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Dynamic modelling of a Sustainable Micro grid with Wind, PV and Fuel Cell Resources.

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Abstract: Power demand in commercial areas and residential areas is being increased on daily basis, so to meet the expected load, renewable energy sources like, wind and solar power generators are playing a major role in generating green power, so, micro grid provides an objective to connect and disconnect to the main grid according to the requirements, a micro grid operates on a grid mode and islanded mode, one of the drawbacks found in the micro grid operations is the sustainability of the grid during changes or disturbances in environmental conditions.The objective of this paper is to model a micro grid of 75KW using MATLAB/Simulink, and make the micro grid a sustainable one, when the load is fully dependent on the micro grid by supplying power without fluctuation. The wind and PV energy sources behaves well in different environmental conditions and extracts maximum power by incorporating a Maximum power point tracking system (MPPT), and the sustainability of the system is obtainedby connecting a fuel cell and supplying its power to the load and avoiding blackout.

Keywords: Battery management system, Fuel cells, MPPT, MI-CUK converters PV model, Three-level inverters wind energy conversion system.

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I. INTRODUCTION

Rapid growth in power demand has led to the requirement for generation of large power to supply the load, so, use of renewable energy sources have been increasing in recent days to expand the power generation and to meet the estimated load without any fluctuation in the power delivered to the load at a lower cost, Among them, the photovoltaic systems manufacturing process has been improving continuously over the last decade and photovoltaic systems have become an remarkable solution. [1]. A number of PV modules are arranged in series and parallel to meet the energy requirements. PV modules of different sizes are commercially available (generally sized from 60W to 170W). For example, a typical small scale desalination plant requires a few thousand watts of power [2].another such renewable energy source is Wind power generators, which can be used as standalone power generation system PMSG has received much attention in wind energy applications because of its self-excitation capability, leading to a high power factor and high efficiency operation[3]. To operate the WECS at an optimum power extraction point, a maximum power point tracking (MPPT) algorithm should be implemented [4]. Fuel cells are electrochemical devices that convert chemical energy in fuels into electrical energy directly, promising power generation with high efficiency and low environmental impact [5],these power sources are integrated with each other through a MI-CUK converter,the proposed multi-input power converter consists of a Cuk multi-input dc–dc converter. The incremental conductance (Inc Cond) method is mainly used to achieve the maximum power point tracking (MPPT) algorithm for input sources [6]. Solar energy produces dc power which needs to be converted into ac for further applications. Conversion of dc power to ac is done using cascaded H bridge multilevel inverter with less THD. The high power cascaded H Bridge multilevel [7]. Micro grids are independently controlled portions of an electric grid.

Distributed generation (DG) resources, called micro sources, a micro grid does not necessarily need a mains tie to operate. However, energy storage devices are necessary to provide power when there is a load change. Inverter should be analysed with respect to its output active power, reactive power and THD in output voltage.This paper deals with the modelling of a sustainable micro grid, the modelling is carried out using MATLAB/Simulink.The work of this development concentrates mainly on the sustainability of micro grid by continuously supplying the power to the load using a fuel cell and preventing the blackout.

II. POWER RESOURCES

1. SOLAR MODEL

PV panels, which are made through series or parallel connected solar cells, electrically consist of a current source, series and parallel resistances and parallel diodes. The relation between the voltage of solar battery cells and current switched on the load exposes *I-V* and *P-V* characteristics of the cell. These two characteristics give important indications regarding which conditions are required in order for the power obtained from the panel to reach its maximum level.

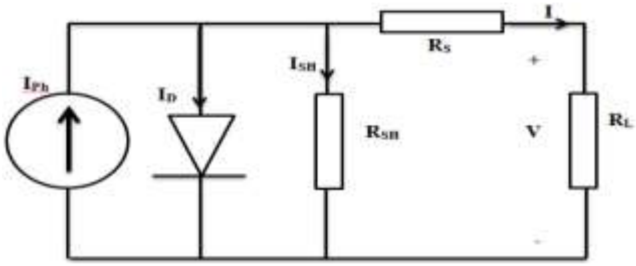

Figure1.Equivalent Circuit of PV Cell.

The output current of the PV cell.

$$I = I_{ph} - I_0 * \left(e^{\frac{q*(v+I*Rs)}{n*k*T}} - 1\right) - \frac{V+I*Rs}{R_p}$$

(1)

- I0 = saturation current of the diode
- q = charge of the electron (1.6x10-19 C)
- k = Boltzmann constant (1.38x10-23J/K)
- n = Ideality factor (from 1 to 2)
- T = Temperature (ºK)

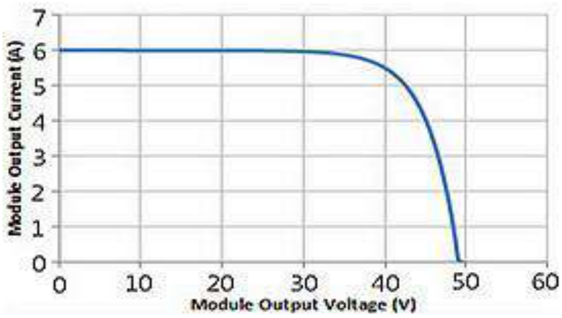

Figure 2. Voltage versus current

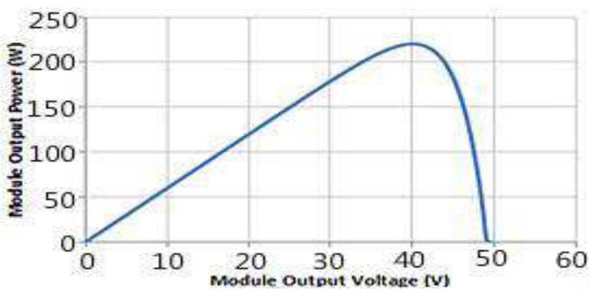

Figure 3: Voltage versus power

The above graph 2.2 shows the current voltage (I-V) characteristics of a PV cell at a normal operating conditions. The product of current and voltage gives the power generated by the solar cell, if the multiplication is done point for point, for all the voltages from short circuit to open circuit conditions, the power curve fig 2.3 is obtained for a given radiation level.

2. Wind Model

Wind energy conversion systems (WECSs) are adapted to transform wind energy into different forms of electrical energy utilizing a wind turbine. Permanent magnet synchronous generators (PMSGs) are progressively more popular due to their benefits of miniature size, high energy density, low maintenance cost, andenable control. Typical present wind turbine has one of two basic operating modes: constant or variable speed, the power developed in a wind turbine is given by,

$$Pm=(1/2)\rho ACpV^3 \quad (2)$$

Pm: the power generated by the wind turbine.
ρ: the air density (1.225 kg/m³)
A: the turbine blade sweep area (m2)
Cp: the Aerodynamic Power Coefficient.
V: the wind velocity (m/s)

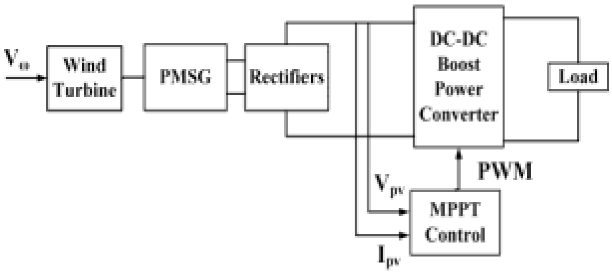

Figure 4. Wind energy system with MPPT**.**

Table 1.PMSG parameters.

Parameter	**Value**	**Unit**
Stator phase resistance	0.0485	Ω
Armature inductance	0.000395	H
Rated speed	3000	RPM
Number of poles	8	-

Table 2. Wind Turbine Parameters.

Parameter	**Value**	**Unit**
Mechanical output power	20	KW
Base wind speed	12	m/s
Maximum power at base wind speed	0.72	P.U of nominal power
Pitch angle	30	degree

4. FUEL CELLS.

A fuel cell is a device that converts directly the chemical energy stored in gaseousmolecules of fuel and oxidant into electrical energy. When the fuel is hydrogen the only byproductsare pure water and heat. The overall process is the reverse of water electrolysis. Inelectrolysis, an electric current applied to water produces hydrogen and oxygen; by reversing the process, hydrogen and oxygen are combined to produce electricity and water.

Fuel cells are classified as
1. Proton exchange membrane fuel cell
2. Phosphoric acid fuel cell.
3. Direct methanol fuel cell.
4. Alkaline fuel cell.
5. Solid oxide fuel cell.
6. Reversible fuel cell.

PEMFC technology distinguishes itself from other fuel cell technologies, in PEMFC a compact phase polymer membrane is used as the cell separator/electrolyte. Because the cell separator is a polymer film and the cell works at moderately low temperatures, problems such as sealing, assembly, and handling are less composite than most other fuel cells.

Typical cell components within a PEMFC stack include:
• The ion exchange membrane
• An electrically conductive porous backing layer
• An electro-catalyst (the electrodes) at the interface between the backing layer and the Membrane
• Cell interconnects and flow plates that deliver the fuel and oxidant to reactive sites via flow channels and electrically connect the cells.

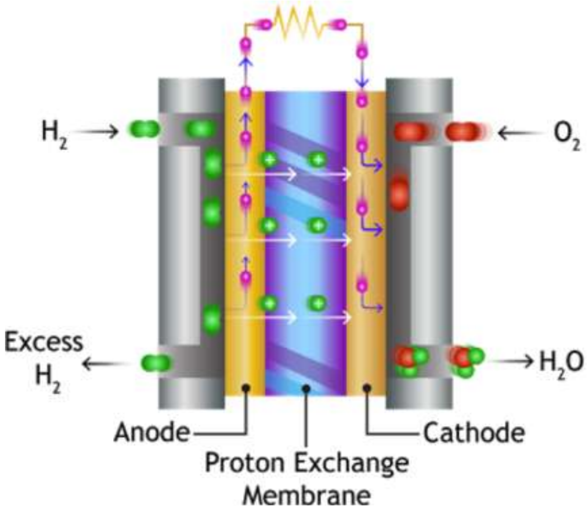

Figure 5.PEMFC Fuel cell

III. MI-CUK DC-DC CONVERTER.

In a steady state condition, the energy stored in the inductors has to remain the same at the beginning and at the end of a commutation cycle. This indicates that the current through the inductors has to be the same at the beginning and the end of the commutation cycle. As the evolution of the current through an inductor is related to the voltage across it:

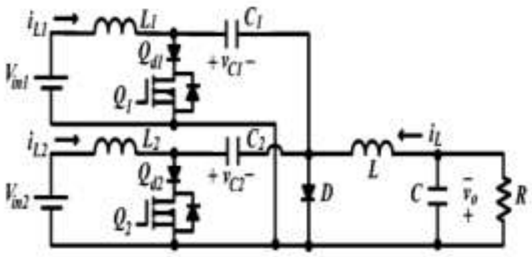

Fig 6. Basic MI-CUK converter.

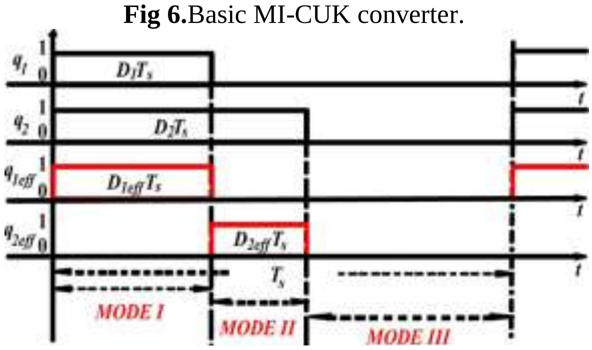

Figure 7. Switching diagram of MI-CUK converter

- ***Switching state 1 (0 < t < d1 Ts):*** At $t = 0$, switches $Q1$ and$Q2$ are turned ON and inductors $L1$ and$L2$ are charged withvoltages across $v1$ and $v2$, respectively.
- ***Switching state 2 (d1 Ts< t <d2 Ts):*** At $t = d1T$, switch $Q1$is turned OFF, while switch$Q2$ is still ON (according to the assumption $d1 < d2$). Therefore, inductor $L1$ is discharged with voltage across $v1 - vo$into the output load and the capacitor through diode $D1$, while inductor $L2$is still charged by voltage across $v2$.
- ***Switching state 3 (d2Ts< t <Ts):*** At $t = d2T$, all the switches are turned off but only the diode D conducts.

IV. MAXIMUM POWER POINT TRACKING.

According to Maximum Power Transfer theorem, the power output of a circuit is maximum when the Thevenin impedance of the circuit (source impedance) matches with the load impedance. Hence our problem of tracking the maximum power point reduces to an impedance matching problem. 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.

a) **Incremental Conductance (IC) Method.**

The principle of the Incremental Conductance (IC) Method is based on the property of the MPP: the derivative of the power is null, as in (6.1). So, the IC method uses an iterative algorithm based on the evolution of the derivative of conductance G, as in (6.2). Where the conductance is the *I/V* ratio.

$$\frac{dP}{dV} = 0, \quad with \quad P = V \cdot I \qquad (3)$$

$$\frac{dP}{dV} = V \cdot \frac{dI}{dV} + I\frac{dV}{dV} = 0, \ Thus: \ \frac{dI}{dV} + \frac{I}{V} = 0 \ \rightarrow dG + G = 0 \qquad (4)$$

This method (IC) has been improved, because when the voltage is constant, dG is not defined. So, a solution is to mix the CV method with the IC method. It is known as the Two-Method MPPT Control (or IC). Figure 8 shows the Two-Method MPPT Control algorithm and the code of the MATLAB embedded function.

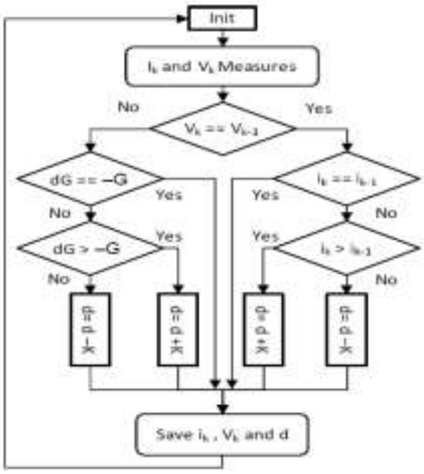

Fig 8. Flowchart of Incremental conductance method.

V. ENERGY STORAGE SYSTEM (ESS).

Energy storage has been the most challenging and complex issue of the industry whether it is the electric utilities or for industrial applications. Energy storage can balance the fluctuations in supply and meet the ever growing demand of electricity. For short duration requirements battery storage can bring about frequency control and stability and for longer duration requirements they can bring about energy management or reserves.

The graph explains that the system demand can be handled efficiently if storage is incorporated into the electrical networkAnd during the peak demand time if storage is taken into account then the demand can be supplied by the peaking plant which runs only for few hours of the day decreasing the total cost of operating such a storage incorporated system.

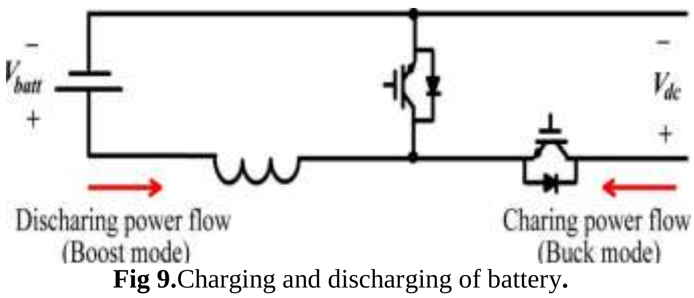

Fig 9. Charging and discharging of battery**.**

Fig 9 shows the charging and discharging of a battery. The operation of a battery in a micro grid demands dedicated operation during excessive energy is generated by the solar and wind power sources. This excess energy can be used for local usage in the power station for the electronic components like RTU units and servers. A battery of larger capacity can also be used according to our requirements.

VI. RESULTS AND DISCUSSION.

Simulation of a sustainable micro grid is carried out using MATLAB software, figure 10.shows the developed sustainable micro grid model generating 75KW of power. Simulation results and waveforms for Micro grid are shown in figures below

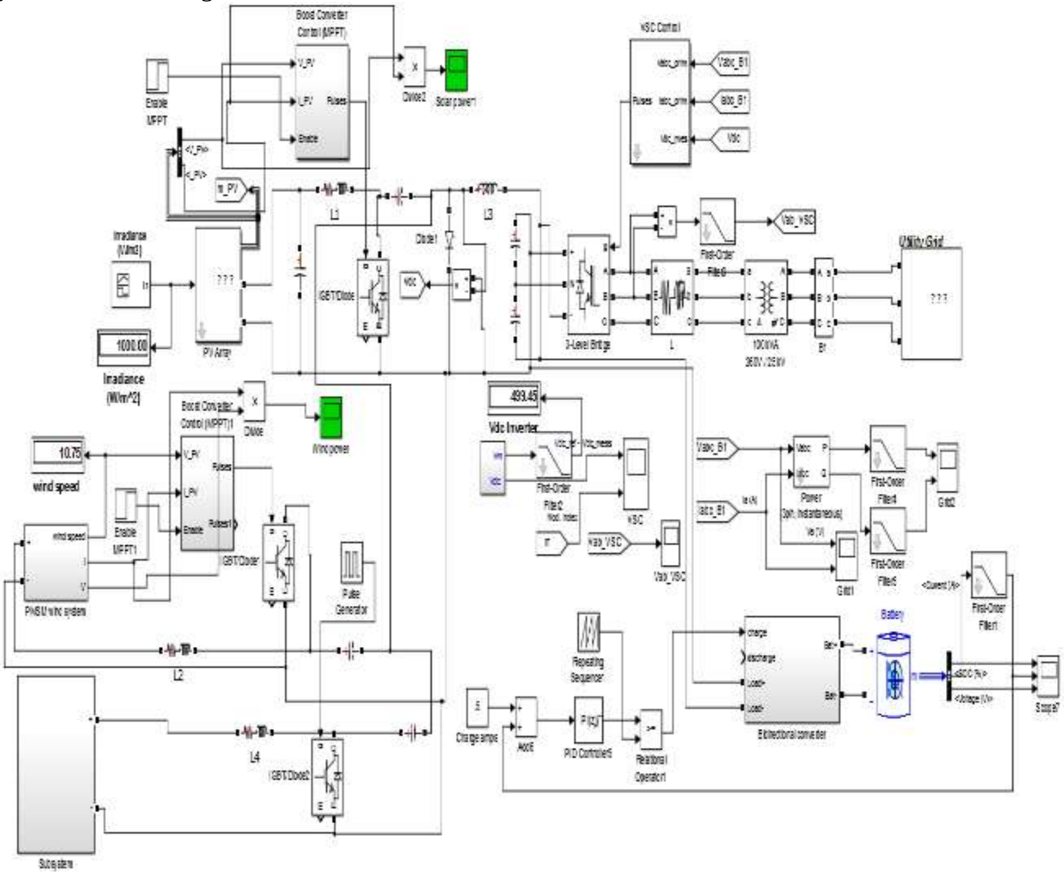

Figure 10.MATLAB model of developed sustainable 75KW micro grid.

Variations in the solar irradiance at different time intervals is considered and the input waveforms from the PV cell is as shown in figure 11.

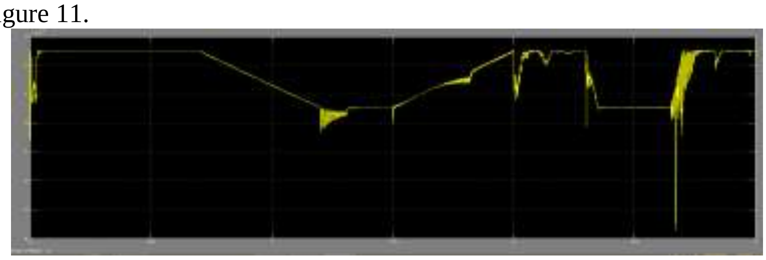

Fig 11. Input from PV Array.

Changes in the wind speed is considered and the input by the wind generator supplied to the MI-CUK converter is shown by the waveform in figure 12.

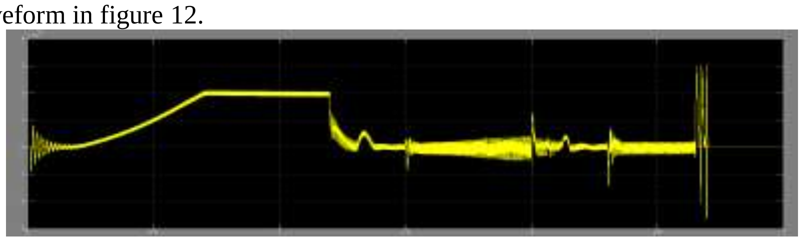

Fig 12. Input from Wind Generator.

voltages from these three power sources are integrated to eachother by MI-CUK dc-dc converter.The output of the dc-dc converter is a 500Vdcas shown below in figure 13.The dc-dc voltage is given to 3-level inverter the resulting inverterd output waveforms are as shown below in figure 14.

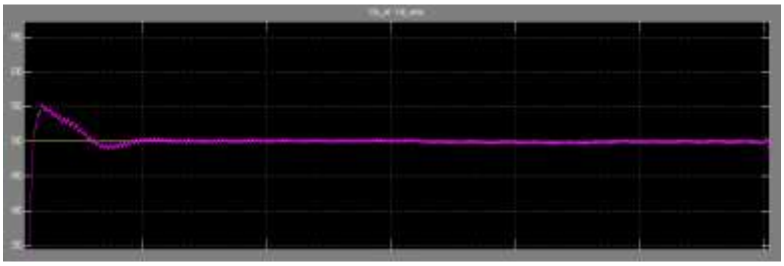

Fig: 13: DC output wave form of CUK converter.

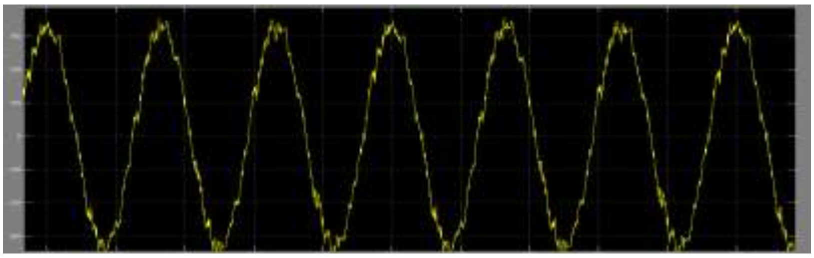

Fig 14. Inverted output waveform of 3-level inverter.

The 3 phase voltages and current waveforms are as shown in the figure 15. The voltages are equal in magnitude and it is fed to a step up 260/25KVA transformer to convert it to a higher level voltage for transmission.The presence of transformer may lead to the 2^{nd} and 5^{th} harmonics in the voltage and current wave form and this may lead to high inrush of current.

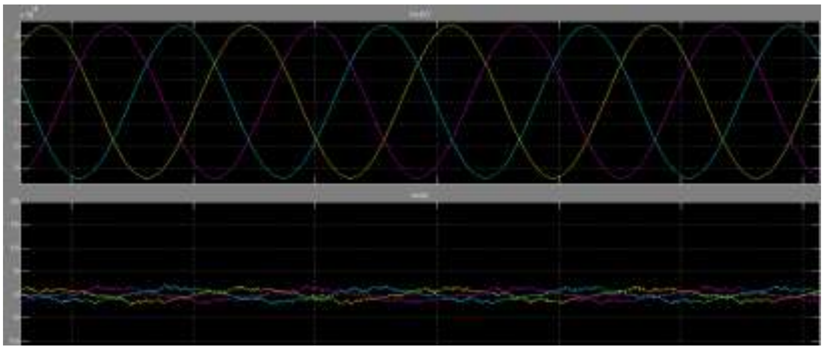

Fig 15 Voltage and current waveform supplied to grid.

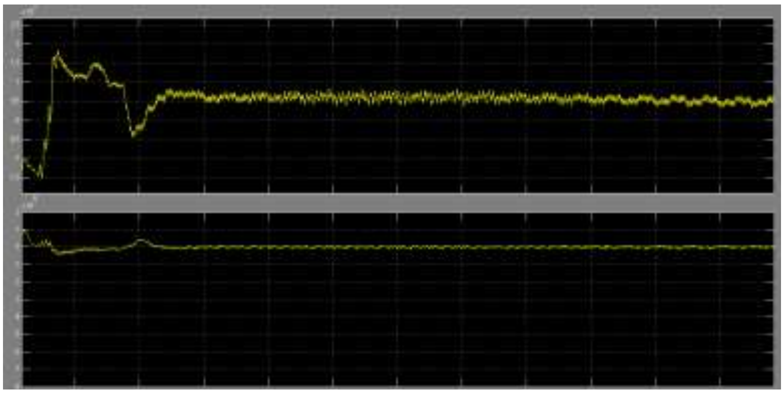

Fig 16: Real Power and reactive power generated.

From the above shown waveforms it is seen that the combined output of three power sources i.e. wind generator of 20KW, PV system 25KW and fuel cell 30KW. The output power generated is 75KW which is supplied to the load, as shown in the figure 16.

VII. CONCLUSION.

To overcome the limitations of the existing technologies in the development of a micro grid with respect to the sustainability of the system, this paper deals with the design of micro grid by using MATLAB, the micro grid modelled, generates a power of 75KW.Solar and wind power generators behaves well in different environmental conditions, maximum power is extracted from the sources by using maximum power point tracker.It is seen that the combined power generated from the three sources is 75KW.If the solar and wind energy sources do not generate power due to environmental disturbances, the fuel cell continues to supply a minimum of 30KW of power to the load irrespective of changes in the environment conditions, thus the designed model is suitable for a sustainable micro grid operation.

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