HIGH-PENETRATION, WITHOUT STORAGE, PV SOLAR-DIESEL GENERATOR IN ISOLATED SYSTEM

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ABSTRACT

The aim of this paper is to reduce the cost of supplying electricity in remote area and to get optimal operation of the distribution network including renewable energy sources. In actual power system operations, the load is changing continuously and randomly, as the ability of the generation to track the changing load is limited due to physical/technical considerations, to maintain the desired active output power of a generator matching with the changing load, there results an imbalance between the actual and the scheduled generation quantities. In recent years, many facilities all over the world the move towards renewable energy uses. For example, wind or photovoltaic power (PV) is an alternative, a source of clean energy and sustainable electricity production. PV certainly does not need to be tall and strong tower, as well as lacking of any vibration or noise, and does not need to be refrigerated. On the other hand volatility and rising fuel prices with considerations of greenhouse gas emission, and carbon footprint reduction therefore, certain features make PV generation worthwhile to consider in planning and electricity network operations now and in the future. The simulation system model and tested using MATLAB/ Simulink and the results are presented.

Keywords: Diesel Generator, PV Solar, Frequency Regulator

INTRODUCTION

Power system can be considered in actual power system operations is a generator supplied with different load ,containing active and reactive power and constant frequency value during the steady-state situation through transmission and distribution stations down to demand. Generation capacity to track the load changes is limited because of the physical / technical reasons, to maintain the desired active output power generator according to the changing load, there is an imbalance between the actual and planned values of generation, this imbalance leads to a frequency error, the difference between the actual and the synchronous frequency.

Power system structure and operation of the distribution system based on alternative energy sources, renewable units (solar, wind) is changing with the integration. The main task of the distribution network while maintaining the voltage level of the appropriate limits is to supply electricity loads. Falls into a major problem with the stability constant conserved in all variables that occur during the flow of energy to power the loads demand. In the network the stability of the distribution systems with a large penetration PV solar generation, voltage stability becomes an important issue, especially in the case of involving the borders of the possibility of loads.

Penetration levels of PV may affect the stability of the system is to improve or worsen the stability of the system. Due assortment of renewable technologies and the complexity of the power system, modeling of PV units becomes decisive to obtain a correct reaction of the impact on the power system stability. Profile of voltage drop along the power supply because of the impedances of the line and the load level is supplied, the load conditions of the grid is changed after photovoltaic connected to the distribution network in the points in which they are connected, namely, the points of common coupling (PCC).

The application of PV systems in power systems can be divided into two broad areas: off-grid or stand-alone applications and on-grid or grid-connected applications. Stand-alone PV systems can be used to provide power to distant loads that have no access to electricity grids as grid connected applications are used to provide energy for local loads and exchange power with utility grids. Photovoltaic systems can improve operation of power systems by improving the voltage profile and reduction of energy loss distribution feeders, the expenditures for maintenance and loading of transformer tap changers at peak hours (Farhoodnea et al,2013).

The diesel engine must be able to follow the variation of loads and PV power. The size of frequency variation indicates how well the diesel and its governor maintain the balance of active power in the system, and the size of voltage variation indicates how well the gen-set and its voltage regulator maintain the balance of reactive power through the generator excitation. Under transient conditions, the frequency and the voltage will not be absolutely constant because PV power and load variations change constantly. Several studies have been carried out to minimize the harmful effects of connecting PV generators to the isolated utility. The most common practice is to use energy storage systems (ESSs) as smoothing devices for a PV system's output (Park, J. S et al, 2001). However, the capital and maintenance cost of large capacity ESS is a barrier to the large-scale installation of PV systems. Besides, these methods cannot control PV output power considering the power utility condition like load variation. Therefore, they are not into providing any frequency control. All of these methods tried to smooth the fluctuating PV power. However, none of them gave emphasis on controlling the PV power according to the load variation and frequency deviations. Therefore, these methods had no sharing of the duties like frequency regulation (Datta M. et al, 2011).

To improve the contribution of distributed generation significantly in the existing electrical networks that pose new technical and economical challenges to power system control and management, coordinated control of distributed resources is necessary. A coordinated management of a diesel power plant and a PV array is suggested in (Canever, D., et al, 2001) in order to fully exploit the PV renewable energy. However, it did not deal with the problems introduced in the power utility by output power fluctuations of PV power systems (Datta, M et al, 2009).

SYSTEM CONFIGURATION

In this paper the concept of the power utility used a diesel – PV actually hybrid power system consisting of diesel generator and PV systems that generate power to feed the load demand is shown in Fig.1. Furthermore, it is assumed that the isolated power utility is not connected to large power utility and is always operated independently as a stand-alone system.

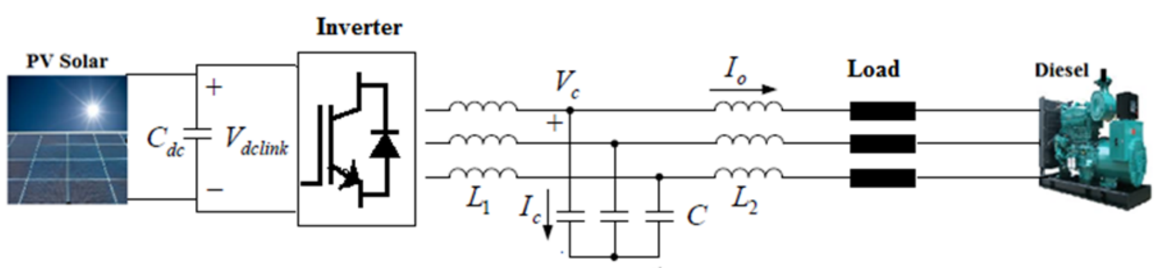

Figure 1: General diagram of diesel generator connected photovoltaic system in isolated network

Photovoltaic generator

The construction of the PV system is the solar cell, which is basically a (p-n) semiconductor junction that directly converts solar radiation into direct current with photovoltaic effect. The simplest equivalent circuit of a PV solar cell is a current source in parallel with a diode, shown in Fig. 2(Ellis, A. et al, 2012).

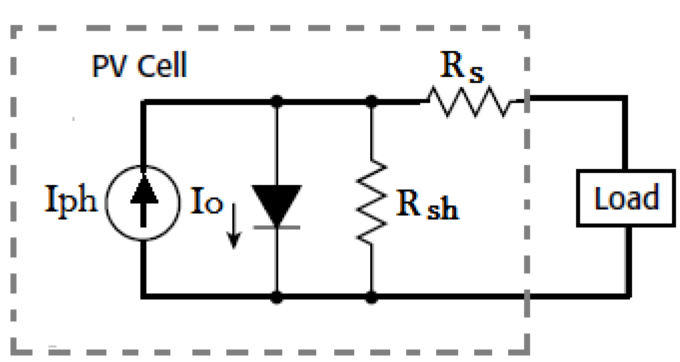

Figure 2: PV cell modeled as diode circuit

Rsh and Rs are intrinsic shunt and series resistance of the cell, respectively. Usually the value of Rsh is very large and that of Rs is very small, so they can be neglected to simplify the analysis. Module photo-current:

$$I_{Ph} = [I_{SCr} + K_i(T - 298)]*\lambda/1000 \quad (1)$$

Saturation current reverses (Irs):

$$I_{rs} = I_{SCr} / [exp(qV_{OC}/N_s\,kAT) - 1] \quad (2)$$

Saturation current Io varies with the cell temperature, which is given by:

$$I_o = I_{rs}\left[\frac{T}{T_r}\right]^3 exp\left[\frac{q*E_{go}}{Bk}\left\{\frac{1}{T_r} - \frac{1}{T}\right\}\right] \quad (3)$$

The output current of PV module is:

$$I_{PV} = N_P*I_{Ph} - N_P*I_O\left[exp\left\{\frac{q*(V_{pv}+I_{PV}\,R_S)}{N_sAkT}\right\} - 1\right] \quad (4)$$

Where Vpv = Voc, Np = 1 and Ns = 36

From Fig. 3 it can be seen that the ambient temperature increases, the power output of photovoltaic cells decline with the other conditions remain unchanged. As shown in Fig. 4, other things being constant, the emerging power from photovoltaic cells increased when the intensity of the light strengthens. In certain light intensity, there is a unique maximum output power Pm for photovoltaic cells, called maximum power point. The above analysis shows that the power output of photovoltaic cells, with uncertainty, and changes with light intensity and ambient temperature. Based on this end, PV arrays must maximize the adoption of control tracking Power Point, in different environmental conditions in order to achieve the maximum output power (Qin, L., et al, 2012).

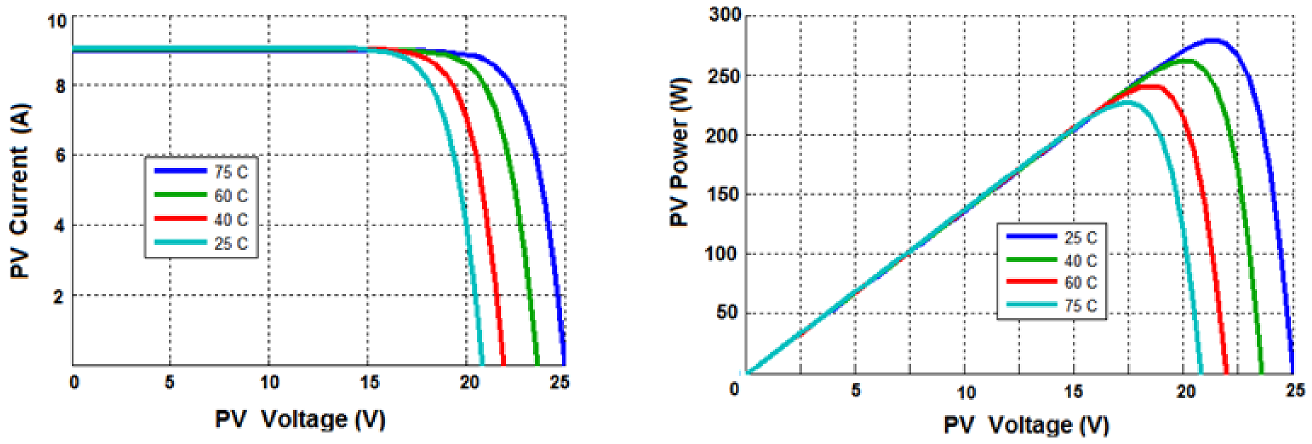

Figure 3: Output – I-V and P-V-characteristics with various temperature and constant irradiations

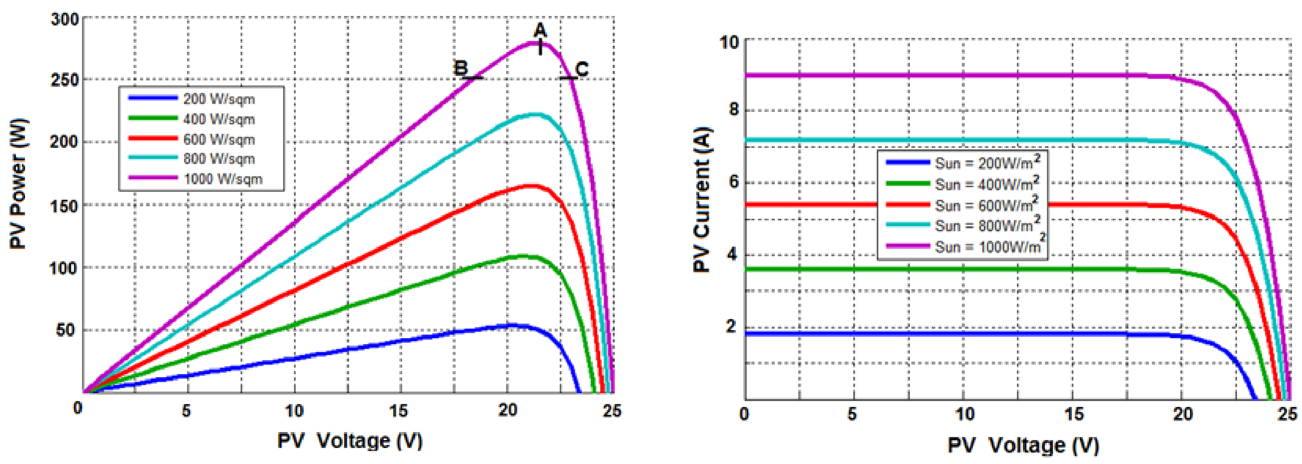

Figure 4: Output – I-V and P-V-characteristics with various irradiations and constant temperature

Maximum Power Point Tracking (MPPT) is an electronic system that controls the Photovoltaic (PV) modules in a way that allows the module to generate all the power they can produce. Photovoltaic cell has a single point of operating at which the values of the current (I) and voltage (V) cells results in maximum power output. It is a challenge to control the PV array maximum power consistent on this point that many algorithms have been developed.

Among these methods, the perturb and observe (P & O) and incremental conductance methods are widely used even though they have some problems, as the oscillation around the MPP and confusion in rapid change in the weather. In general, these approaches monitoring using a fixed iteration step, which is determined in accordance with the requirement of accuracy and speed of tracking (Gomathy, S., et al, 2012). Observing Fig. 4, for a particular level of solar radiation (for example, 1000 watts / m2), the point A is the maximum power point (MPP). At this point, it produces an equation:

$$\frac{dP}{dV} = 0 \qquad (5)$$

When the process is changed to point B, or C, is expressed in equations (6) and (7) respectively.

$$\frac{dP}{dV} > 0 \qquad (6)$$

$$\frac{dP}{dV} < 0 \qquad (7)$$

The purpose of MPPT technique is to track the maximum operating point (point A).

Boost Converter

A boost converter comprises an inductor, switch, diode and capacitor, as shown in Fig. 5.Two modes can be divided scheme of boost converter. Frist mode starts when the switch SW is turned on. The input current that rises flowing through the inductor L and switch SW. In this mode, the energy is stored in the inductor. Second mode begins when the switch is off. Current flowing through the switch should now flows through inductor L, diode D, capacitor C and load R. Inductor current falls until it is switched on again in the next cycle. Energy accumulated in the inductor is transferred to the load (Alsadi, S. et al, 2012).Thus, the output voltage higher than the input voltage, as in the equation (8).

$$V_{out} = \frac{1}{(1-D)} * V_{in} \quad (8)$$

Where V out is the output voltage, D is the duty cycle, and Vin is the input voltage, which in this case would voltage solar panel.

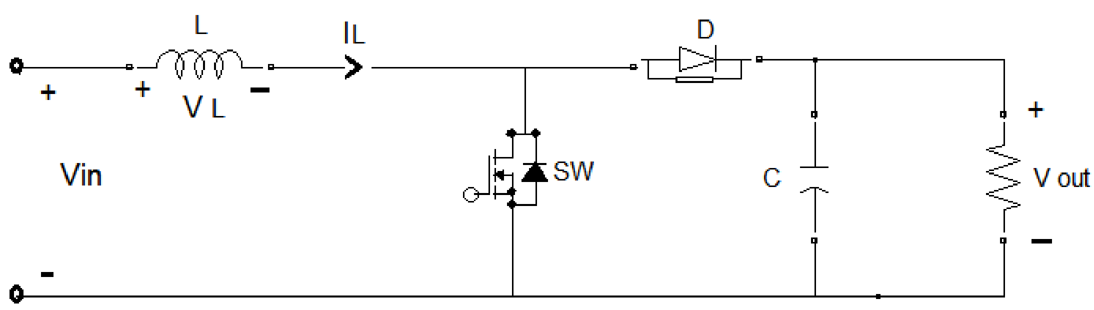

Figure 5: Boost converter

PV Inverters

PV inverters have a technological design, historically; however, PV inverters have been designed for deployment in the distribution system, where applicable interconnection standards (IEEE 1547) do not currently allow for voltage regulation. Inverters for that application are designed to operate at unity power factor, and are sold with a kilowatt (kW) rating, as opposed to a kilovolt-ampere (kVA) rating. With the increased use of PV inverters on the transmission network, the industry is moving towards the ability to provide reactive power capability. Some PV inverters have the capability to absorb or inject reactive power, if needed, provided that current and terminal voltage ratings are not exceeded. Considering that inverter cost is related to current rating, provision of reactive power at "full output" means that the inverter needs to be larger for the same plant MW rating (Ellis, A et al,2012).

By transformation abc to dq0 on a set of three-phase signals. It computes the direct axis Vd, quadratic axis Vq, and zero sequence V0 quantities in a two axis rotating reference frame according to the following transformation:

$$V_d = {}^2/_3\,(V_a \sin(wt) + V_b \sin(wt - 2\pi/3) + V_c \sin(wt + 2\pi/3)) \quad (9)$$

$$V_q = {}^2/_3\,(V_a \cos(wt) + V_b \cos(wt - 2\pi/3) + V_c \cos(wt + 2\pi/3)) \quad (10)$$

$$V_o = {}^1/_3\,(V_a + V_b + V_c) \quad (11)$$

Where w is the rotation speed of the reference frame (rad/s).

The transformation is the same for the case of a three-phase current; and we can easily alter the Va , Vb ,Vc, Vd, Vq and Vo variables with the Ia, Ib, Ic, Id, Iq, and Io variables.

Synchronous generators

In a synchronous generator, the frequency of the output is directly related to the rotational speed of the rotor—at a given speed; the generator will always produce the same frequency. Synchronous generators are commonly used in isolated mini-grids, since they do not require a supply of reactive power from the grid and can self-start with no external supply of reactive power. Synchronous generators have an advantage over induction generators in that a synchronous generator's AVR can directly control power factor by supplying reactive power to the grid if needed, providing additional voltage support. The standard model of the diesel generator and speed governor is illustrated in block diagram form. This model is widely used and describes well the dynamic behavior of small diesel-generator sets, as it has been shown in Fig.6. The diesel engine and the valve actuator servomechanism are represented by first-order lags, with time constants Td and Tsm , respectively. Parameters of the speed governor are the droop R and the integral Control gain Ki. The objective of the integral control is to eliminate the steady-state frequency error and in many cases (particularly in small and older units) may be absent. The actuator position limiter is ignored in the frequency domain analysis, where linearized models are used. Input to the model is the load demand PL , i.e., the output power of the electrical generator.

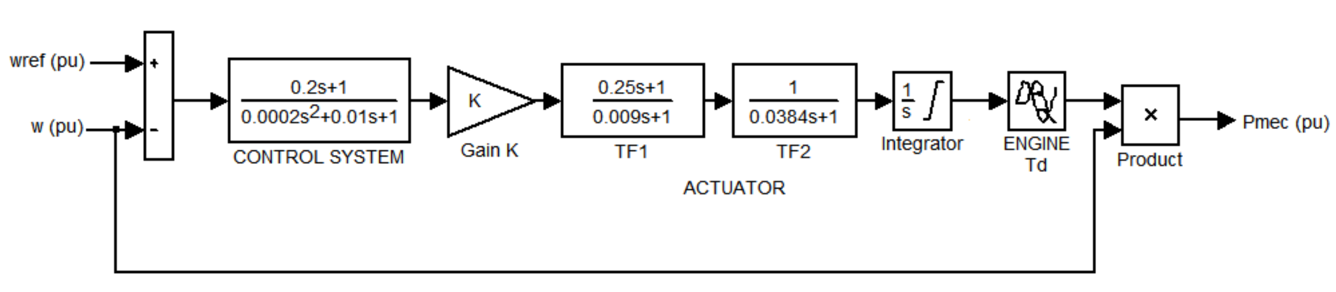

Figure 6: Diesel Engine and Governor System

SIMULATION AND RESULT

Model presented in this work uses a 400 V, 300 kVA synchronous machine, a 75 kW with 3kVar customer load and a variable secondary load (0 to 446.25 kW) as shown in Fig. 7. At decline the output power of photovoltaic cells both the synchronous condenser and the diesel-driven synchronous generator are required to feed the load. The PV voltage source feeds a 300V, through a DC-AC converter, when the PV solar power exceeds the load demand; it is possible to shut down the diesel generator or photovoltaic cells. In this all-PV mode, the synchronous machine is used as a synchronous condenser and its excitation system controls the grid voltage at its nominal value. A secondary load bank is used to regulate the system frequency by absorbing the PV solar power exceeding consumer demand. Table 1shows the parameters of the system.

Table 1: Parameters of the system

Parameters of PV Solar	
Open circuit voltage (VOC)	66 V
Short circuit current (ISC)	25.44 A
Rated Power	530.5W
Voltage at Maximum power (Vmp)	54.2 V
Current at Maximum power (Imp)	23.25 A
Total number of cells in parallel (Np)	1
Total number of cells in series (Ns)	36
Module operating temperature (TaK)	30 to 70C
Module reference temperature (TrK)	25C
Insolation/ Irradiation – (G / 1000)	1 kW/ m2 = 1
Parameters of Inverter PV Solar	
Snubber resistance	5000 Ω
Filter	0.5H / 216e-6 F/0.02H
Carrier frequency	2000Hz
Maximum dc input voltage	800V
Parameters of diesel generator	
Nominal power	300KW
line-to-line voltage	400V
Frequency	60Hz
Stator resistance Rs (pu)	0.0036 (pu)
Inertia coefficient	1.07 H(s)
pole pairs	2

The Secondary Load consists of eight sets of three-phase resistors connected in series with GTO thyristor switches. The nominal power of each set follows a binary progression so that the load can be varied from 0 to 446.25 kW by steps of 1.75kW.

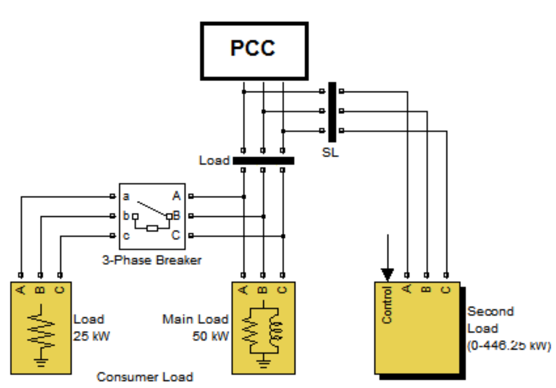

Figure7: Main and secondary load connected to PCC

The frequency is controlled from Phase Locked Loop (PLL) system which is connection between PV and synchronous machine (diesel generator) by inverter to measure the system frequency as shown in Fig.8. The measured frequency is compared to the reference frequency (60 Hz) to obtain the frequency error. This error is integrated to obtain the phase error. The phase error is then used by a Proportional-Differential (PD) controller to produce an output signal representing the required secondary load power. This signal is converted to an 8-bit digital signal controlling switching of the eight three-phase secondary loads. In order to minimize voltage disturbances, switching is performed at zero crossing of voltage .Fig. 9 illustrates the terminal voltage of PV unit during isolated.

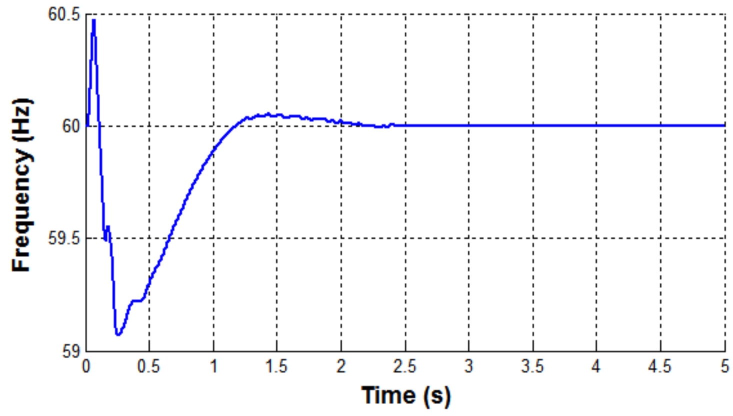

Figure 8: Frequency measured at synchronous machine

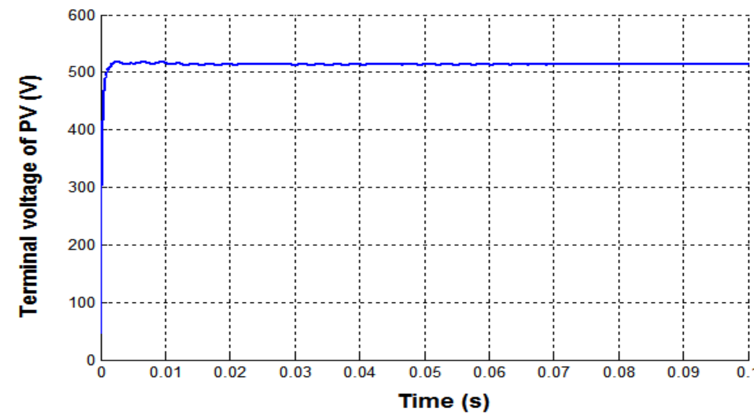

Figure 9: Terminal voltage of PV unit during isolated.

Fig. 10 describe the Power of diesel generator during the simulation and Fig. 11 shows the Power of main load for the system .Fig. 12 depicts the waveform of the load bus voltage .

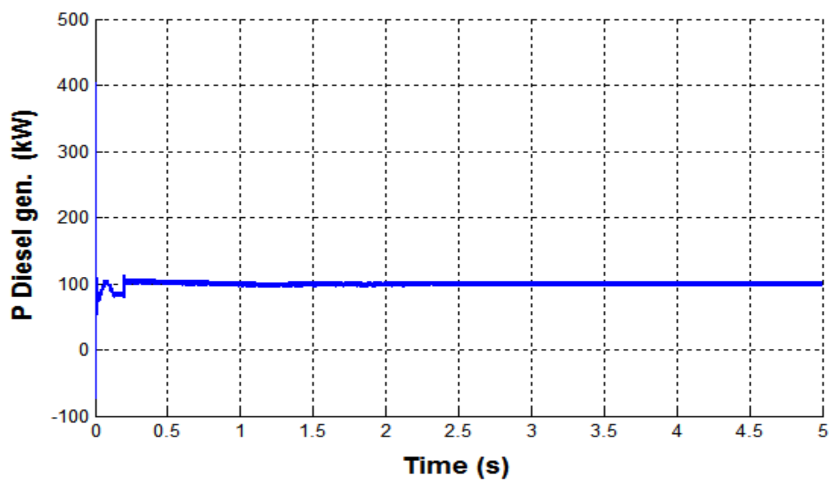

Figure 10:Power of diesel generator

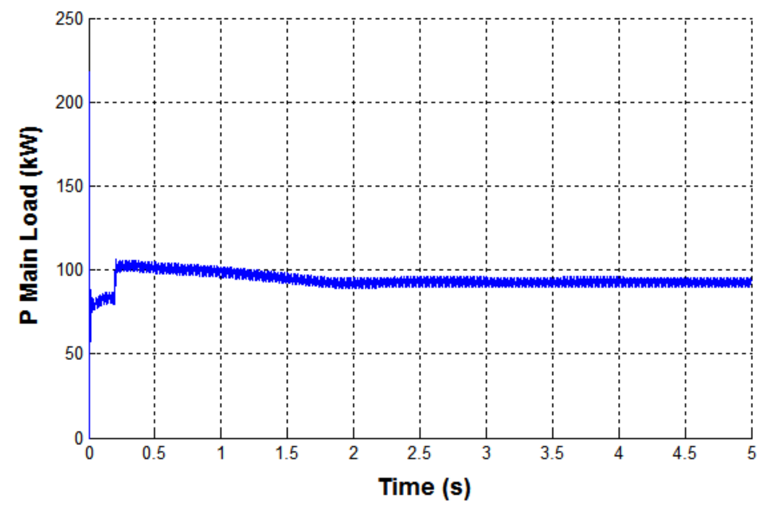

Figure 11: Power of main load

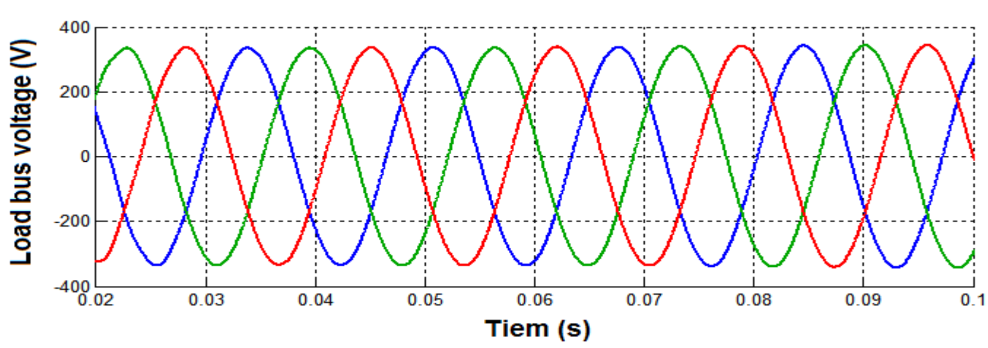

Figure12 : The load bus voltage

CONCLUSION

The power controller is designed to operate the diesel generator in an economical way to reduce the fuel consumption and total cost of the generation, which can be observed from the simulation results using Matlab/simulink. As the PV solar output depends on irradiations and temperature which varies time to time, a diesel generator with automatic power controller is coupled to the system to make the power output of the system more reliable. An MPPT controller is used to extract the optimal photovoltaic power; a current and a dc link voltage regulator are used to transfer the photovoltaic power and to synchronize the output inverter with the diesel generator in system. The simulated model and the results, obtained for standard operating conditions, are shown the performances of the diesel generator connected photovoltaic.

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