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Design and Modeling of Grid Connected Hybrid Renewable Energy Power Generation

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Abstract
This paper proposes a design and modeling of grid connected hybrid renewable energy power generation. The energy system having a photo voltaic (PV) panel, Srg wind turbine and fuel cell (sofc) for continuous power flow management. Fuel cells (storage & generating) are added to ensure uninterrupted power supply due to the discontinuous nature of solar and wind resources. Renewable energy generated during times of plenty can be stored for use during periods when sufficient electricity is not available. But storing this energy is a difficult task: batteries and similar technologies perform well over short timescales, but over periods of weeks or months a different approach is necessary. Energy storage in the form of hydrogen is one such possibility: excess electricity is fed into an electrolyser to split water into its constituent parts, oxygen and hydrogen. The hydrogen is then used in fuel cells to produce electricity when needed which will overcome the problem of storage. This work is mainly concentrated on the design, analysis and modelling of Fuel cells and Analysis and modelling of Switched Reluctance Generator (SRG) in the application of Wind Energy Generation and pv cell. Also an effective approach is proposed in this thesis to ensure renewable energy diversity and effective utilization. The pv cell, wind and fuel cell renewable energy system is digitally simulated using the MATLAB/SIMULINK software environment and fully validated for efficient energy utilizations and enhanced interface power quality under different operating conditions and load excursions

Keywords: Photovoltaic (PV) system, SRG based wind Turbine, Fuel cell, Grid

I. INTRODUCTION

Now-a-days increasing the energy consumption has become a primary concern, the soaring cost and the exhaustible nature of fossil fuel, and the worsening global interest in renewable energy sources increase of fossil fuel resources and the need of reducing CO2 emissions, grid connected renewable power systems have gained outstanding interest[1]. Energy is considered as an important mechanism in a country for the development, but in the current situation, the energy consumption is insufficient and the price is increasing [2]. The abundant energy available in nature can be harnessed and converted to electricity in a sustainable way to supply the necessary power to elevate the living standards of the people without access to the electricity grid[3]. The advantages of using renewable energy sources for generating power in remote islands are obvious such as the cost of transported fuel are Often prohibitive fossil fuel and that there is increasing concern on the issues of climate change and global warming. PV cells convert the energy from sunlight into DC electricity and wind turbine convert the energy from wind of renewable energy and fossil fuel generators together with an energy storage system and power conditioning system, is known as a hybrid power system.

Renewable energy system has an ability to provide 24-hour grid quality electricity to the load. This system offers a better efficiency, flexibility of planning and environmental benefits compared to the diesel generator stand-alone system. The operational and maintenance costs of the diesel generator can be decreased as a consequence of improving the efficiency of operation and reducing the operational time which also means less fuel usage. The system also gives the opportunity for expanding its capacity in order to cope with the increasing demand in the future. This can be done by increasing either the rated power of diesel generator, renewable generator or both of them. Financial markets are awakening to the future growth potential of renewable and other new energy technologies, and this is a likely harbinger of the economic reality of truly competitive renewable energy systems. In integrated electricity grids the load equalizes due to the large number of consumers and its statistical application. This is how base, medium and peak load are defined which are covered by dedicated base, medium and peak load power plant to minimize the electricity cost price. Base load is needed continuously 24 hours per day, medium load is required in consecutive 3 to 6 hours and peak load is required in shorter sequences. Unfortunately, this cost effective procedure cannot be transferred to Hybrid

Power Systems in most of the cases. Thus, different energy management structures have to be applied. These energy management structures vary with the size of the Hybrid Power System depending on the financially optimal system design.

Fig.1.1Shows line diagram of hybrid solar-wind-fuel cell system. It includes PV panels and/or wind turbines and/or solid oxide fuel cell. These energy systems are considered as one of the cost effective solutions to meet energy requirements of remote areas. It have developed the Hybrid Optimization by Genetic Algorithms (HOGA) program helping to determine the optimal configuration of the hybrid PV/fuel cell. presented a techno-economic analysis based on solar and wind biased months for an autonomous hybrid PV/wind energy/fuel cell system.

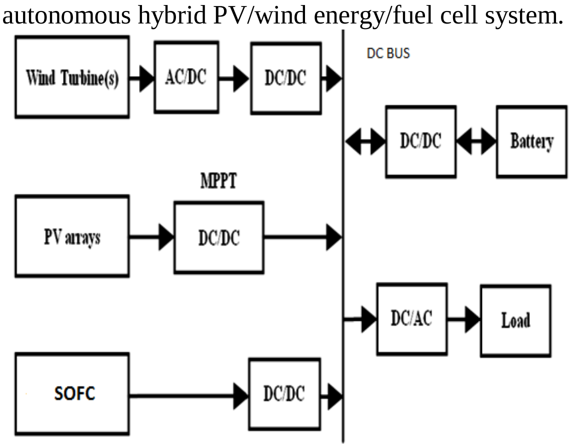

Fig.1.1 Schematic of a hybrid solar-wind-fuel cell system

Fig1.2 shows, Grid Connected Photovoltaic/Wind turbine/ Fuel cell Hybrid system. It comprises of Photovoltaic panel, Wind turbine, Fuel cell. Grid Connected Photovoltaic/Wind turbine/Fuel cell Hybrid System technology is the key for an efficient use of distributed energy sources. PV and wind turbine are being major energy source enables the dc loads and AC loads to be connected directly to the DC bus and grid. In the hybrid generator system, they are integrated and complement with each other in order to meet performance targets of the generation system and access to the most economic power generation.

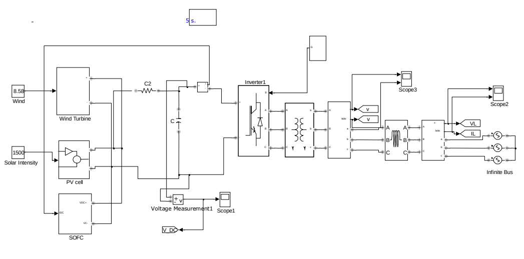

Figure 1.2 Grid Connected Photovoltaic/Wind turbine/Fuel cell Hybrid System

II. SOLID OXIDE FUEL CELL

2.1 Working of Solid Oxide Fuel cell

In principle, a fuel cell operates like a battery. By contrast, batteries store electrical energy chemically and hence represent a thermodynamically closed system. Unlike a battery however, a fuel cell does not run down or require recharging. It will produce electricity and heat as long as fuel and an oxidizer are supplied. Both batteries and fuel cells are electrochemical devices. As such, both have a positively charged anode, a negatively charged cathode and an ion-conducting material called an electrolyte [4]. Fuel cells are classified by their electrolyte material. SOFCs employ a solid state electrolyte and operate at the highest temperature (1000°C/1800°F) of all fuel cell types. The SOFC uses a solid yittra-stabilized zirconium ceramic material as the electrolyte layer. In general, the solid phase design is simpler than PAFCs or MCFCs since it requires only two phases (gas-solid) for the charge transfer reactions at the electrolyte-electrode interface. The two-phase contact simplifies the design because it eliminates corrosion and electrolyte management concerns commonly associated with the liquid electrolyte fuel cells. During operation, oxidant (usually air) enters the cathode compartment and, after the electrode reaction, oxygen ions migrate through the electrolyte layer to the anode where hydrogen is oxidized. The operating temperature of SOFCs is sufficiently high to provide the necessary heat for the endothermic reforming reaction. SOFCs, therefore, are more tolerant of fuel impurities and can operate using hydrogen and carbon monoxide fuels directly at the anode. They don't require costly external reformers or catalysts to produce hydrogen. The basic components of a typical fuel cell include two electrodes, an anode and cathode where the reactions take place. An electrolyte is sandwiched between anode and the cathode which allows the ions to cross over, while blocking the electrons. The electrolyte also allows the ions that are formed to cross-over to the other electrode, which happens because of the tendency of charged particles migrating to regions of lower electrochemical energy. The reduction reaction is carried out at the cathode where molecular oxygen reacts with the electrons supplied from external circuit to produce oxide ions. The oxygen ions migrate through the solid electrolyte to anode where they combine with the hydrogen molecule to produce water, Carbon dioxide and electrons. The electrons flow through the externally connected circuit to reach the cathode, doing electrical work and producing electrical energy in the process. Water is produced at the anode on recombination of oxygen ions and electrons with hydrogen, as opposed to PEMFCs where water is produced at the cathode. Under operation, SOFC can use either an oxygen ion-conducting electrolyte or a proton conducting electrolyte.

2.2 Mathematical model of Solid Oxide Fuel Cell

The following are the assumptions made in developing the mathematical model of fuel cell stack

- fuel cell is fed with hydrogen and oxygen
- the gases considered are ideal that is their chemical and physical properties are not correlated to the pressure
- Nernst equation is applicable
- Fuel cell temperature is stable at all times
- Electrode channels are small enough so that the pressure drop across them is negligible Without losses:

The concept of Gibbs free energy is very important in the development of a fuel cell model. The Gibbs free energy can be defined as the energy available to do the external work, neglecting any work done by changes in the pressure and or volume of the reactants and products of the fuel cell [3].

$\Delta gf = gf$ of products − gf of reactants

The reversible open circuit voltage of a fuel cell is given by

$$E = -\frac{\Delta \overline{gf}}{zF} \qquad (1)$$

With losses:

Considering the Nernst equation

$$E = E^0 + \frac{RT}{2F}\ln\left[\frac{P_{H_2}\cdot P_{O_2}^{\frac{1}{2}}}{P_{H_2O}}\right] \qquad (2)$$

When partial pressures of hydrogen, oxygen and water are considered.

The hydrogen gas might be part of a mixture of and C from a fuel reformer, together with product steam. The oxygen will nearly always be part of air. It is also often the case that the pressure on both the cathode and the anode is approximately the same – this simplifies the design.

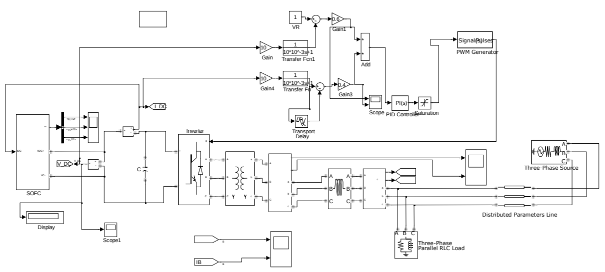

Figure 2.1 Simulink model of SOFC

III. PHOTOVOLTAIC SYSTEM

3.1 Photovoltaic module

A solar cell or photovoltaic cell is a device that converts solar energy into electricity by the photovoltaic effect. Photovoltaic is the field of technology and research related to the application of solar cells as solar energy. Sometimes the term solar cell is reserved for devices intended specifically to capture energy from sunlight, while the term photovoltaic cell is used when the source is un specified. The general mathematical model for the solar cell has been studied over the past three decades [5]. The model of PV power plant used in this study is based on the dy- namic PV model developed and validated in our previous work . The following equation model the current of the PV cell [6].

$$I_{pv} = I_{gc} - I_0\left[\exp^{\left(\frac{qV_d}{K_B F T_C}\right)} - 1\right] - \frac{V_d}{R_p} \qquad (3)$$

where *Igc* is the light generated current, *Io* is the dark saturation current dependant on the cell temperature, *q* is the electric charge (1.6 × 10–19 C), *KB* is the Boltzmann's constant, *F* is the cell idealizing factor, *Tc* is the cell's absolute temperature, *vd* is the diode voltage, and *Rp* is the parallel resistance.

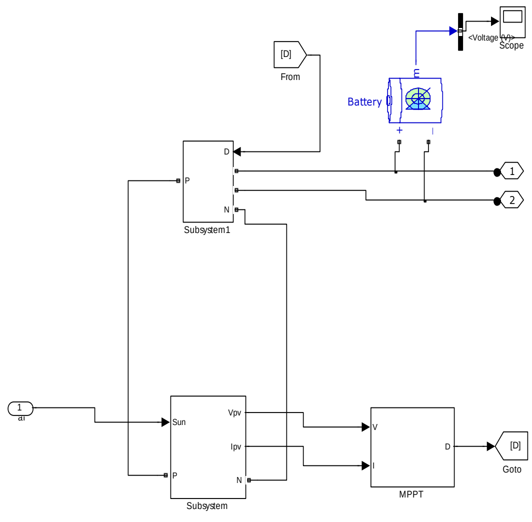

Figure 3.1 Block Diagram model of PV Panel

3.2Maximum Power Point Technique (MPPT)

Photovoltaic (PV) array under uniform irradiance exhibits a voltage-current characteristics with an unique point, called the maximum power point (MPP), where the array produces maximum output power. 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 power output of a circuit is maximum when the thevenin impedance of the circuit (source impedance) matches with the load impedance.

One significant problem in PV systems is the probable mismatch between the operating characteristics of the load and the PV array. When a PV array is directly connected to a load, the system's operating point will be at the intersection of the V-I curves of the PV array and load. Under most conditions, this operating point is not at the PV array's maximum power point (MPP). To overcome this problem, an MPPT can be used to maintain the PV array's operating point at the MPP.

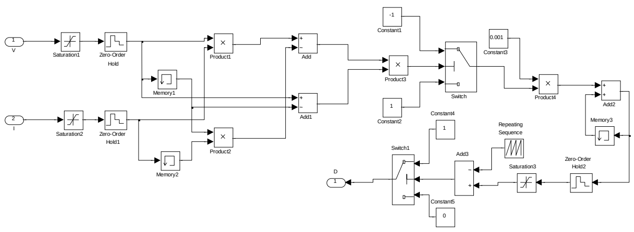

Figure 3.2.MPPT FOR PV CELL

IV. SWITCHED RELUCTANCE GENERATOR

4.1 SR Based Wind Energy Generation

Wind is a natural source of energy related to the low and medium speed range. In order to extract energy from the wind, machine that can be controlled to generate at variable speed are preferred/of advantage to ensure optimum performance. . Among the common types of machines used for wind energy are: double fed induction generator (DFIG), induction generator and also synchronous generator. The potential candidate to the group is the Switched Reluctance Generator (SRG) which comprises of SR generator, power converter and controller as shown. The doubly salient poles structure and the phase coils concentrated only in the stator poles are remarkable features of this machine. There is a minimal thermal loss in the rotor and it is easy to construct and to maintain. It does not have any windings or magnets on the rotor poles. A switched reluctance generator (SRG) belongs to the new, modern types of brushless, electronically commutated, rotating electrical machines.

The operation of the machine as a generator is by controlling the switching sequence of the power converter during the decreasing inductance profile. It is referred to as a doubly salient pole due to the salient pole of its stator and rotor structure. Salient pole refers to the structure of the element protruding from the yoke into the air gap. Rotor and stator are made of steel laminations and only the stator poles have windings concentrated around it. This leaves the rotor free from windings, magnets and brushes. The windings of one stator pole are connected in series with the opposite stator to form one phase. The windings can be arranged in such a way that more than 2 opposite stator poles can form one phase. Typical configuration of the machine includes 3 phase 6 stator or4rotor(6/4)or12/8and4phase8/6or16/12

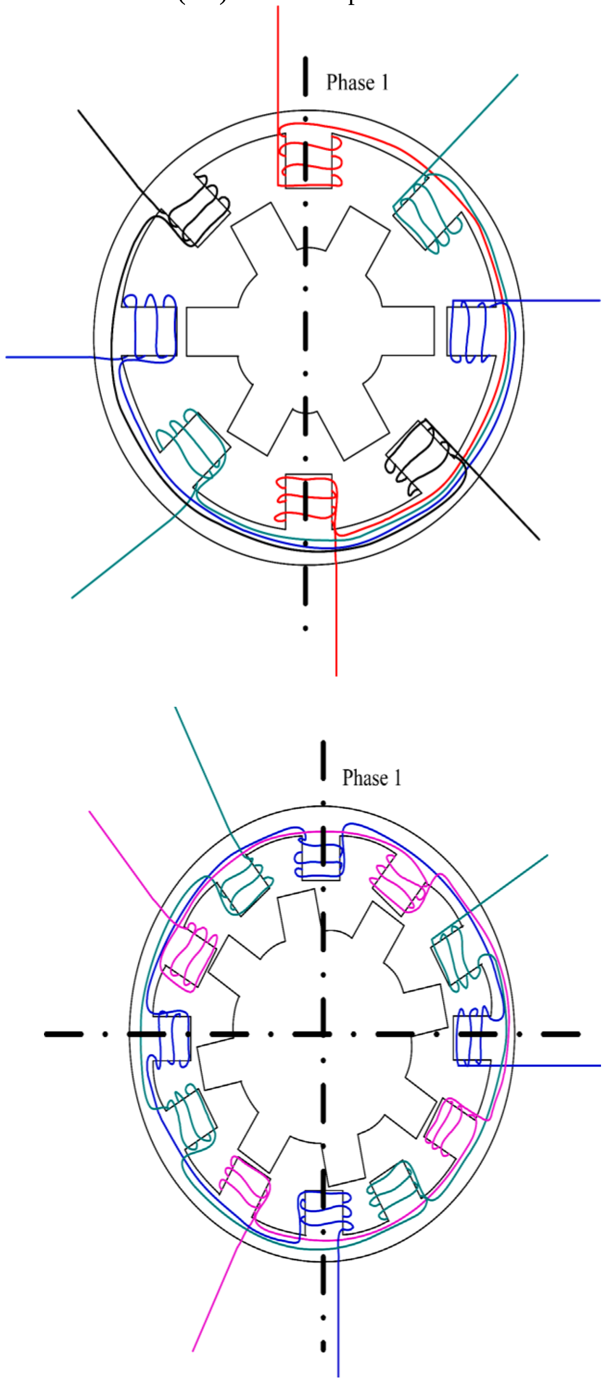

Figure 4.1. **Configuration of switched reluctance generator: (a) 4 phase 8/6 and (b) 3 phase 12/8.**

4.2 SRG Working Principle

The operation of SRG depends entirely on synchronized excitation of the set of stator windings to create continuous rotation of rotor. The movement of rotor with respect to excited stator phase varies the inductance of the machine periodically from maximum to minimum hence torque and power is produced. During the aligned position of rotor and stator, inductance is maximum and minimum during the non-aligned position. The operation of Switched Reluctance Generator (SRG) is similar to Switched Reluctance Motor (SRM). However, for SRG the excitation of stator phase must be made when rotor is moving pass the stator when inductance is decreasing as shown in Figure 6(a)(ii) and 1(b) whereas for motoring the excitation is on the increasing inductance region. Movement of rotor in an out of alignment with the stator poles creates variation of reluctance flux path[4.5]. It can be seen that this variation creates conversion of energy. Hence in every cycle the flux must be established and returned to zero before excitation of the next phase. The torque (*T*) is produced by the tendency of the rotor moving to the excited stator phase winding where minimum reluctance occurs independent of direction of current flow as shown by equation

$$T = \frac{1}{2} i^2 \frac{dL}{d\theta} \qquad (4)$$

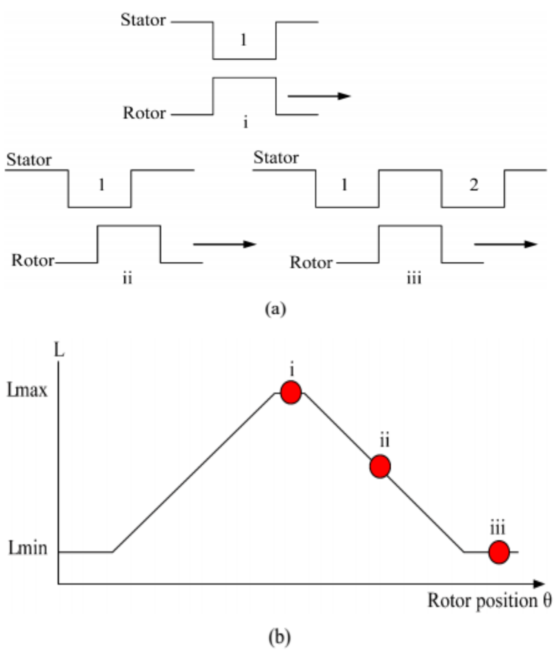

Figure 4.2. Variation of inductance with respect to movement of rotor. (a) Rotor movement with respect to stator; i) Maximum inductance, minimum reluctance (full alignment); ii) Inductance decreasing linearly; iii) Minimum inductance (mis-alignment); (b) Complete inductance profile with respect to rotor position.

4.3 Control Methods for SRG:

The heart of the SRG depends on its control strategy which is through proper switching of power electronic devices as shown in Figure. Careful placement of the firing angles must be made to ensure continuous operation of the generator as well as maximizing its efficiency. It has been mentioned that by increasing the excitation current, output power will increase as compared to increasing speed. Also the firing angles determine the area of flux linkage which corresponds to energy converted per stroke [9]. Current research shows that the output power and voltage depend on angular speed and excitation voltage. By adjusting the excitation voltage the out-put power can be controlled. This shows the importance of firing angles on output power. Due to its inherent characteristics such as nonlinearity its optimal control is difficult to achieve. The main reason is because there are various combinations of firing angles that would produce the same amount of output power. This implies that its efficiency, torque ripple and dc link current are also different according to the various angle combi-nations.

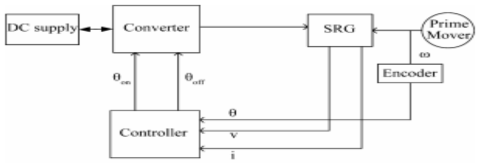

Figure4.3. Basic control model for SRG

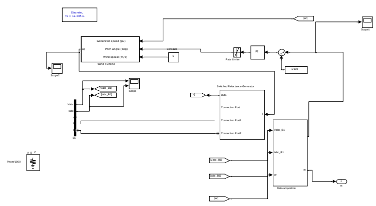

Fig 4.4. Simulink model of SRG based wind turbine

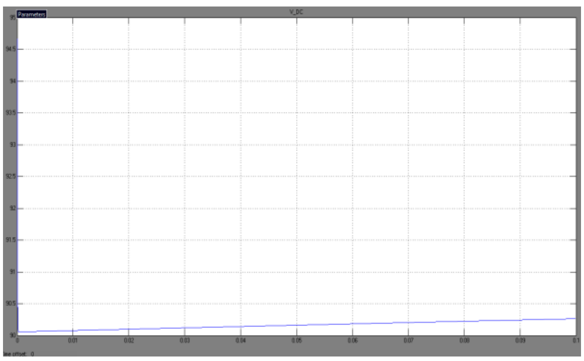

Fig.5 DC voltage vs time simulation output characteristics' for an sofc using 100 cells in series

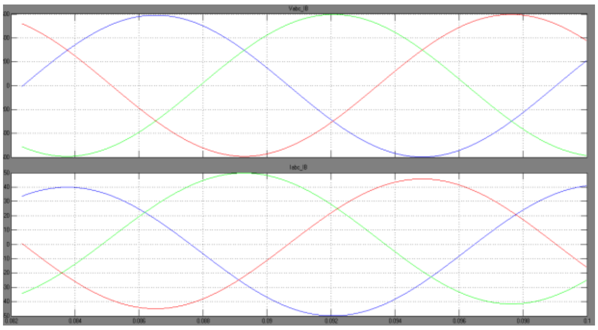

Fig.6Fuel cell AC voltage vs time and current vs time output characteristics after inversion

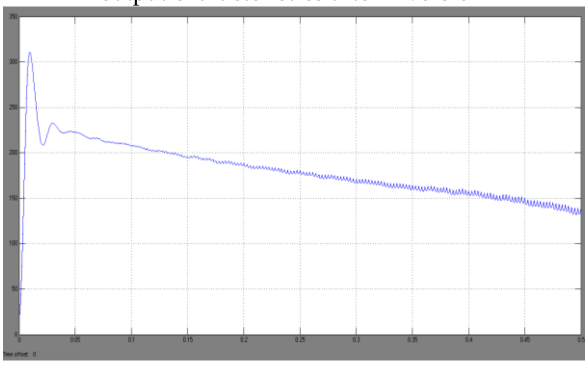

Fig.7 Hybrid Power System DC output voltage

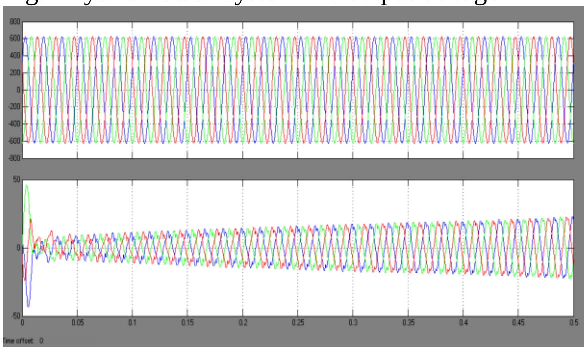

Fig.8Hybrid AC voltage vs time and current vs time output characteristics' after inversion

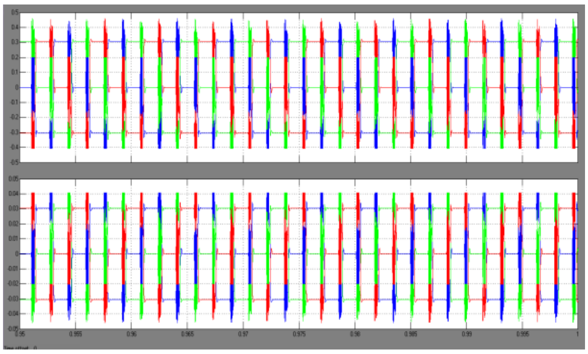

Fig.9 output voltage and current of srg based wind turbine

V. CONCLUSION

Hybrid systems are the right solution for a clean energy production and hybridizing solar and wind power sources provide a realistic form of power generation. In this proposed system, Grid Connected Photovoltaic/Wind turbine/Fuel cell(sofc) generator hybrid system can be used to *supply* continuous power to the AC/DC loads. Solar panels and wind turbine are the Main energy sources of the proposed grid connected system. Diesel generators are the auxiliary energy sources of the proposed grid connected system. Solar power generation and Wind power generation are the independent power generation can effectively solve the problem without electricity in the power demand conditions. The power management developed helps integration of PV power and Wind power in to the gird as peak loads are shaved. The analysis and modelling of Fuel Cells and Analysis and modelling of Switched Reluctance Generator (SRG) in the application of Wind Energy Generation and pv cell obtained. The results are good for the future improvements in the integrated systems. The SRG is used for the Wind energy generator which is having a very good control for the low speed applications in power generation. Also an effective approach is proposed in this paper to ensure renewable energy diversity and effective utilization.

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