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IJIEMR Transactions, online available on 17th September 2017. Link :
http://www.ijiemr.org/downloads.php?vol=Volume-6&issue=ISSUE-08

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Volume 06, Issue 08, Page No: 821 – 828.

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A STUDY AND ANALYSIS OF GRID CONNECTED SOLAR PV SYSTEM

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ABSTRACT:
Solar PV energy is one of the most promising renewable resources that use the abundant and free energy from the sun having clean, inexhaustible and environment friendly cyclic operations. However, the intermittent nature of the output power of PV systems reduces their reliability in providing continuous power to customers. Solar PV energy can be used mainly in standalone (off-grid) and grid connected system. A stand alone solar PV cannot provide a continuous supply of energy due to seasonal and periodic variations. Therefore, in order to satisfy consumer load demand, grid connected PV energy systems that combine solar energy and other conventional conversion units are becoming more popular in recent years. But, the fluctuations in the PV output power with climatic conditions might lead to undesirable performance of the electric network in grid connected system. The objective of this work to study the performance analysis of grid connected solar PV system. To accomplish this, the mathematical modeling of 1kWp grid connected system is carried out and the power profile is estimated using historical environmental data collected over a number of years at Kathmandu. Identified the possible operational problems that might arise in grid connected PV system and different strategies that can mitigate these problems are studied. In addition, the performance of the system is evaluated.

Keywords:, grid connected Solar PV system Maximum Power Point Tracking (MPPT), Total Harmonic Distortion (THD), power factor (Pf).

INTRODUCTION:

A Grid Connected solar PV system is a type of electrical inverter that converts direct current electricity from PV module into alternating current (AC). When the PV system is connected to the grid, it can transfer the extra energy to the grid after fulfilling the local demand. But when the system generates less than what is required to support the local demand, than extra energy is extracted from the grid. Thus PV solar energy acts as an alternative resource of electricity. The PV system, designed in this work, aims to transfer electrical power from PV panels to the grid. First, a dc-dc Converter is used to boost up PV voltage to a level higher than the peak of grid voltage. The converter also tracks the maximum power point of PV module. There are many algorithms for tracking maximum power point. In this system I used perturb and observe method. PV module‘s voltage and power need to sense for tracking maximum power point in this method. Then, a pulse width modulation (PWM) based dc-ac inverter (voltage source inverter) is used for enforcing sinusoidal voltage waveform with matching phase frequency with grid voltage. The output voltage wave shape of PWM inverter is square PWM wave. Therefore, I used an LCL filter for

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coupling the inverter to the grid. It is one kind of low pass filter that converts PWM square wave to pure sine wave .Finally I incorporated a control mechanism in order to supply the desired amount of real and reactive power to the grid from the PV system. Active power is controlled by varying the angle between grid and inverter voltage. The supply of reactive power is controlled by varying the amplitude of inverter voltage.

GRID CONNECTED SOLAR PV SYSTEM

The general grid connected SPV system is shown in Fig.1. First stage PV array or module is connected with the system which connects the input to the inverter. The 3-phase VSI is used to convert DC voltage to AC voltage and feeds the energy to the load and grid [10] through LC filter circuit. The inverter has to be controlled in order to obtain harmonic less voltage to achieve good power quality. Various PWM techniques are used to switch the inverter circuit. A PLL is used for proper synchronization.

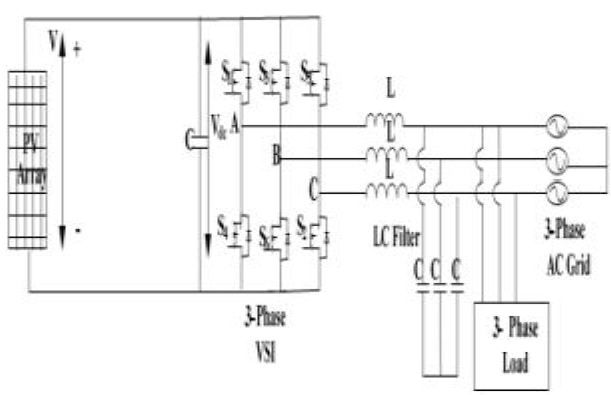

Fig 1: General Block Diagram of Grid Connected SPV system

Literature Review:

Swati Bhasme et al [1] gives a complete computer simulation program of a single phase grid connected PV system using Matlab/Simulink and SimPower System tool in order to monitor the performance of each unit of the system during a selected day in the year representing a sunny day and another cloudy day using the hourly data of load demand, solar radiation and temperature at the college of Engineering, Pune site, as a case study.

Zameer Ahmad et al [2] focuses on the latest development of modeling and control of grid connected photovoltaic energy conversion system. Modeling of photovoltaic systems include modeling of SPV array, power electronics inverter/converter based on MATLAB/SIMULINK.

Almas Hossain Mollah et al [3] proposes a three phase grid connected photovoltaic system in which maximum power point of PV array is traced using perturb and observe algorithm. Power converter consists of a switch mode DC-DC boost converter and a neutral point clamped 3-level inverter. An overview of the dq transformation and sinusoidal PWM technique are presented for the inverter control system along with grid synchronization condition.

Maulik Dave et al [4] depict information about dc-ac inverter used in solar inverter. We will get DC power from solar panels and this converter inverts DC to AC. Modeling and simulation using MATLAB. This method is very efficient than other methods and also it reduces harmonics to very much extent in output. Project objective are, to design an inverter model by using MATLAB and making analysis on the output voltage and to study the function of PWM in single phase inverter.

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Saban YILMAZ et al [5] the modeling and cost analysis of an on-grid photovoltaic generator of 500 kW, which was installed to provide energy for a textile factory located in the Pazarcık district of Kahramanmara¸s Province (37.5 ◦ N, 37.3 ◦E; altitude: 748 m), was performed. The findings suggest that the photovoltaic generator of 500 kW installed in the Pazarcık district of Kahramanmara¸s Province in August 2013 produces 816,639 MWh energy and reaches its initial cost in 6.2198 years.

Bhubaneswari Parida et al [6] reviews the photovoltaic technology, its power generating capability, the different existing light absorbing materials used, its environmental aspect coupled with a variety of its applications. The different existing performance and reliability evaluation models, sizing and control, grid connection and distribution have also been discussed.

Modeling of Solar PV

The Solar-PV cells are used to produce electricity by directly converting solar energy to electrical energy. Each solar cell is basically a p-n diode. As sunlight strikes a solar cell, the incident energy is converted directly into electrical energy without any mechanical effort. The voltage and current levels are produced from PV cells are very less, thus these PV cells are connected in series and parallel called modules and arrays to produce required voltage and current levels. The solar PV array is modeled by considering the output characteristics of PV panel which directly have relation with power converters which exists in the system. The solar PV cell is a non linear device which can be represented by a current source connected parallel with diode as shown in Fig.2. The characteristics of equivalent solar cell circuit are given in (1).

$$I_{PV} = N_p * I_{Ph} - N_p * I_0[\exp\{\frac{q*(V_{PV}+I_{PV}R_s)}{N_s AkT}\}-1] \quad (1)$$

Where Ipv is the PV array output current, Vpv is the PV array output voltage, Ip his module photo current, R s is the series resistance, k is the Boltzmann constant (138e-23 J/K), A is the ideal factor, N sis the series no of cells and Np is parallel number of cells. T is the operating temperature. The equation (1) is simulated using MATLAB/Simulink and P-V and I-V characteristics are obtained. The operating curves shows that solar PV output power is function of solar irradiation.

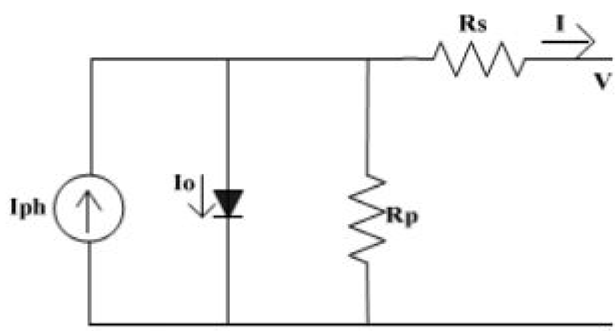

Fig.2. PV Module

3-Phase VSI and Filter A 3-phase VSI is used to convert DC voltage into AC voltage and feeds power to consumer loads and utility grid. The 3-phase inverters are used in grid connected SPV systems. A 3-phase inverter is a six step bridge inverter. It uses a minimum of six devices. As stated earlier, the transistor family of devices is now very widely used in inverter circuits. Presently the use of IGBT in three-phase inverter is on the rise. A capacitor connected at the input terminals tends to make the the input dc voltage constant. This capacitor also suppresses the harmonics fed back to the

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source. In inverter terminology, a step is defined as a change in the firing from one IGBT to the next IGBT in proper sequence. For one cycle of 360, each step would be of 60 intervals for a six step inverter as shown in Fig.2. This means that the IGBT would be gated at regular intervals of a six step inverter. There are two possible patterns of gating the switches. In one pattern, each switch conducts for 180 and in the other each switches conducts for 120. But in both these patterns gating signals are applied and removed at 60 intervals of the output voltage. A LC type filter is used to provide 50Hz frequency output to consumer loads and electric grid. There are various factors which decide the selection of filter capacitor and inductor. Generally in order to eliminate the higher order harmonics, the resonant frequency of the filter should be greater than 6 times of desired output frequency.

Modeling of MPPT system algorithms

Maximum Power Point Tracker (MPPT) is used to operate the module at the peak power point so that the maximum power can be delivered to the load under varying temperature and irradiance conditions. A DC to DC converter serves the purpose of transferring maximum power from the solar PV module to the load by changing the duty cycle of it and load impedance as seen by the source is varied and matched at the point of the peak power with the source so as to transfer the maximum power.

Among various algorithms, Perturb and Observe (P&O) algorithm is used in this work for the MPP tracking. A slight perturbation is introduced to the system, due to this perturbation, the power of the module changes. If the power increases due to the perturbation then the perturbation is continued in that direction. After the peak power is reached the power at the next instant decreases and hence after that the perturbation reverses. The Matlab/Simulink model has shown in Fig. 3.

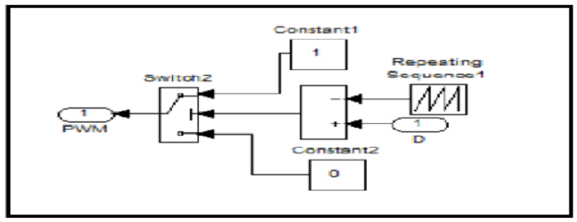

Fig 3: Model for MPPT: Simulink model for PWM wave generation

Requirements of grid connection system

Power quality, protection coordination and grid synchronization are the major issues to be concern over the grid connection of solar PV system. Harmonics, voltage regulation, power factor, EMI and DC current injection are the main power quality issues that may cause adverse effects like additional heating, reduction of transmission system efficiency, overheating of distribution transformers, malfunctioning of electronic equipment etc. in gird connected system if not properly addressed. According to IEEE1547 standard, allowable current THD is 5% (Even harmonics are limited to 25% of the odd harmonic limits), 2 % for voltage THD and 1% for individual voltage harmonics in Distributive Resource (DR) connected to area Electric Power System (EPS). DC current injection shall not be greater than 0.5% of the full rated output current at the point of DR connection as per IEEE standards.
The complete model for gird connection of 1kWp PV system has shown in figure 4.

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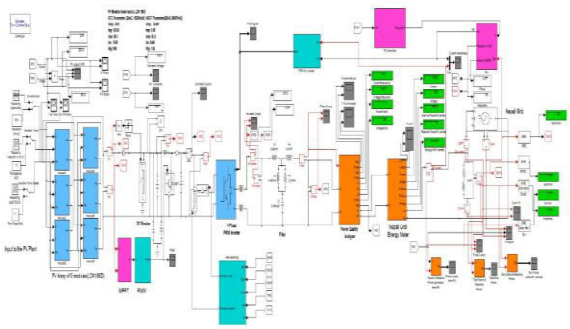

Fig 4: Simulation of grid connected PV array with BOS (185Wp * 6 PV modules connected in series).

Simulation Results:

A. Output from array

The IV and PV curve from array has shown in Fig. 5 under the time varying input of irradiance and ambient temperature. The open circuit voltage of array was about 250V and short circuit current was 3.9A. It has found that increase in irradiance caused array current to increase while small reduction of array voltage but ambient temperature has reverse relation unlike irradiance. At very low irradiance, array voltage has dropped below the threshold voltage level for the inverter resulting highly distorted waveform and it needs to use undervoltage protection circuit for such cases.

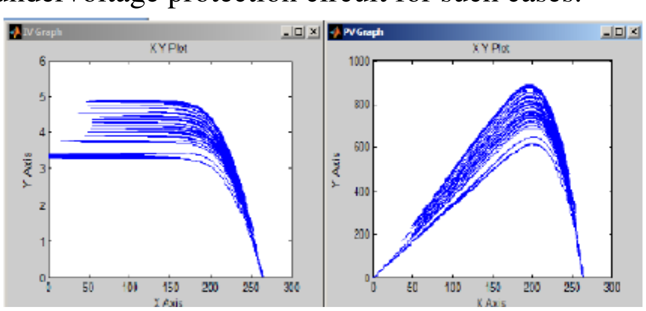

Fig 5: IV and PV curve of array with RL load and time varying input

It has found that the use of P&O MPPT algorithm increased the array power output by 23%. Especially at low irradiance, the MPPT system was more effective. As shown in Fig. 9, initially it took few seconds to maintain the operating point and the ripple voltage appeared due to the perturbance of the algorithms. Upon the use of small perturbance, ripple was reduced but it took more time to track the operating point.

B. Power quality

It has found that current THD is 21.35% and fundamental or 1st harmonic component (50Hz) is 4.124Apeak (2.91Arms). The even harmonics are much less than the odd harmonics and they have severe impacts on power quality. Similarly, voltage signal contained 5.01% of THD with fundamental components of 312.8 Vpeak (221.18Vrms). The details of even and odd harmonics are shown in Table I. Since the harmonics present in the inverter output are higher than the IEEE 159 standard (below 5%), harmonic filter is used for suppression of harmonics. In this work, a passive LCL harmonic filter is used for the harmonics compensation techniques.

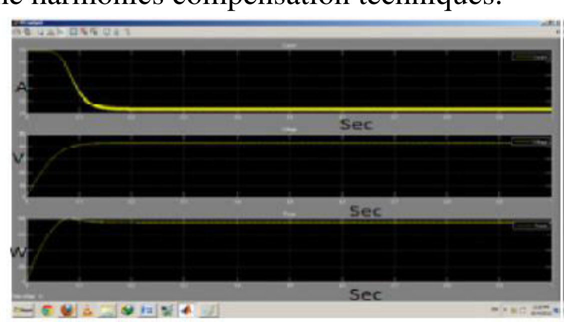

Fig 6: Output current, voltage and power from PV array without MPPT

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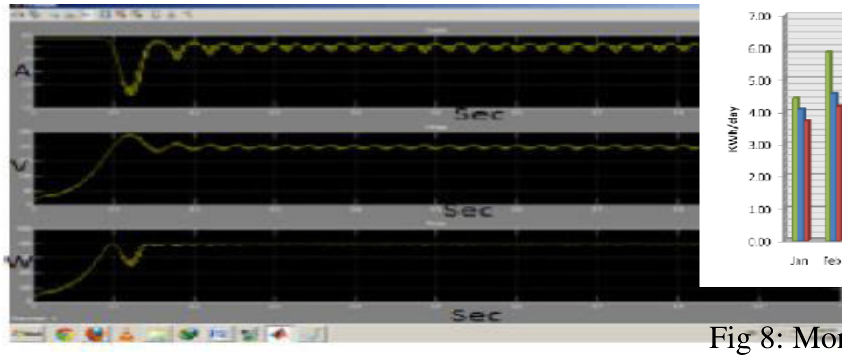

Fig 7: Output current, voltage and power from PV array without MPPT

C. Power outputs from the array and system efficiency

The system is simulated individually for the inputs of meteorological data collected over 12 month. The array energy was 1886.1 kWh/Year at STC but the array actually produced 1699.62kWh/year out of which 1523.69 kWh/year is injected to the grid and the performance ratio is 80.76%. The least energy is generated in January and August (4.09kWh/day) and total energy in this month is 126.66kWh/month. The highest energy is produced in October with 5.68kWh/day and total of 176.2kWh/month. The average inverter efficiency throughout the year ranged from 87% to 93%. The average gird penetration throughout the year varied from 95%, in June, to 99%, in February. Similarly, the overall performance ratio is 78% to 84 %. A thesis work done by A. Bhattrai 2012 shows that average final yield is 2.31kWh/day; array yield is 2.64 kWh/day under the average 4 hours of load shedding during day time at Kathmandu. Grid penetration is the ratio of energy injected to the grid to the energy available at inverter output and performance ratio is the power at inverter output to the energy fall to the PV array.

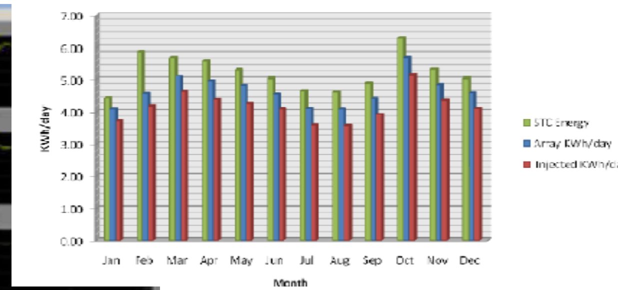

Fig 8: Monthly energy generation from 1kWp PV system throughout the year

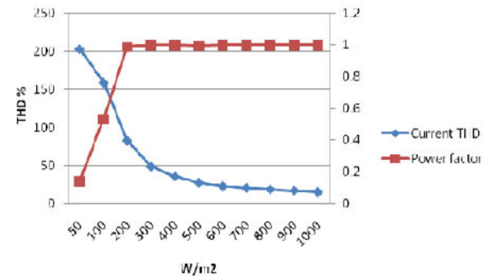

Fig 9a) Variation of current THD and power factor with irradiance

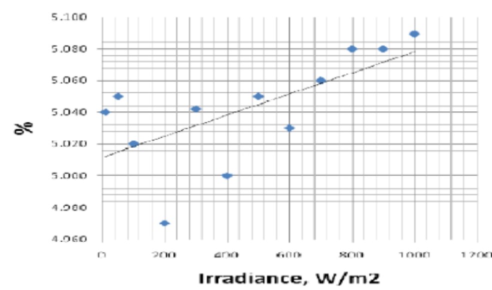

Fig 9b) Variation of voltage THD with irradiance

Fig 9: Effect of irradiance on power quality on inverter output

Inductive load decreased the power factor and to compensate it, capacitive load should be added. But, the power factor also varied with the irradiance in grid connected solar PV. The variation of power factor with time at constant load and it has found that for most fraction of day, the power factor is acceptable. Also, the

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current THD became lowest at peak day but voltage THD is highest and it slowly decreased on either side.

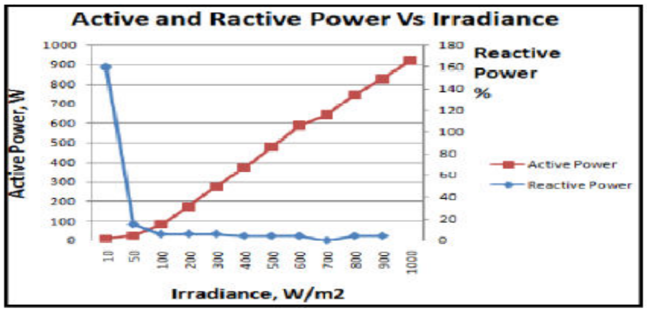

Fig 10a) Active and reactive power variation at inverter output

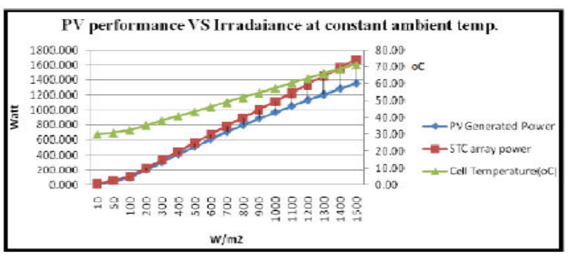

Fig 10b) Performance of PV system with irradiance

Fig 10: Active and Reactive power vs. Irrad; PV performance vs. Irrad.

Objectives:

- A Study and analysis of Grid connected SPV System.
- Controlling the active and regulate the reactive power injected into the grid;
- A Study on mathematical modeling of 1kWp grid connected system

Conclusion

Grid tied inverters convert DC power to AC power with an efficiency of 90% or more most of the time. Inverters can even work to some extent when irradiance levels up to 200W/m2, but performance starts to drop off dramatically when irradiance levels falls below it.

The use of MPPT system is of great value to the array output as it (P&O algorithm) optimizes the PV power output by 23% than without the use of MPPT system. The nonlinear devices used in the converter circuits are the great source of harmonics in the PV grid connected system. The harmonics generated in the PV power converting systems greatly vary with the solar irradiance. The odd harmonics have greater impacts on power quality than even harmonics as they have higher magnitude. The current THD is more sensitive on the fluctuation of solar irradiance than the respective voltage THD. Current THD greatly decreases with the increase in the solar irradiance while voltage THD slightly increases with increase in solar irradiance. Power factor varies linearly for values of solar irradiance lower than 200 W/m2 and remains close to unity for higher solar irradiance values. In addition, reactive power injection increases at low irradiance.

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