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Power Management of Solar-Fuel Cell Based Grid Tied Hybrid Energy System

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Abstract- *A lot of research has been carried out to make renewable resources more efficient and easier to use. The use of photovoltaic cells and fuel cells in the last few days has been one of the greatest researches. This paper provides an implementation of photovoltaic energy system with fuel cell for energy supply in the utility grid. For controlling the energy of both sources a control method is also proposed in this paper. This technique can be applied in the future for independent renewable energy integration. In this proposed work hybrid power system, consisting of a PV cell and the Proton Exchange Membrane Fuel Cell (PEMFC), is the most efficient combination of renewable energy sources. The whole work is simulated in MATLAB/SIMULINK environment to validate the mode. The result is discussed with variable loading condition in this paper.*

***Keywords*:-** PV, FC, Wind Energy, RES, HES EMS.

Introduction

Since the beginning of the last century, fossil fuel has been and still is the main energy source to meet the world's increased energy demand. The improved quality of life is pushing the world's energy consumption year after year. As a result of extensive fossil fuel consumption, millions of tones of pollutant gases have been released into the atmosphere, which is believed to be the main cause of global warming [1]. There is growing high pressure on governments around the world to meet future energy demand and to reduce CO_2 emissions at the same time. During the years 2007 and 2008, oil prices hit their highest ever since the Second World War. The world realized that oil is no longer a cheap energy source. Besides the sudden increase in oil prices, more scientific evidence has pointed out that burning fossil fuel is the main reason behind global warming and climate changes. The reasons above and the expected growth of the world's energy demands have put world leaders under heavy pressure to invest and investigate new sustainable sources of energy, to reduce CO_2 emissions and to close the gap of the predicated increases in future energy demand.

Despite the recession the world economy went through during 2008, it is estimated that the world's energy consumption will grow up by about 49% from 2007 until the year 2035, with an average increase of 1.4 % per year [2]. However, energy demand in fast growing economy countries like China and India is expected to grow dramatically in the next two decades. Both countries were consuming about 10% of the world's energy consumptionin 1990, but their consumption had jumped to 20% by the year 2007. By 2035 it is predicted that about 30% of the overall world energy consumption will be shared between China and India [2]. For example, car ownership increased in 2007 in China and India by 37% and 17% respectively [3]. On the other hand, the US share in world energy consumption will drop from 21% in 2007 to 16% by the year 2035. This is due to high improvement in building and equipment efficiency [2].

The other problem with oil supply is the increasing gap between oil predicted future demand and expected new discovery. Figure 3 shows the actual oil discoveries in grey bars and oil consumption in dotted black lines for the period from 1930 to 2008. As a result of the first oil crisis, consumption hit a peak in 1979. For the following five years the world's consumption decreased owing to the world economy slow down and the introduction of more efficient transport vehicles. This includestheworld'slargestoilfield, Ghawar, discovered in Saudi Arabia in 1948 and Burgan Kuwait's big oil field discovered the late 30s. It is important to note that oil discovery was far greater than oil consumption until 1984; since then, oil consumption has been exceeding discoveries. In the future the already existing large gap between new oil discoveries and predicted production demand will continue to increase. The future projected growth demand is shown in red. The yellow bars are the estimated future oil discoveries [3].

In this paper discuss the new type of generation system based on the combination of PV cell and Fuel cell. In the next section discuss the literature based on the hybrid energy system which is used in generation of energy with utility grid. Further discuss the simulation of the proposed work with the utility grid.

II. Background of Work

A hybrid energy system, or hybrid power, usually consists of two or more renewable energy sources used together to provide increased system efficiency as well as greater balance in energy supply.[1]. Completely Renewable Hybrid Power Plant (solar, wind, biomass, hydrogen) is a hybrid power plant consisting of all four renewable energy sources which can be made into operation by proper utilization of these resources in a completely controlled manner. In Europe introduce hybridizing HVDC transmission with Marine hydro pumped Energy Storage via ellipse. A hybrid energy system, or hybrid power, usually consists of two or more renewable energy sources used together to provide increased system efficiency as well as greater balance in energy supply.

In [5] reviewed the research on the unit sizing, optimization, energy management and modelling of the hybrid renewable energy system components. In [6] reviewed the different software tools in the field of hybrid energy system. The research work related to hybrid systems carried out using this software at different locations worldwide is also reviewed. Investigation based on the feasibility of different power generation configurations comprising solar array, wind turbine and diesel generator in different locations within the geo-political zones of Nigeria is discussed in [7]. A hybrid energy storage system (HESS), which combines battery for long-term energy management and super capacitor for fast dynamic power regulation, is proposed for remote area renewable energy power supply systems in [8]. In [9] compare PSO (Particle Swarm Optimisation) to HOMER for the simultaneous optimization of size and PMS (Power Management Strategy) in stand-alone hybrid energy systems. A comprehensive review of the research work carried out in planning, configurations, and modelling and optimization techniques of hybrid renewable energy systems for off grid applications is presented in [10]. Paper [11] provides a detailed comparative analysis of optimal sizing of battery-only, ultra capacitor-only and battery-ultra capacitor hybrid energy storage systems (ESSs) for a plug-in electric city bus (PECB). It is shown how the configuration affects the optimal size of the ESS. Three decision variables related to the system renewable energy components: number of storage tanks, total swept area by the rotating turbine blades and total area occupied by the set of photovoltaic panels is discussed in [12].

In [13] proposed a novel energy management system (EMS) based on a rolling horizon (RH) strategy for a renewable-based Microgrid. An operational architecture for Real Time Operation (RTO) of an islanded MG is presented in [14]. The mathematical formulation of the microgrids energy management problem and its implementation in a centralized Energy Management System (EMS) for isolated microgrids is presented in [15]. Design and investigation of a decentralized energy management system for the autonomous poly-generation microgrid topology is presented in [16]. In [17] proposes a novel control strategy for coordinated operation of networked microgrids (MGs) in a distribution system. A decentralized energy management system for the coordinated operation of networked microgrids (MGs) in a

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distribution system is proposed in [18]. The development of an intelligent dynamic energy management system (I-DEMS) for a smart microgrid is discussed in [19]. In [20] proposes an energy management and control system for laboratory scale microgrid based on hybrid energy resources such as wind, solar, and battery.

III. PV Energy System

The circuit of the solar cell model, which consists of a photocurrent, diode, parallel resistor (leakage current) and a series resistor; is shown in Figure 1. According figure by the Kirchhoff's circuit laws, the photovoltaic current can be presented as follows:

$$I_{PV} = I_{gc} - I_0\left[esp^{\left(\frac{eV_d}{KFT_c}\right)} - 1\right] - \frac{V_d}{R_P} \quad [1]$$

Where, I_{PV} is photovoltaic current, I_{gc} is light Generated current, I_0 is the dark saturation current, V_d is the diode voltage, K is the Boltzmann's Constant, T_c is the cell temperature, F is cell idealizing temperature, R_P is parallel resistance.

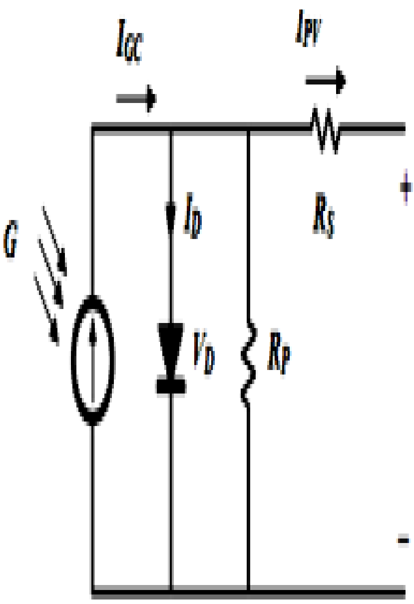

Fig. 1: Electrical Equivalent Model of PV Cell

For tracking the maximum power incremental conductance method is employed. This method is better than the conventional P& O method. The disadvantage of P&O method, of oscillation of operating point around MPP during changing environmental conditions can be reduced in INC method by comparing the instantaneous panel conductance $\left(I_{PV}/V_{PV}\right)$ with the incremental panel conductance $\left(dI_{PV}/dV_{PV}\right)$. The voltage of MPP is tracked to satisfy $\left(dP_{PV}/dV_{PV}\right) = 0$, which is MPP. INC based algorithm is advantageous over other conventional methods because it is easy to implement, high tracking speed and better efficiency.

Output power from solar panel is: $P_{PV} = PV$ array output power.

$$P_{PV} = V_{PV} I_{PV} \quad [2]$$

$$\frac{dP_{PV}}{dV_{PV}} = I_{PV} + V_{PV}\left(\frac{dI_{PV}}{dV_{PV}}\right) \quad [3]$$

From the PV curve at MPP

$$\frac{dP_{PV}}{dV_{PV}} = 0 \quad [4]$$

$$\frac{dI_{PV}}{dV_{PV}} = -\frac{I_{PV}}{V_{PV}} \quad [5]$$

If the operating point is on the right of the power curve then we have

$$\frac{dP_{PV}}{dV_{PV}} < 0 \quad [6]$$

If the operating point is on the left of the power curve then we have

$$\frac{dP_{PV}}{dV_{PV}} < 0 \quad [7]$$

In this algorithm the present and previous values of the solar panel voltage and current are sensed and are used to calculate the values of dI_{PV} and dV_{PV} .

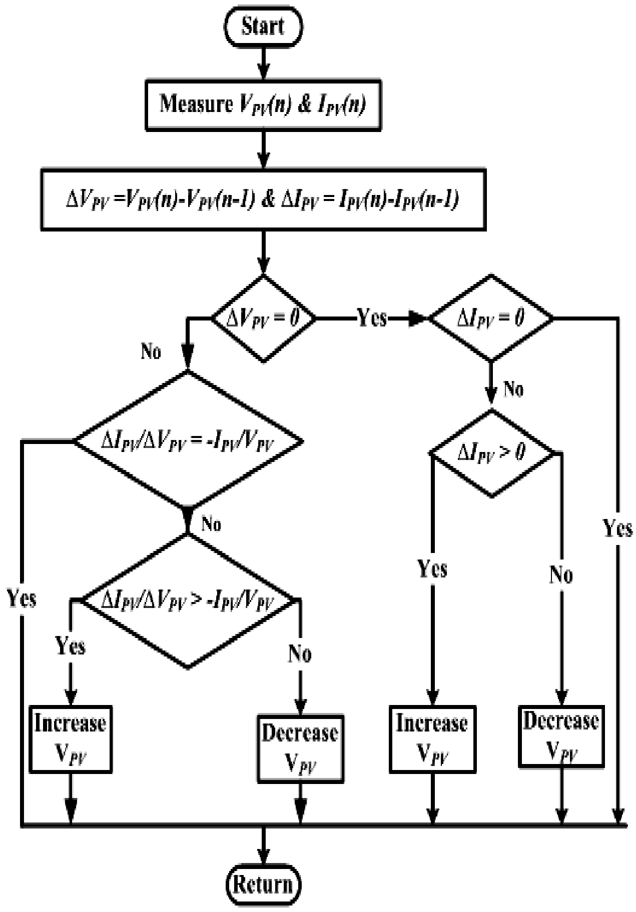

Fig 2: Incremental Conductance MPPT Algorithm.

The algorithm is as shown in Fig.2 for voltage based Incremental Conductance MPPT, similar algorithm exists for current based control where current is sensed compared and changed. From the flow chart, If $dV_{PV} = 0$ and $dI_{PV} > 0$, and amount of insolation increases, the PV power increases raising the MPP voltage. This requires the MPPT to increase the operating voltage to track the MPP. On the other hand if $dI_{PV} < 0$, decrease in insolation lowers the PV power and also lowering the MPP voltage and this requires the MPPT to decrease the PV array operating voltage. Table 1 shows the process of the proposed MPPT

Table I: INC based MPPT System

Comparison	Position on P-V curve	Change in voltage
$\frac{dI_{PV}}{dV_{PV}} < -\frac{I_{PV}}{V_{PV}}$	Right of MPP	To be decreased to move towards V_{MPP}
$\frac{dI_{PV}}{dV_{PV}} > -\frac{I_{PV}}{V_{PV}}$	Left of MPP	To be increased to move towards V_{MPP}
$\frac{dI_{PV}}{dV_{PV}} = -\frac{I_{PV}}{V_{PV}}$	at MPP	At V_{MPP}

The duty cycle of the DC/DC converter is changed accordingly which changes the PV operating voltage to track the MPP. The problem of fixed small or large steps can be resolved, if MPPT with variable step size is used, where the algorithm changes the step size automatically according to the PV array characteristics as suggested in the Variable Step Size (Modified) INC MPPT algorithm.

IV. FC Energy System

A fuel cell can be defined as a device which converts the chemical energy stored in hydrogen, or hydrogen-containing fuels, directly into electricity, plus potentially useful heat. Typically, fuel cell main components are: a fuel electrode (positive anode), an oxidant electrode (negative cathode). An electrolyte (ion-conducting membrane) is sandwiched by the anode and cathode. In general, a fuel cell operates by feeding hydrogen to the anode side and oxygen to the cathode side. At the anode side a catalyst enhances Hydrogen atoms to separate into electrons and protons. Electrons travel through the external circuit to generate electricity while Protons move through the membrane (electrolyte). At the cathode side, both electron and proton meet with Oxygen to form water (H_2O) and release heat as shown in Figure 3.

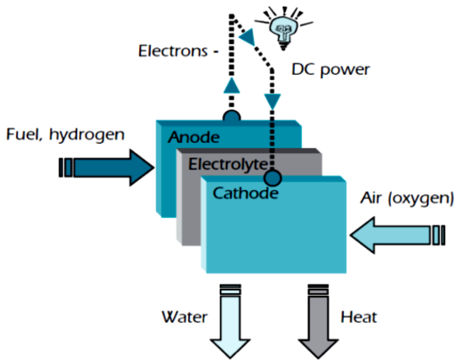

Fig. 3: Basic Component of Fuel Cell.

V. Voltage Control Strategy

Control issues related to the use of gird connected converters are mainly the control of the DC voltage and the control of the AC power. The AC power can be controlled with the aim of either feeding the main grid or feeding stand – alone loads or a microgrid. The DC voltage can be subjected to transient conditions due to change of power. DC voltage control is necessary to compensate for voltage variations during power changes. DC voltage control is achieved through the control of the power exchanged by the converter with the grid. This is achieved by injecting/absorbing power to/from the grid, thus changing the value of the reference for the AC current loop. The control of the DC voltage through the AC current can result in the identification of two loops, an outer DC voltage loop and an internal current loop. The internal loop is designed to achieve short settling times while the outer loop is designed to achieve optimum regulation and stability.

For controlling of the voltage to the gird is applied here is vector control strategy. Figure 4 shows the block diagram of vector control strategy of the proposed hybrid energy system.

In Vector Control strategy instantaneous grid voltages and currents of the three-phase a-b-c-stationary frame are measured and transformed into the two-phase α-β stationary frame by using the α-β transformation. The rotating angle, θ, of the grid voltage is obtained from the transformed voltages V_α and V_β. The angle is used as the reference angle for the transformations in order to synchronize the transformed signals with the grid voltage. The voltages and currents in the α-β can further be transformed into two DC signal components in the d-q rotating frame which rotates at the AC grid voltage frequency. As far as the control system is concerned, the grid voltage now appears as a constant DC disturbance which is much more easily compensated than the sinusoidal varying value in the stationary frame previously discussed. If the d-axis voltage is aligned with the vector of the grid voltage, the d and q- axis components account for the active power and reactive power current respectively.

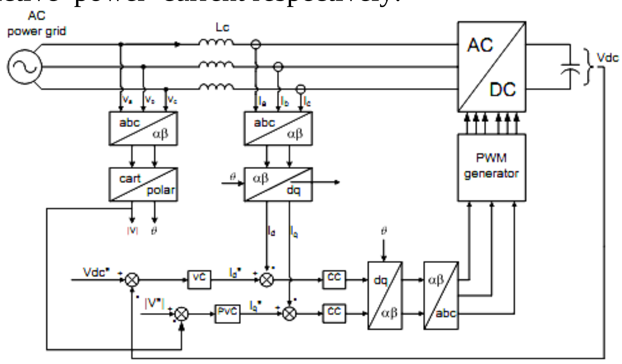

Fig. 4: Vector Control Strategy for Voltage Controller of the Proposed Hybrid System.

The DC voltage is kept constant by the DC voltage controller (V_C). The output of the DC voltage controller gives the active power reference (I_d*). The PCC (point of common coupling) voltage is kept constant by the PCC voltage controller (PVC).The output of the PCC voltage controller is the reactive power reference (I_q*). The reference demands (I_d* and I_q*) are compared with the measured and transformed currents (I_d and I_q). Two current controllers are used, one for each axis, to generate the voltage demands V_d' and V_q' which are transformed to V_a' Vb' and V_c', which are then passed to the PWM generator to produce the associated voltages at the ac terminals of the converter.

VI. Simulation and Results

Due to need of new type of energy system for reducing the price of generation here in this paper discuss the new type of hybrid energy system. Here in this work uses solar and fuel cell for generation of the electrical power. The whole hybrid energy system is coupled through the utility grid. Figure 5 shows the proposed solar and fuel cell based hybrid energy system. The whole work is simulated in MATLAB software with Simpower sim tool box. Table 1 show the parameter used in this simulation.

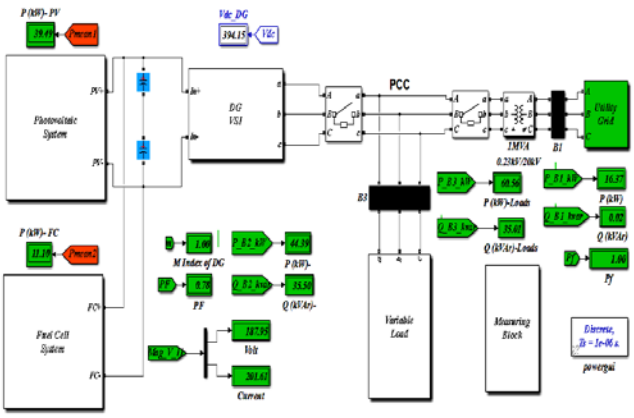

Fig. 5: SIMULINK Model of PV/Fuel Cell Based Hybrid Energy System.

Table II: Parameter used in Proposed Work.

Parameter	Value
PV Module Parameter	
Module Type	Sun Power SPR305-WHT
Number of Cell Per Module	96
Number of String	6
Number of Parallel String	18
Open Circuit Voltage (V_{oc})	64.2 V
Short Circuit Current (I_{sc})	5.96
Maximum Peak Voltage (V_{mp})	54.7
Maximum Peak Current (I_{mp})	5.58
Fuel Cell Parameter	
Voltage Rating	At 0A= 305; At 1A= 300
Nominal Operating current (I_{nom})	55A
Nominal Operating Voltage (V_{nom})	258V
Maximum Operating Current (I_{end})	85A
Maximum Operating Voltage (V_{end})	250V
Utility Grid Parameter	
Generating Station Capacity	2500MVA, 120kV,50Hz
Feeder Length	14 KM+5KM, PI Section
Load Parameter	
Load 1	Vn=230V; 50Hz; P=14.25 kW, Q= 4.68kVAr
Load 2`	V_n=230 V; 50Hz; P=28kW;Q=18.5kVAr
Load 3	V_n=230 V; 50Hz; P=18kW;Q=12.3kVAr

For running the simulation here the power time and sampling time is set as 1µ and for controller the time is set to 100µs. the whole simulation is used for ode23 discrete solver for solving the differential equations which is used for the designing of the work done in this work.

A. Grid Side Performance

Figure 6 shows the grid voltage of the proposed system. Initially grid is not connected at t=1 s it connected to the Hybrid Energy System. Figure 7 shows the current variation of the grid side bus B1. The load is connected at t=0.5s, t=1.0 s and t=1.5 s. Due to connection of load the grid current varies from 0A to 0.75 A. it's shown in the result.

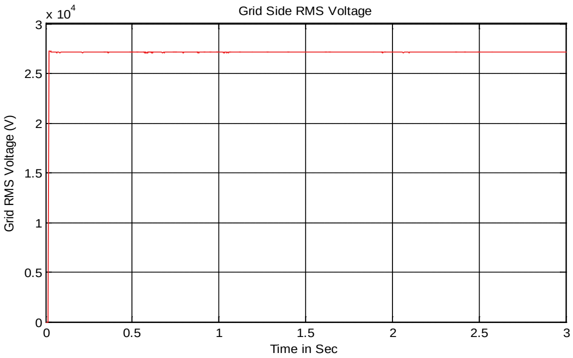

Fig. 6: Grid Side Voltage at B1.

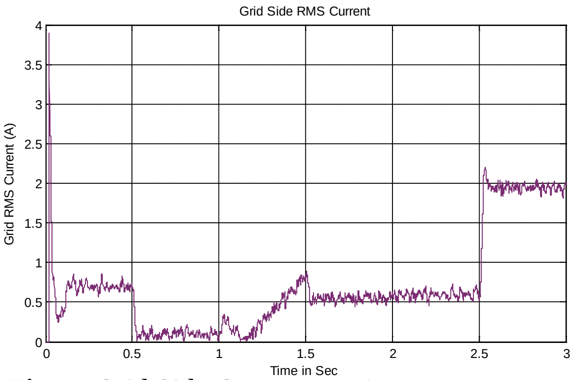

Fig. 7: Grid Side Current at B1.

Figure 8 and 9 shows the active and reactive power in the grid side at bus B1. Initially the grid is not connected so no current is passing through it so the power consumption is zero as shown in the result. At t=1 sec when grid is connected to the load the load sudden change so the power get negative and further turn to positive state as shown in figure 8 and 9. Further at t=1.5 load 3 is connected so active power get increase.

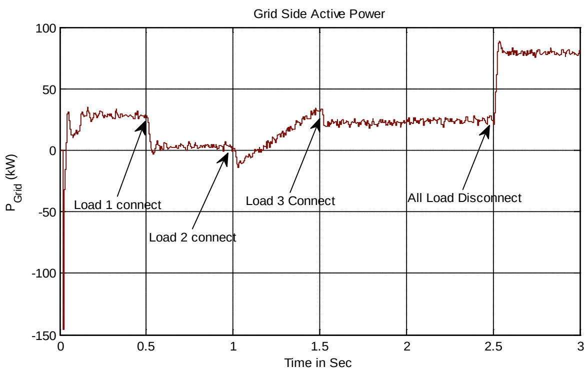

Fig. 8: Grid Side Active Power Variation.

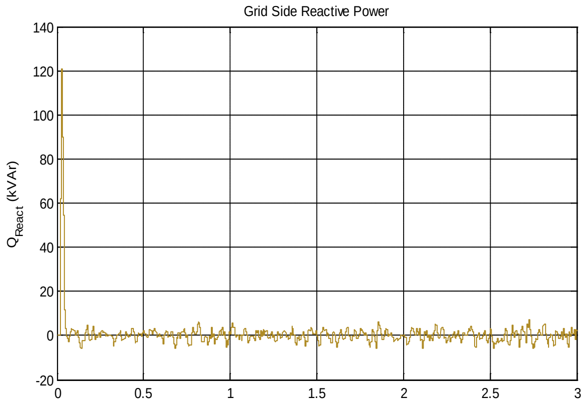

Fig. 9: Grid Side Reactive Power Variation.

B. Load Side Performance

Figure 10 shows the voltage variation at load side bus of the proposed system. Initially both solar and fuel cell works together for developing voltage at bus B3 which is shown in figure. At t=0.5 load 1 is connected so bus voltage get decreased and also produce voltage to meet the requirement of the load 230V. At t= 1both grid and load 2 is connected simultaneously. A small voltage drop is shown in the figure. This drop is due to presence of unbalanced load.

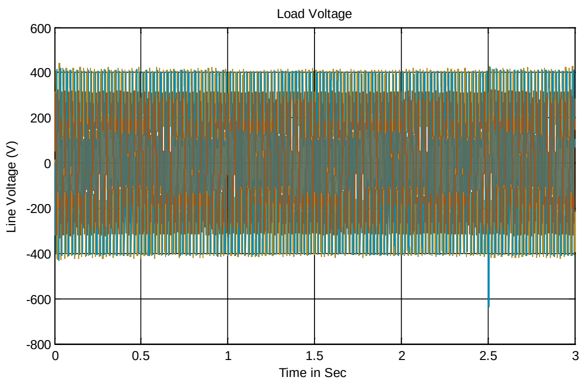

Fig. 10: Load Side Voltage Variation at bus B3.

Figure 11 shows the current variation of the bus 2. At t=0.5 load 1 is connected so current increases from 0 to 60 A. At t=1.0 second load and grid is connected is connected so now current becomes 110 A and when load 3 is connected it becomes 140A.

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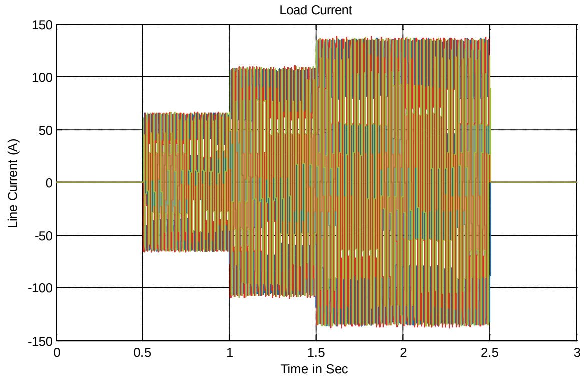

Fig. 11: Load Side Current Variation at Bus B3.

Figure 12 and 13 shows the active power and reactive power at bus B3. Initially it is clearly shown due to absence of the load the power consumption is zero. At t=0.5 when first load is connected so due to sudden change the power flow increase suddenly but the presence of the power controller is settle down in 0.1 s. At t=1.0 both load and grid connected simultaneously. The power curve gets change now.

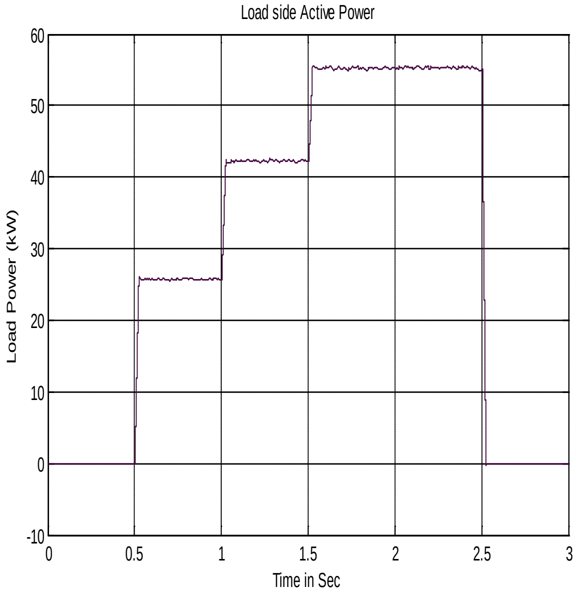

Fig. 12: Active Power Variation at Load Bus B3.

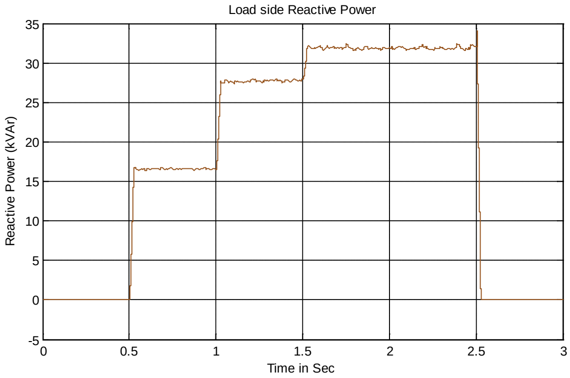

Fig. 13: Reactive Power Variation at Load Bus B3.

VII. Conclusion

Due to regular increasing in the price rate of electricity, here required to shift the generation toward new type of energy system. Hybrid energy system is the best method by which we can shift conventional generation to renewable system. So in this paper discuss the new type of hybrid energy system which is the combination of two sources solar and fuel. Also here in this paper discuss the MATLAB simulation of the proposed system with connection to utility grid. The response of the system is discussed with variable load and found system is stable.

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