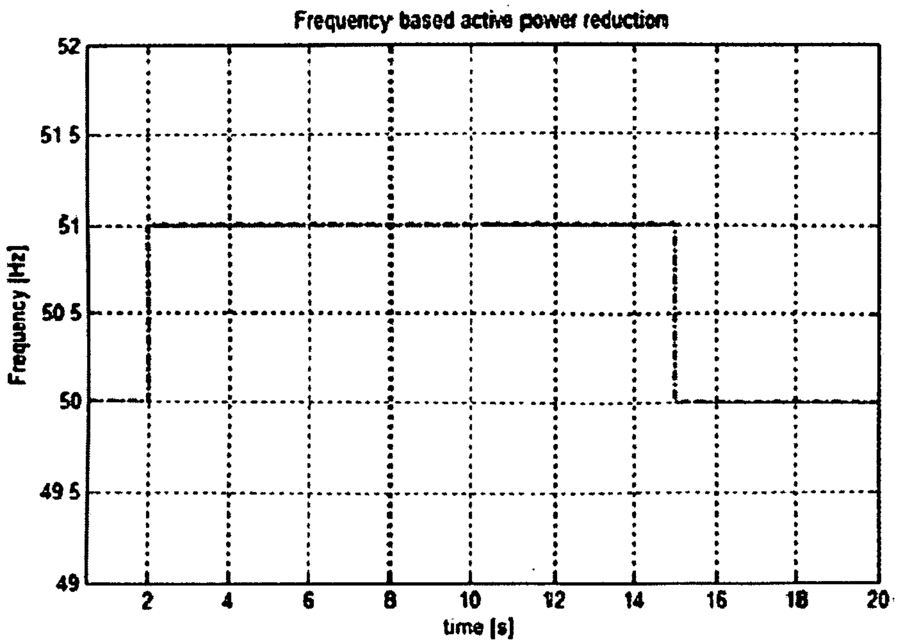



**Fig.-45 System Frequency**

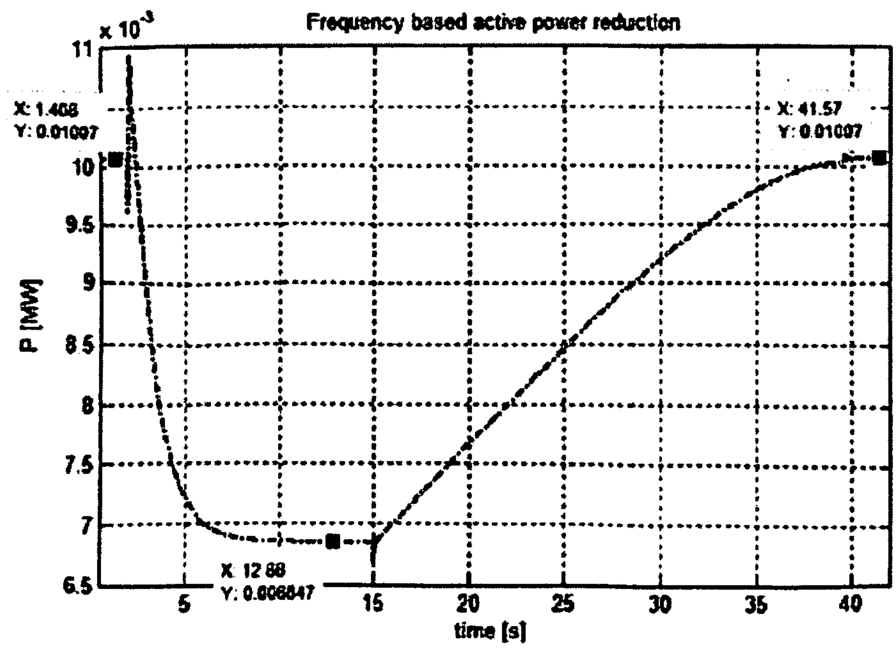



**Fig.-46 Active Power of the PV System**

49

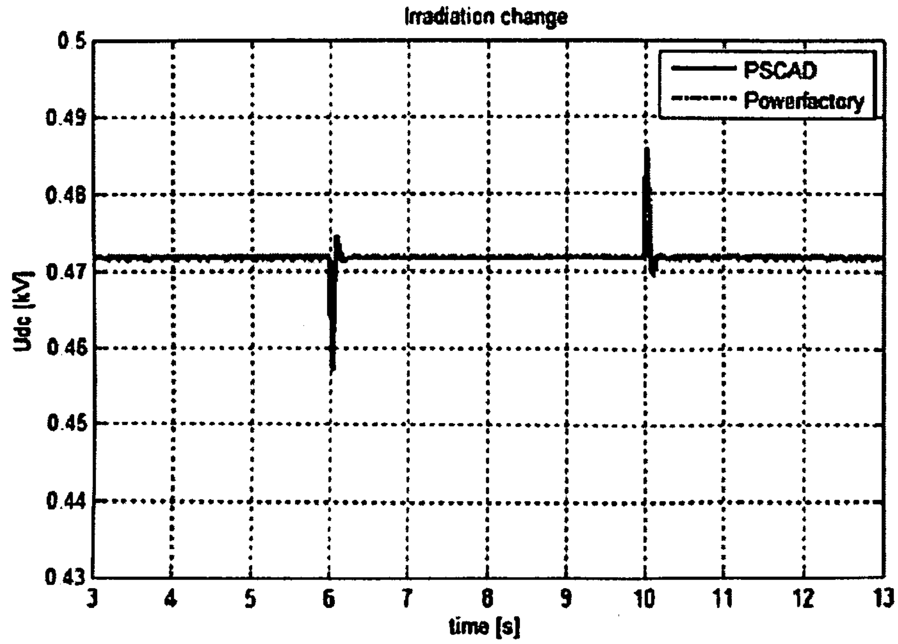



**Fig.47** **DC Voltage of the PV System**

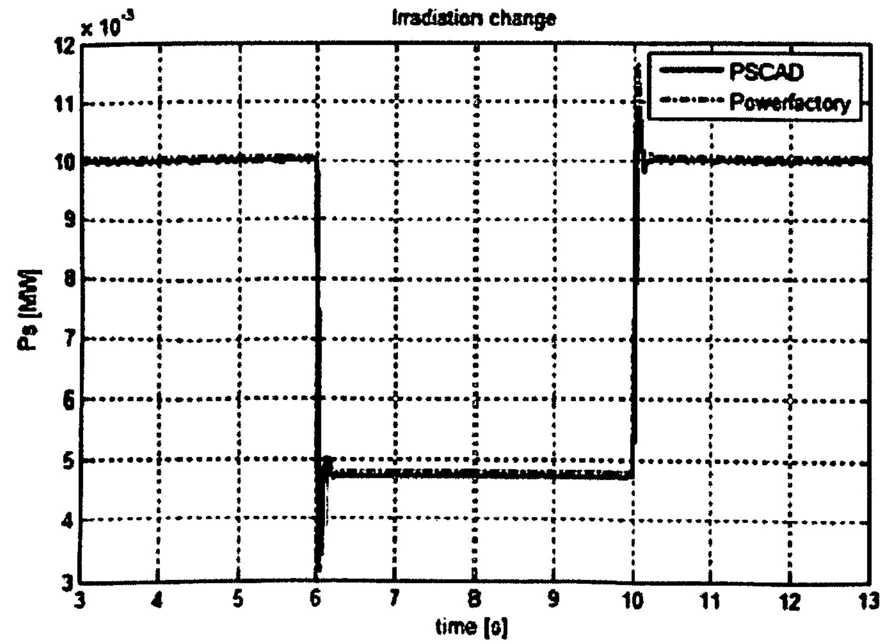



**Fig.48** **Active Power of the PV System**

**50**

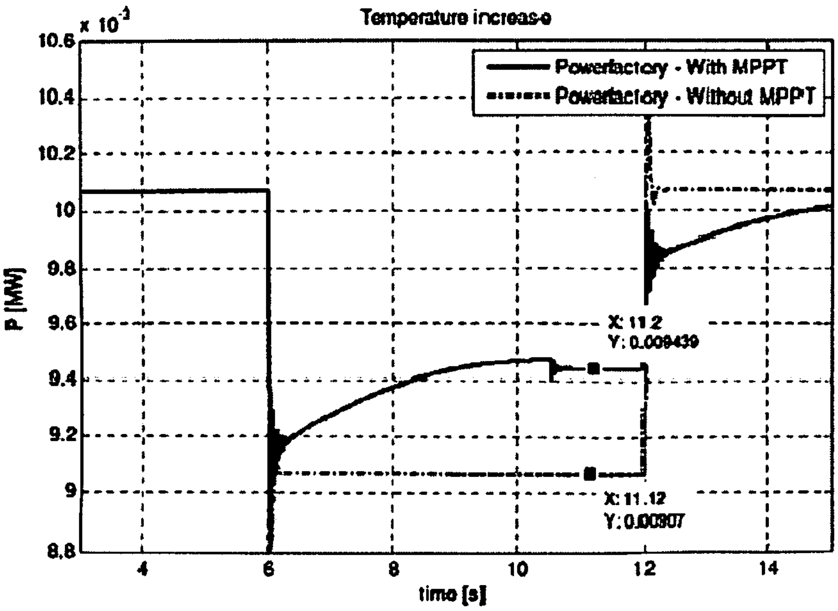



**Fig.-49** **Active Power of the PV System**

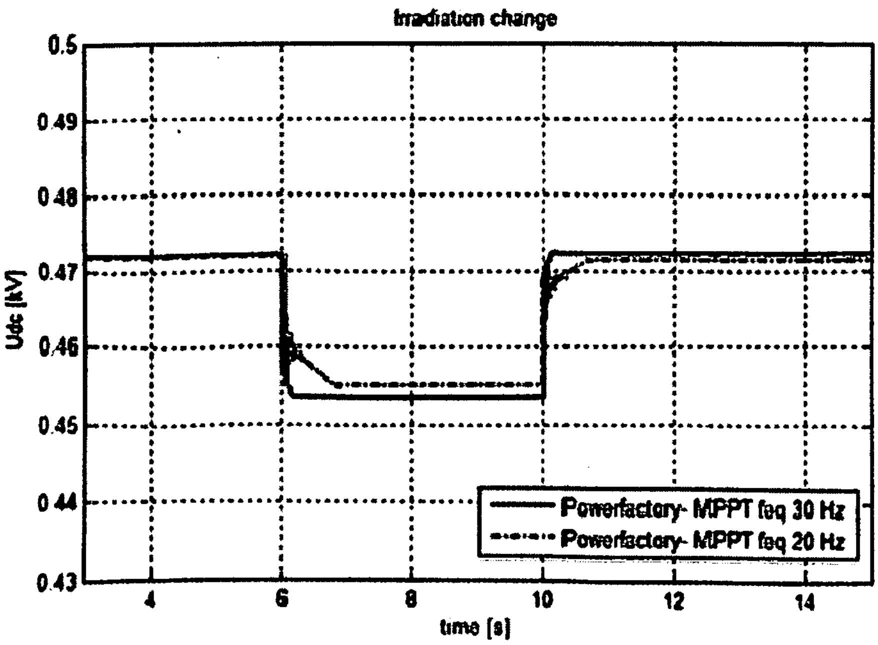



**Fig.-50** **DC Voltages of the PV System**

51

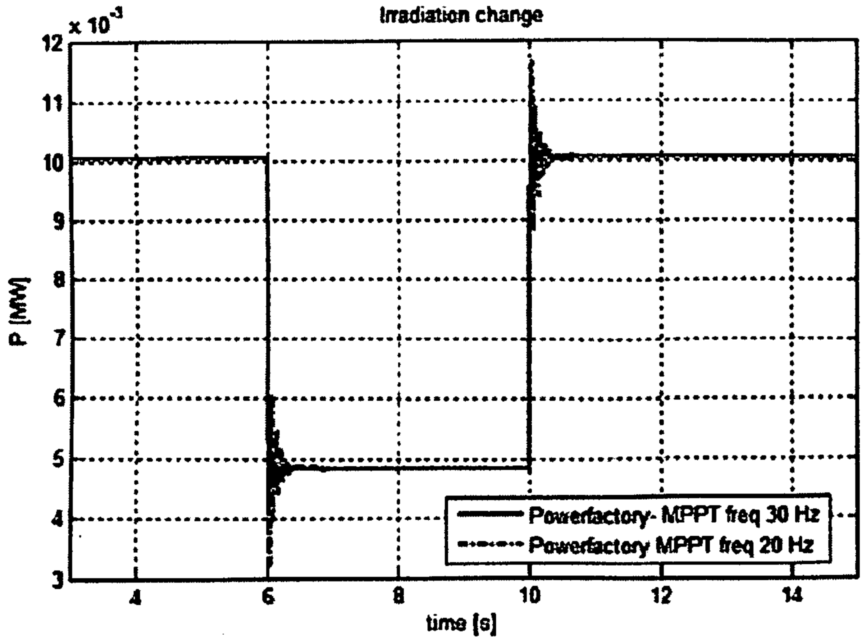



**Fig.-51** **Active Power of the PV system**

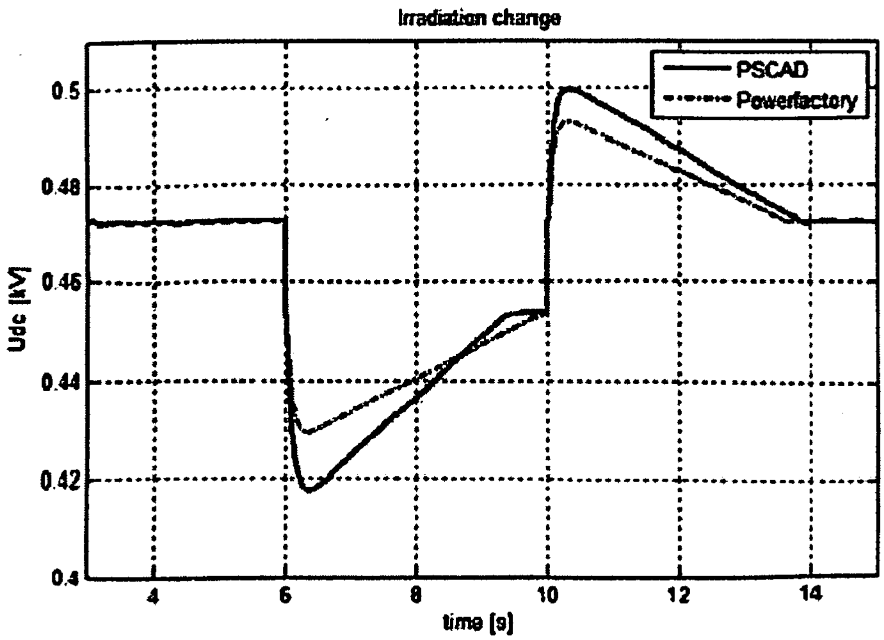



**Fig.-52** **DC voltages of the PV System**

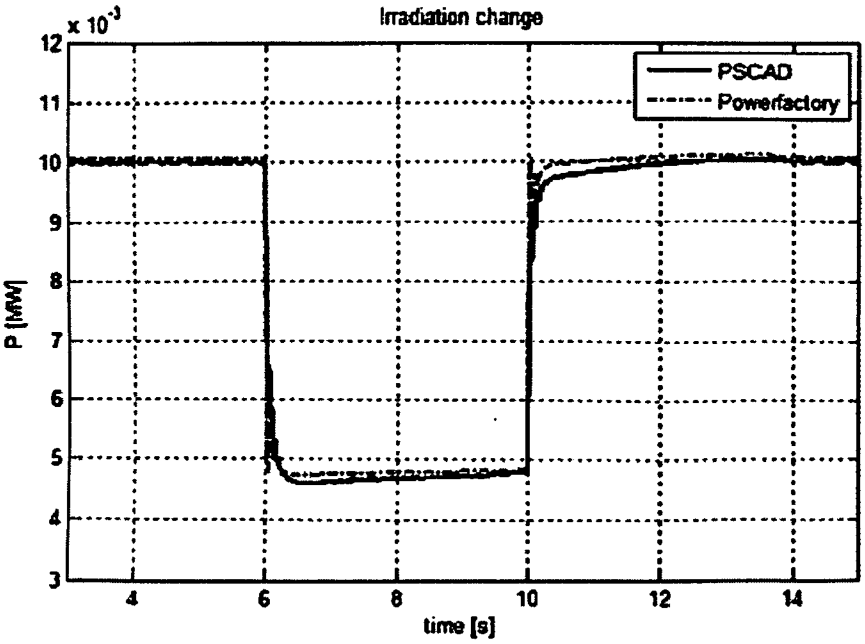



**Fig.-53 Active Power of the PV system**

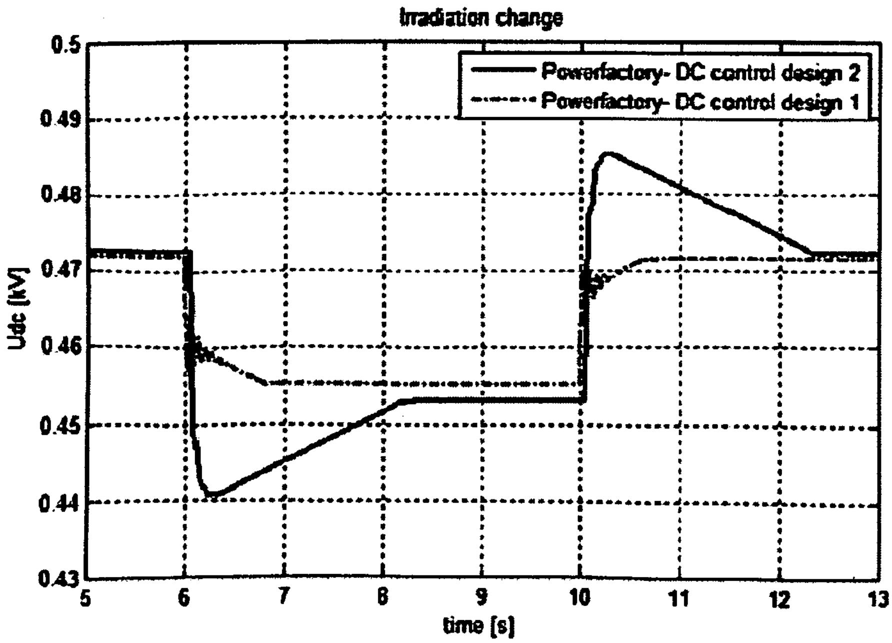



**Fig.-54 DC Voltages of the PV system**

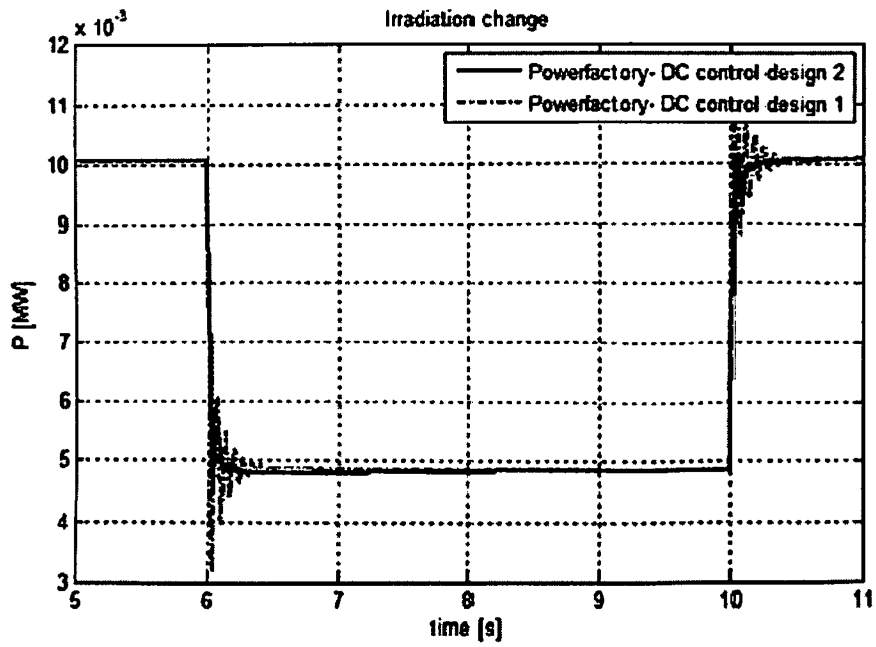



**Fig.-55 Active Power of the PV system**

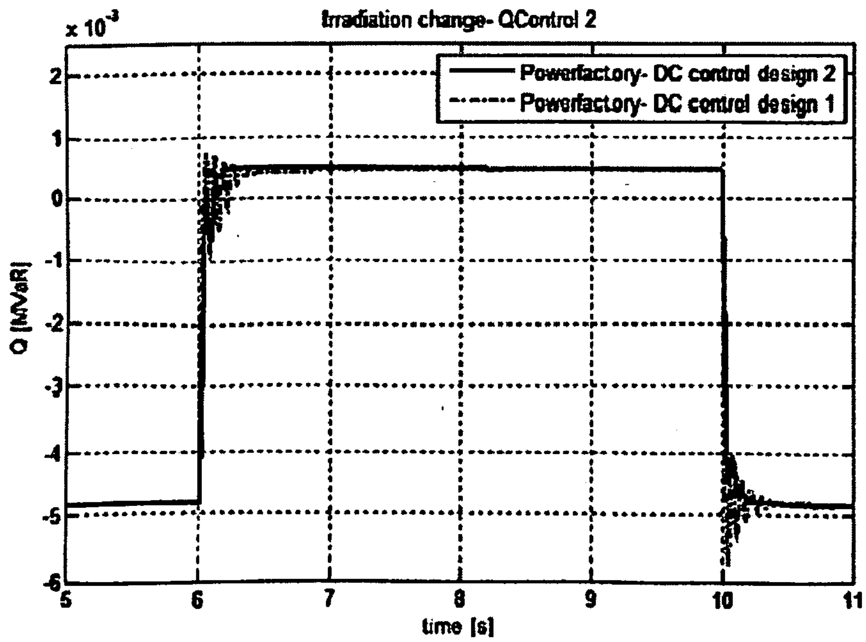



**Fig.-56 Reactive Power of the PV system**

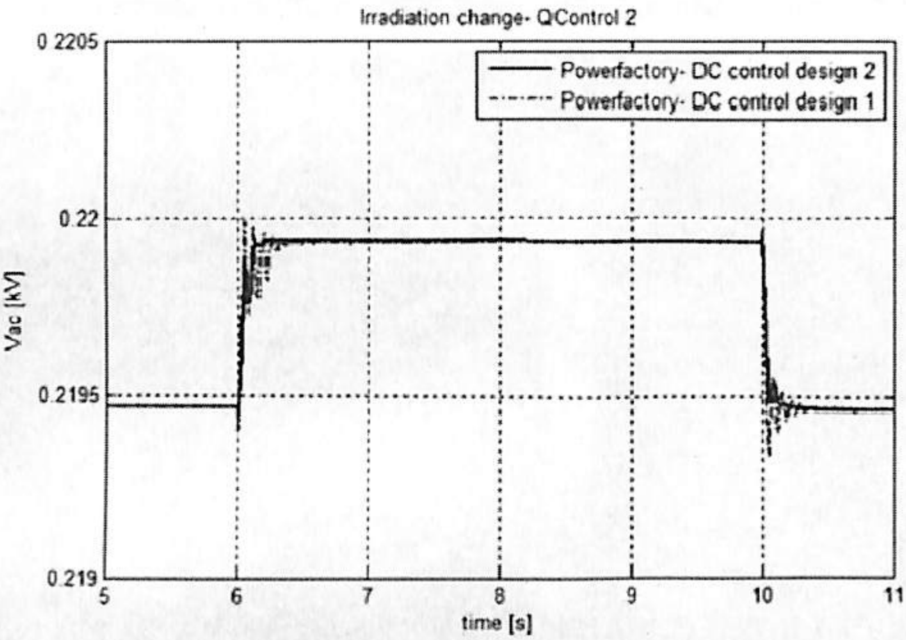
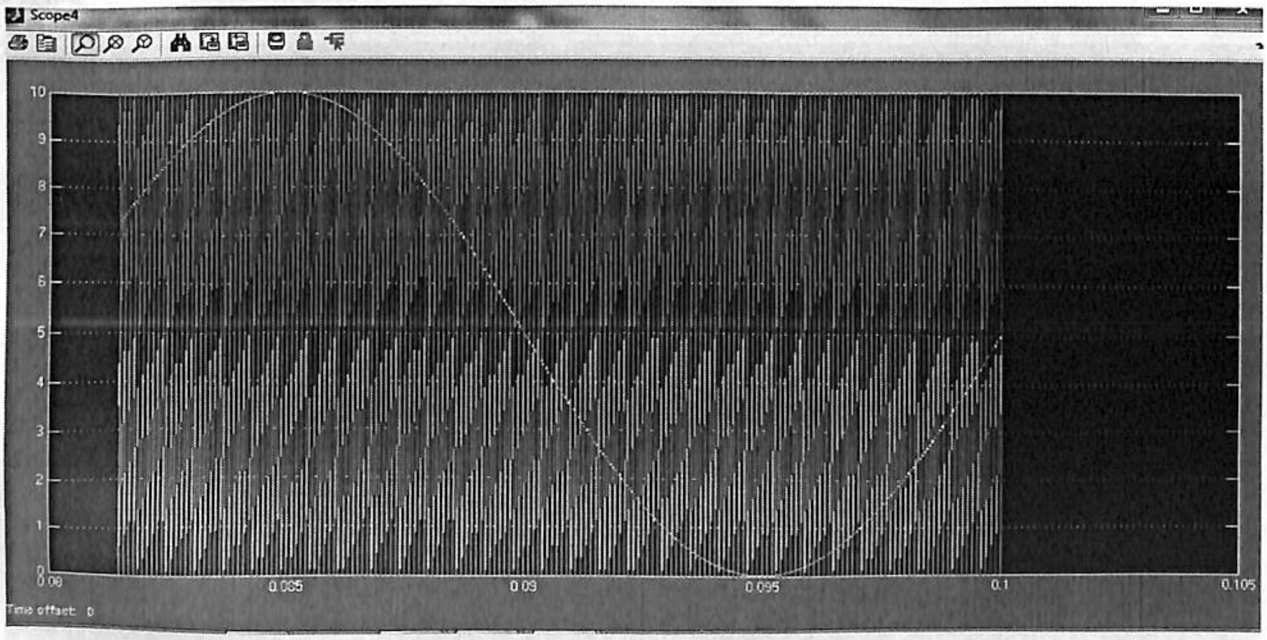



**Fig.-57 AC Voltage at terminal L-2**

**Fig.58 Input Signal-1**



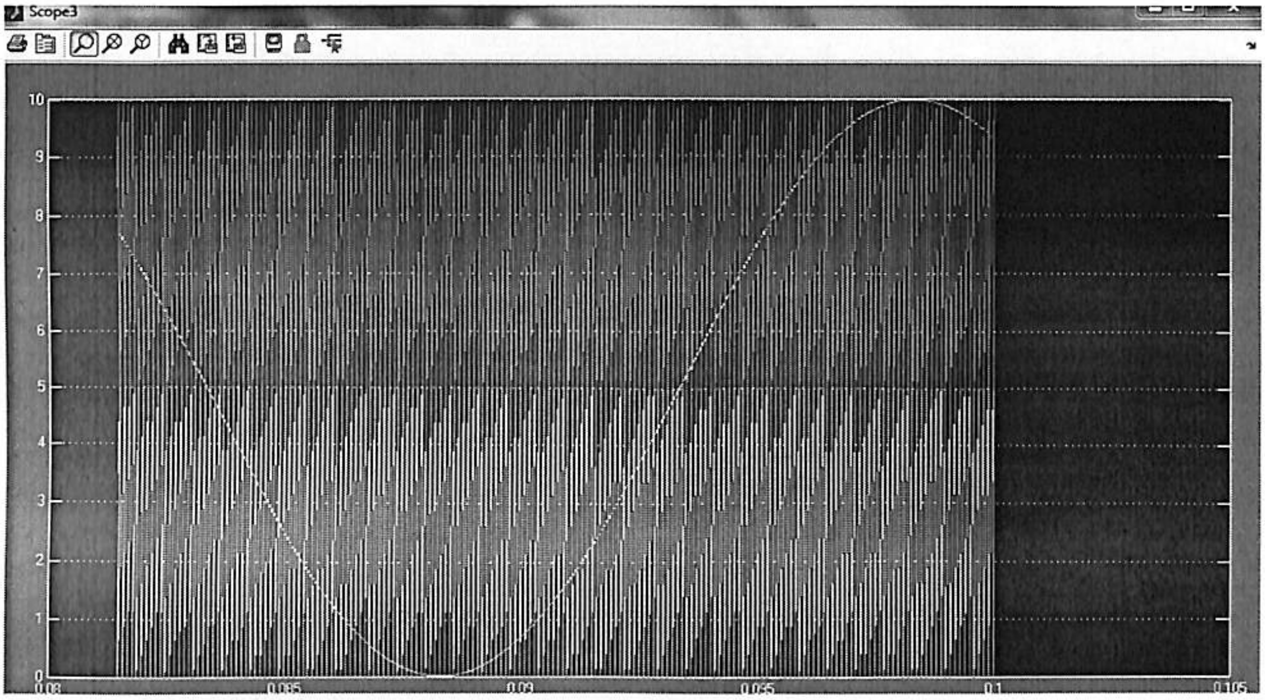
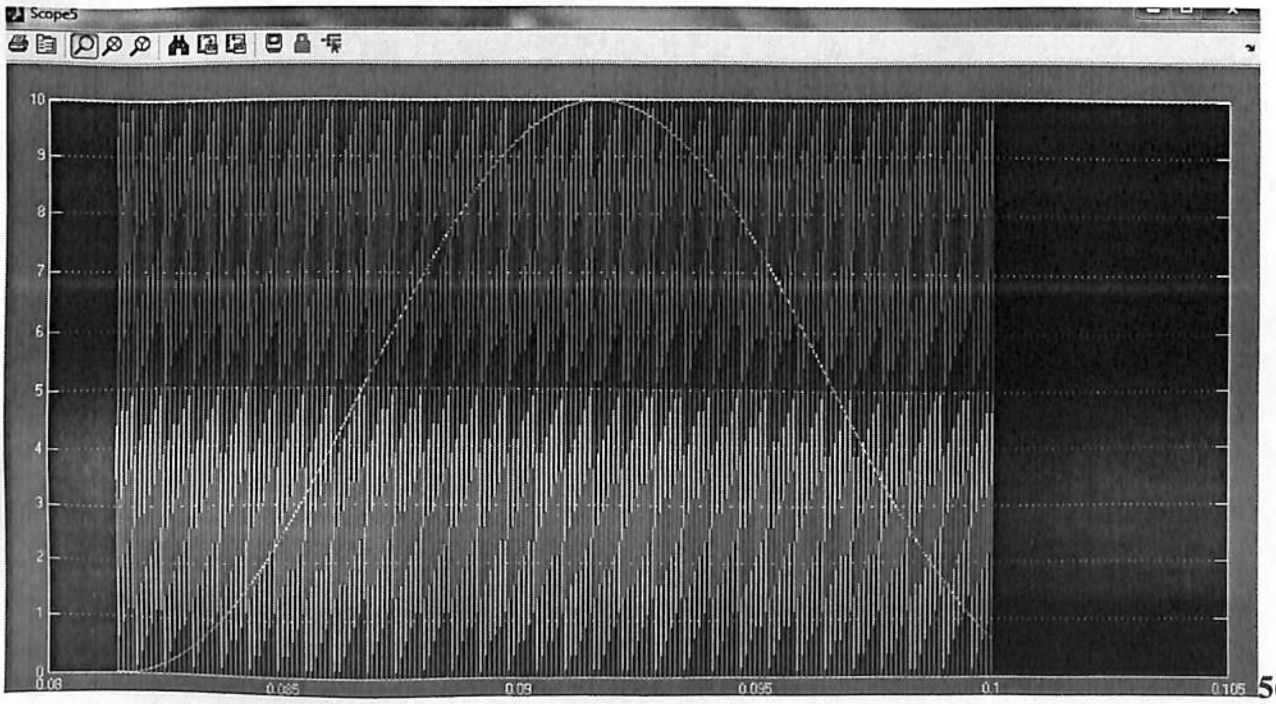



Fig.-59 **Input Signal-2**

**Fig.60** **Input Signal-3**




**56**

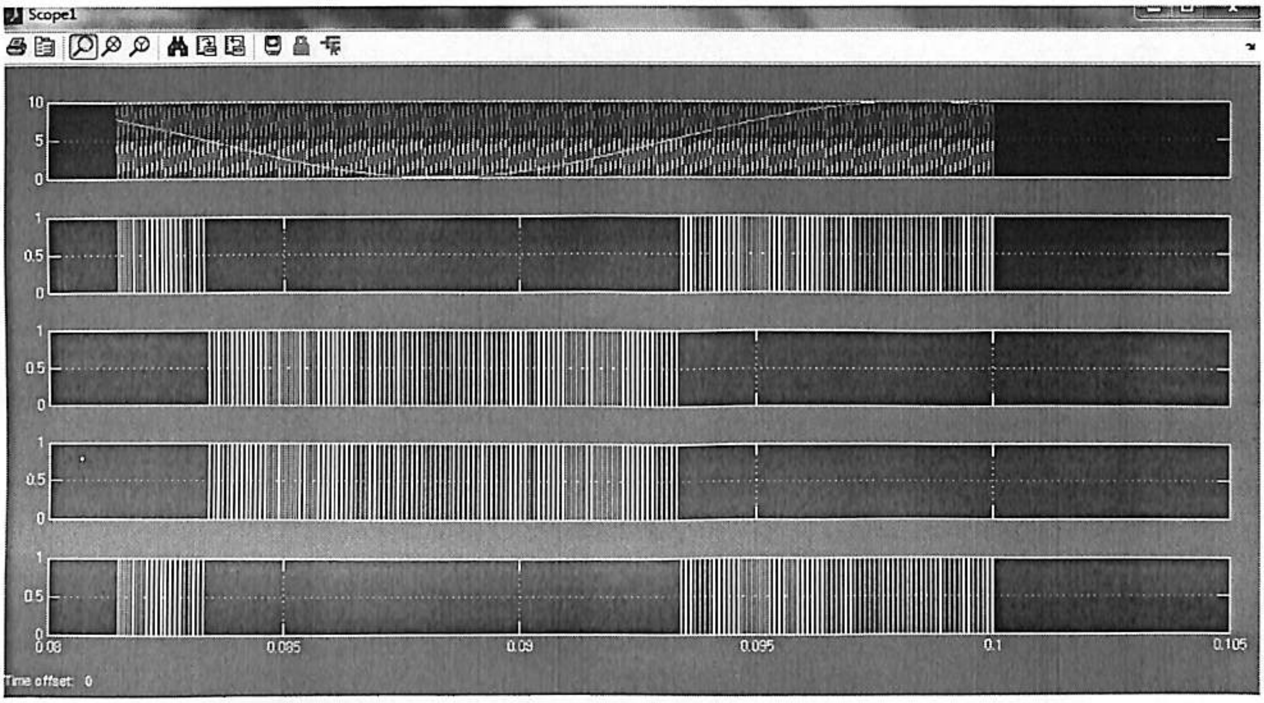
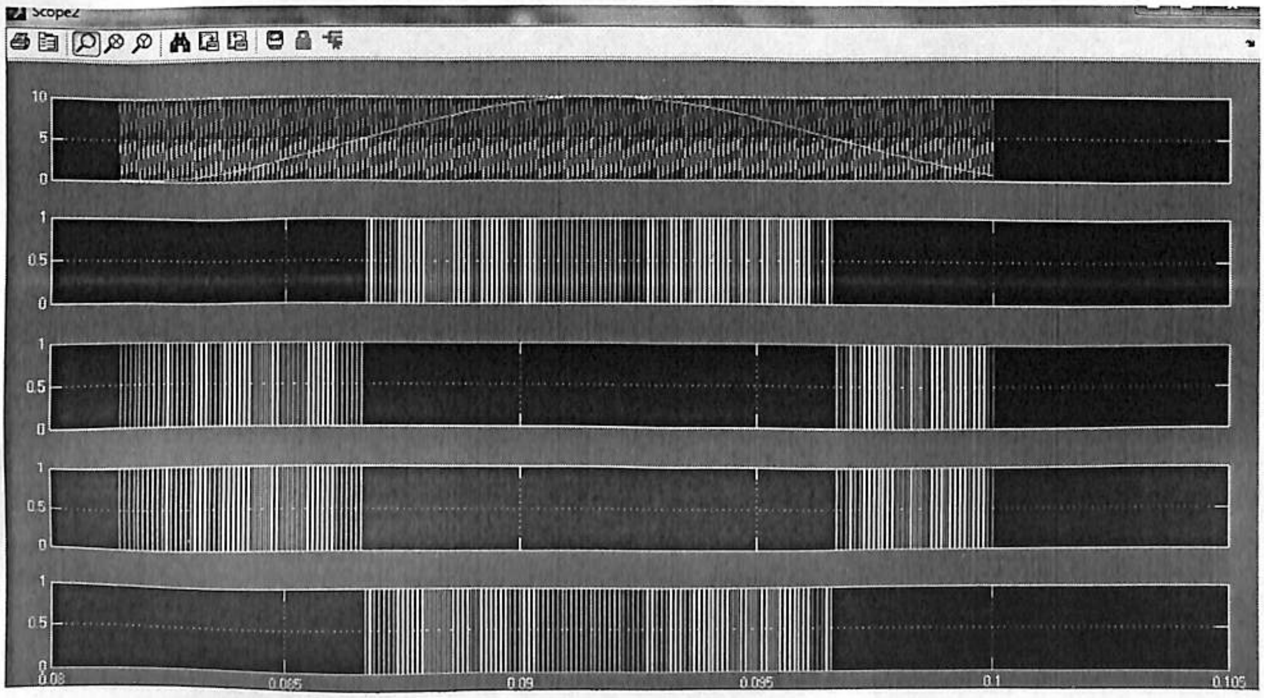



**Fig.-61** **Input Signal with 120 degrees phase delay**

**Fig.-62** **Input Signal with 240 degree phase delay**



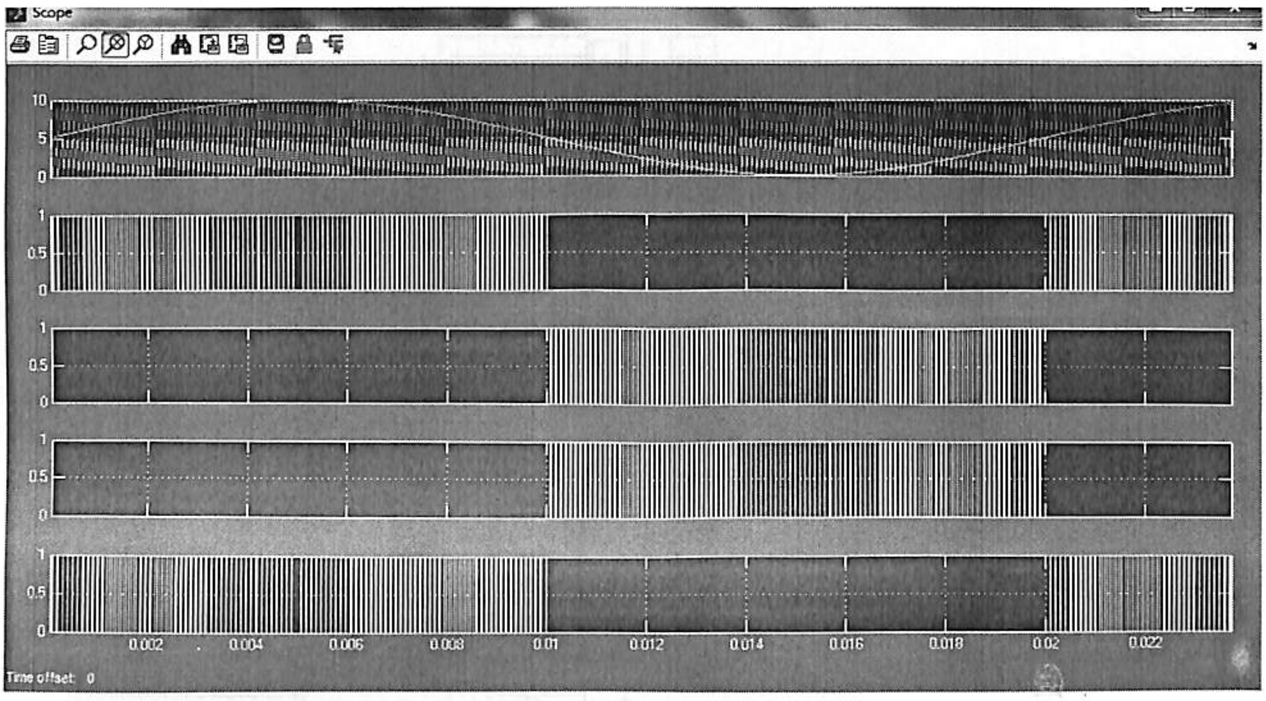



**Fig.-63** **Pulse signal with 0 phase delay**

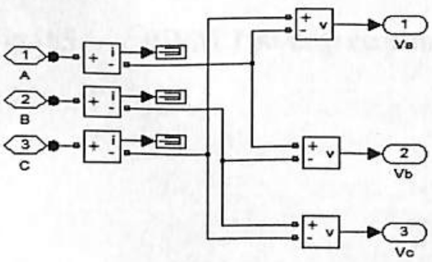



**Fig.-64** **Current measurement and Voltage Measurment**

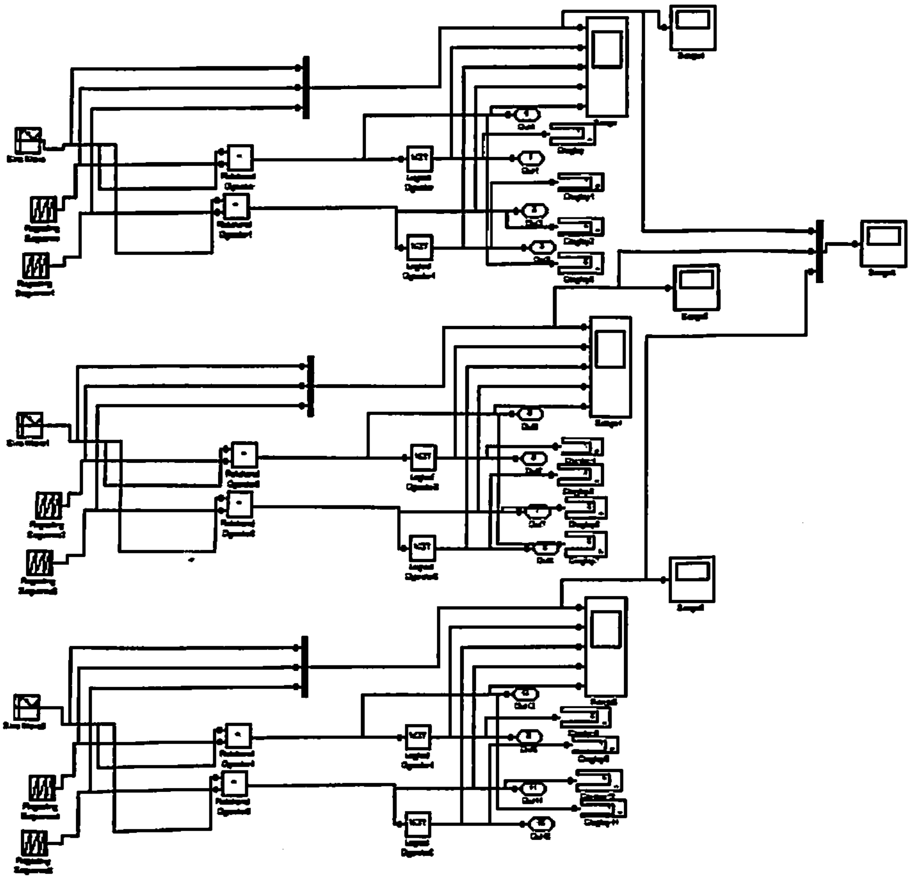


**Fig.-65 PWM 180 degree pulse**

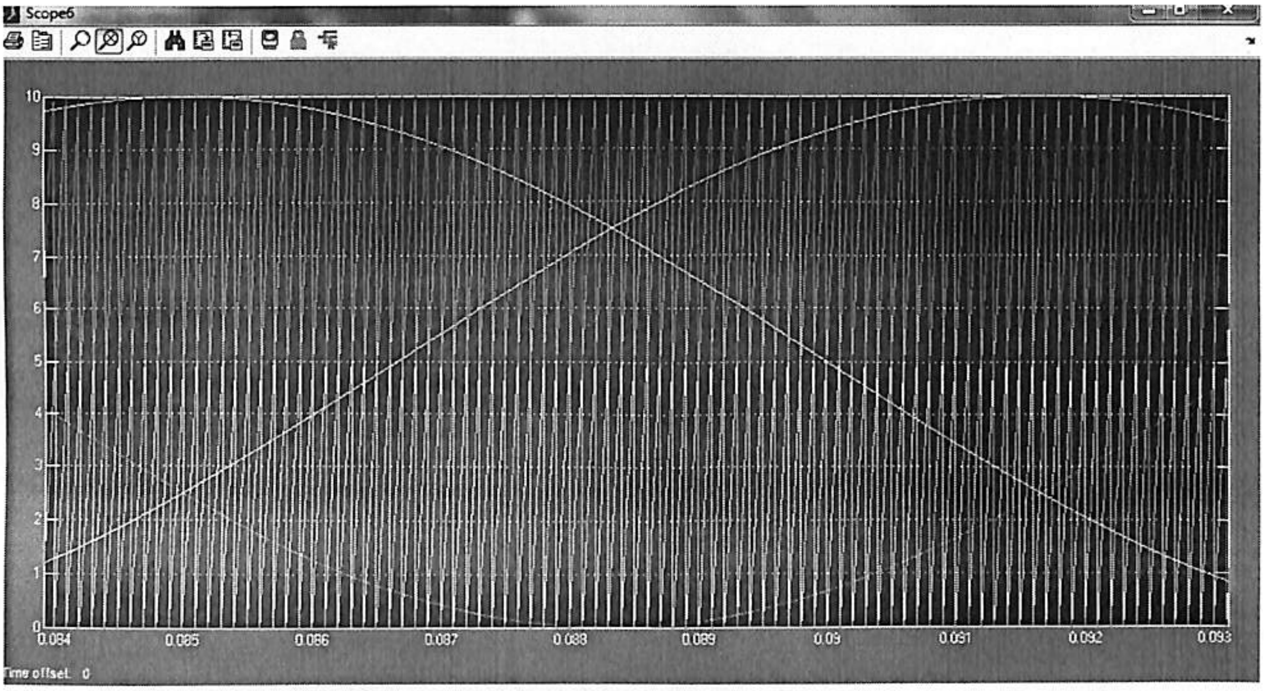



**Fig.-66 Complete PWM Signal**

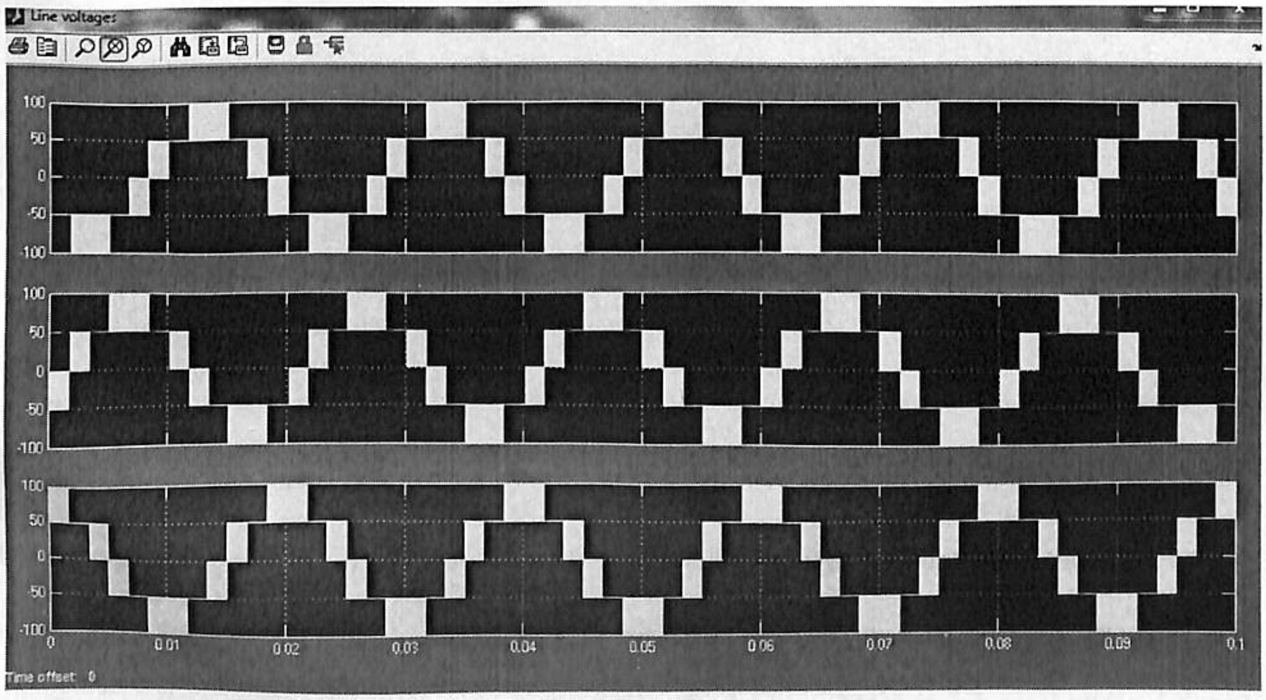



**Fig.-67 Final Sine wave form**

**CONCLUSION**

This study presents a single-phase five-level Photo-Voltaic (PV) inverter topology for grid connected application. The photovoltaic models, operation of suggested inverter topology, control system computations, modulation technique and results of simulation were checked.

The control system methods are created in Computer language C++ and it's inserted in MATLAB version.

The FUZZY - PI current controller was generated low harmonic distortion and improved sudden step response compare to PI current controller. The grid current is nearly sine wave and the power factor also near unity. Further, in the system will be approached to real time application.

# Future Application

Over the past few decades, the photovoltaic (PV) market has grown radically and the price for PV systems has decreased rapidly due to technology development in solar cell manufacture and performance improvement on efficiency conversion. Nowadays, PV systems are commonly used in three main fields:

(1) Satellite applications, where the solar panels generate power to satellite.

(2) Off-grid applications, where solar arrays are used to power remote load that are not connected to power grid.

(3) Grid-connected applications, in which solar arrays are used to supply solar energy to local loads as well as the electric grid.

Resulted from the world's fast growing energy demand and improvement on solar technology, more and more large scale solar power station will be installed and connected to electric grid such as concentrated solar power (CSP). CSP systems use lenses or mirrors and tracking systems to focus a large area of sunlight into a small beam using the photoelectric effect. The first commercial CSP plant was developed in the 1980s. Since then large scale CSP plants are widely installed all over the world. Other applications in future for solar energy include solar chemical, solar vehicles and etc.

As the increasing installation of grid-connected PV systems, especially large systems in the order of megawatts, might lead to some operational problems in the electric network. Such negative impacts include power and voltage fluctuation problems,harmonic distortion, malfunctioning of protective devices and so on. This may still stop further share of grid-connected PV system in electricity market. Therefore,studying the possible influences of PV systems on the electric network is and will be becoming an important issue and receiving a lot of attention from both researchers and electric utilities. For example, different algorithms are developed to reduce the harmonics inserted into the electric network. Active power filter is one of the most used methods.

However, the algorithm discussed in the report is the most simple, effective and easy to implement.

More research will also focus on dynamic response and system performance when interfaced with power grid, like sudden grid voltage change, system fault both in AC and DC side, solar irradiation change and etc. Various control schemes have been developed to check faults and to protect devices and the system. For instance, anti islanding scheme has been existed for solar energy connected with utility system to ensure personnel safety and power quality.

Another issue is that the output power of solar system depends on solar irradiance. Therefore, a lot of research will be focused on the effect of solar irradiance on the PV system. Models are going to be required to estimate the irradiance on the surface of the PV system, for which the accuracy of the models is usually dependant on the location where the PV system is installed. Meanwhile, the fluctuations in irradiance due to pass of cloud also receives a lot of attentions.

Finally, the use of storage devices with PV systems will gain more and more attention. These devices can be used to bridge fluctuations in the output power of PV systems, shift the peak generations of the system to match the load peaks, and provide reactive power support. However, more effort needs to be put to reduce the high cost associated with their installation, as well as to increase the capacity of energy storage.

# Results and Discussion

Some technical problems which has been solved by PV grid connected system.

- Harmonics for single inverter
- AC Modules
- Grounding and ground fault detection of PV-systems
- Lightning induced overvoltages
- EMI of inverters
- Reclosing
- External disconnect
- Isolation transformer and DC-injection
- Lower THD,
- Improved output waveform,
- Lower Electromagnetic Interference (EMI)

Need for further research in PV Grid Connected System.

· Harmonics with several inverters

· Effects on power system with more than one inverters

· Islanding of inverters in a part of the system

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