Performance analysis of Micro-Grid fed by Renewable Energy Sources with fuzzy logic controller

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Abstract

This paper presents a fuzzy logic control of a micro-grid at an isolated location fed from wind and solar based hybrid energy sources. The machine used for wind energy conversion is doubly fed induction generator (DFIG) and a battery bank is connected to a common DC bus of them. A solar photovoltaic (PV) array is used to convert solar power, which is evacuated at the common DC bus of DFIG using a DC-DC boost converter in a cost effective way. The voltage and frequency are controlled through an indirect vector control of the line side converter, which is incorporated with droop characteristics. It alters the frequency set point based on the energy level of the battery, which slows down over charging or discharging of the battery. The system is also able to work when wind power source is unavailable. Both wind and solar energy blocks, have maximum power point tracking (MPPT) in their control algorithm. The system is designed for complete automatic operation taking consideration of all the practical conditions. The system is also provided with a provision of external power support for the battery charging without any additional requirement. A simulation model of system is developed in Matlab environment and simulation results are presented for various conditions e.g. unviability of wind or solar energies, unbalanced and nonlinear loads, low state of charge of the battery.

I. INTRODUCTION

There are many remote locations in the world, which don't have access to electricity. There are also many places, which are connected to the grid, however, they don't receive electricity for up to 10-12 hours in the day and as a result of it, economic activities of inhabitants suffer. Many of such places are rich in renewable energy (RE) sources such as wind, solar and bio-mass. An autonomous generation system utilising locally available RE sources, can greatly reduce the dependency on the grid power, which is predominantly fossil power. Wind and solar energy sources, are more favorite than bio-mass based system as latter is susceptible to supply chain issue. However, wind and solar energies suffer from high level of power variability, low capacity utilization factor combined with unpredictable nature. As a result of these factors, firm power cannot be guaranteed for autonomous system. While the battery energy storage (BES) can be helpful of lowering power fluctuation and increasing predictability, utilisation factor can be increased by operating each energy source at optimum operating point. The optimum operating point also called as maximum power point tracking (MPPT), requires regulation of the operating point of wind energy generator and solar PV (Photovoltaic) array in term of speed and voltage to extract maximum electrical energy from input resource. The MPPT can be achieved by power electronics (PE) based control. PE based control can also help energy management for BES. Many authors have reported autonomous solar PV systems [1-2] and autonomous wind energy systems [3-4]. However, autonomous system with only one source of energy, requires very large size of storage and associated PE components. A hybrid energy system consisting of two or more type of energy sources, has ability to reduce the BES requirement and increases reliability. Wind and solar energies are natural allies for hybridization. Both have been known to be complementary to each other in daily as well as yearly pattern of the behavior. Acknowledging advantages of this combination, many authors have presented autonomous wind solar hybrid systems [5-10]. The most favorite machine for small wind power application, is permanent magnet synchronous generator [4-5]. It is possible to achieve gearless configuration with PMSG, however, it requires 100% rated converter in addition to costlier machine [11]. Some authors have also used wind solar hybrid system with a squirrel cage induction generator (SCIG) [6], Though SCIG has commercial edge regarding machine cost, however, the scheme doesn’t have speed regulation required to achieve MPPT. Moreover, if the speed regulation is done, it requires full power rated converter. A doubly fed induction generator (DFIG) as a generator is commonly used for commercial wind power generation and its applications, have been presented by many authors in their publications for autonomous application along with solar PV array [7-10]. DFIG may operate variable speed operation with lower power rated converters. However, to work the system as a micro-grid, the generated voltage should be balanced and THD (Total Harmonics Distortion), must be within requirement of IEEE-519 standard at no-load, unbalanced load as well as nonlinear load. Moreover, both the wind and solar energies sources should operate at MPPT. None of the authors, has reported all these issues. They have not presented performance parameters e.g. power quality, system efficiency etc under the different operating conditions. Moreover, they also lack experimental verification. This paper presents a micro-grid fed from wind and solar based renewable energy generating sources (REGS). DFIG is used for wind power conversion while crystalline solar photovoltaic (PV) panels are used to convert solar energy. The control of overall scheme, helps to provide quality power to its consumers for all conditions e.g. no-load, nonlinear load and unbalanced loads. The controls of both generating sources, are equipped with MPPT. Emmanouil *et al.* [12] have proposed a droop based control system for micro-grid with the help of standalone battery converter. In the presented scheme, the droop characteristic is embedded in control of load side converter (LSC) of DFIG. This function varies the system frequency based on state of charge of the battery and slows down deep discharge and over-charge of the battery. The DFIG in a proposed system, has also two voltage source converters (VSC). In addition to LSC, DFIG also has another VSC connected to rotor circuit termed as rotor side converter (RSC). The function of RSC is to achieve wind MPPT (W-MPPT). The solar PV system is connected to the DC bus through solar converter, which boosts the solar PV array voltage. With this configuration, the solar power can be evacuated in a cost effective way. This converter too is equipped with solar MPPT(S-MPPT) control strategy to extract maximum solar energy. In case of unavailabity of wind energy source and lower state of charge of the battery, the battery bank can be charged through the grid power or a diesel generator through the same RSC. With the help of the LSC, rated frequency and voltage at the load terminals, are maintained under following conditions.

- Varying amount of solar and wind powers.
- Unavailability of solar power or wind power.
- Loss of load or breakdown of the distribution system.
- Different types of loads as unbalanced and nonlinear loads.

It presents the design criteria of major components and control strategies for various converters. Finally it presents simulation results followed by experimental results obtained on a prototype developed in the laboratory.

II Doubly fed induction generator

PRINCIPLE OF OPERATION

The block diagram of the doubly fed generator, operating in the super synchronous mode is shown in Figure 6.1 (Leonhard 1996 and Liexu et al 2006). The stator is directly connected to the grid. The rotor is also connected to the grid but by means of two back-to-back pulse width modulation converters. The rotor side converter is current controlled to inject the desired currents into the rotor (Fernando Valenciage 2007).

When the machine is operating in the generating mode, the mechanical power Pm gets converted into electrical power in the stator (Pstator) and in the rotor (Protor). The rotor power is processed by the PWM converters and the grid side converter can be controlled to feed this power as both real and reactive powers (Pr and Qr) (Rajib Datta et al, 2002).

A. Wind Turbine and Gear

The wind turbine captures the kinetic energy of the wind and provides driving torque for DFIG. The value of captured mechanical power is given as,

$$P_m = 0.5 c_p \pi r^2 \rho V_w^3 \quad (1)$$

Here *Vw*, and *r*, are wind speed and radius of wind turbine respectively. *Cp* is the coefficient of performance of wind turbine and is mathematically derived as [13],

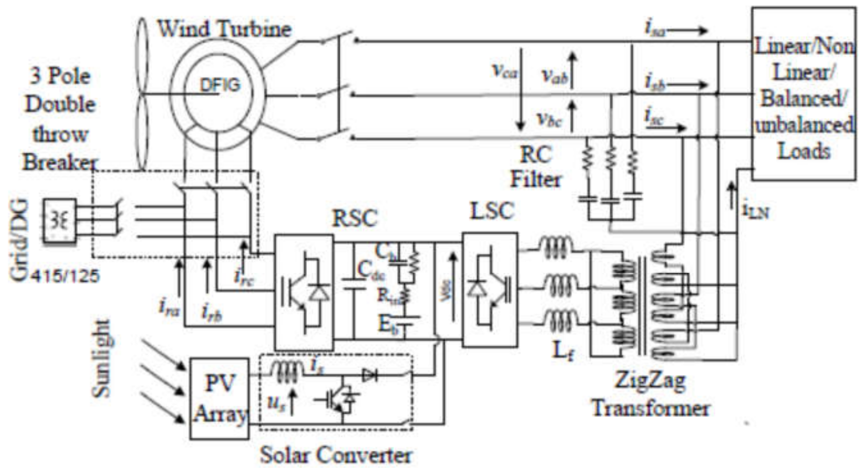

Fig. 1 Schematic of isolated micro-grid network fed by renewable energy source using battery storage

$$c_p(\lambda, \beta) = 0.73\left(\frac{151}{\lambda_i} - 0.002 * \beta^{2.14} - 13.2\right) e^{-(18.4/\lambda_i)}$$

λ and *β* are the tip speed ratio(TSR) and the turbine blade pitch angle, respectively. TSR is related to the of the turbine speed ω**r,** turbine radius *r* and wind speed *Vw* as,

$$\lambda = \omega_r r / (\eta_G V_W)$$
$$\eta_G = \omega_{rm} r / (\lambda^* V_{Wr})$$

where ηG is the turbine shaft gear ratio. The rated capacity of wind generator used in proposed scheme is 15 kW at a rated wind speed (*Vwr*) of 9 m/s and rotational speed (ω**rm)** of 198 rad/s**.** The optimum TSR (*λ**) and turbine radius, are taken 5.67 and 4.3 m, respectively.

The error signals of reference currents and sensed currents (*ira*, *irb* and *irc*) through hysteresis current regulator, generate control signals for RSC.

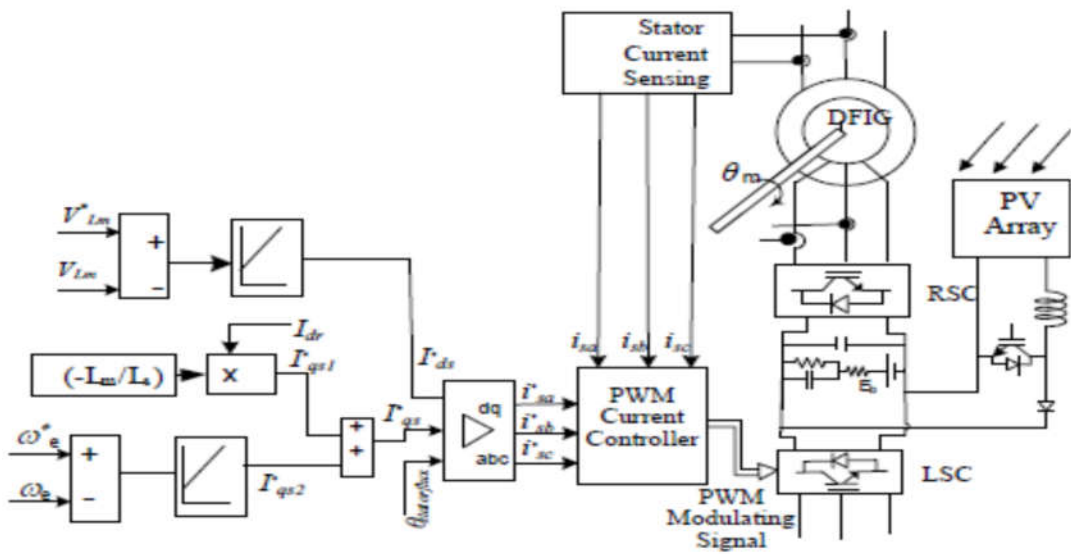

Fig.2. Control scheme

III Fuzzy control scheme:

Fuzzy control is a methodology to represent and implement a (smart) human's knowledge about how to control a system. A fuzzy controller is shown in Fig 5. The fuzzy controller has several components:

- A rule base that determines on how to perform control
- Fuzzification that transforms the numeric inputs so that the inference mechanisms can understand.
- The inference mechanism uses information about the current inputs and decides the rules that are suitable in the current situation and can form conclusion about system input.
- Defuzzification is opposite of Fuzzification which converts the conclusions reached by inference mechanism into numeric input for the plant.

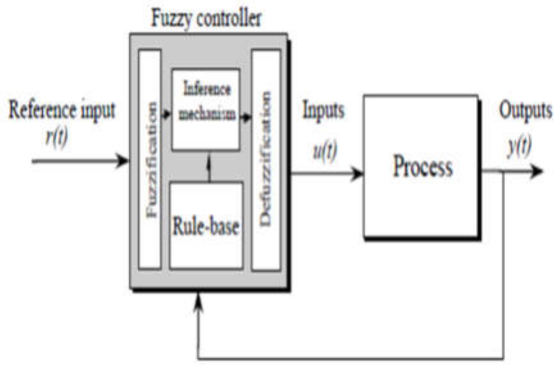

Fig.3. Fuzzy Control System

Δe \ e	NL	NM	NS	EZ	PS	PM	PL
NL	NL	NL	NL	NL	NM	NS	EZ
NM	NL	NL	NL	NM	NS	EZ	PS
NS	NL	NL	NM	NS	EZ	PS	PM
EZ	NL	NM	NS	EZ	PS	PM	PL
PS	NM	NS	EZ	PS	PM	PL	PL
PM	NS	EZ	PS	PM	PL	PL	PL
PL	NL	NM	NS	EZ	PS	PM	PL

Table-1. Rules for Fuzzy System

Fuzzy logic is a form of logic that is the extension of boolean logic, which incorporates partial values of truth. Instead of sentences being "completely true" or "completely false," they are assigned a value that represents their degree of truth. In fuzzy systems, values are indicated by a number (called a truth value) in the range from 0 to 1, where 0.0 represents absolute false and 1.0 represents absolute truth. Fuzzification is the generalization of any theory from discrete to continuous. Fuzzy logic is important to artificial intelligence because they allow computers to answer ‘to a certain degree’ as opposed to in one extreme or the other. In this sense, computers are allowed to think more 'human-like' since almost nothing in our perception is extreme, but is true only to a certain degree.

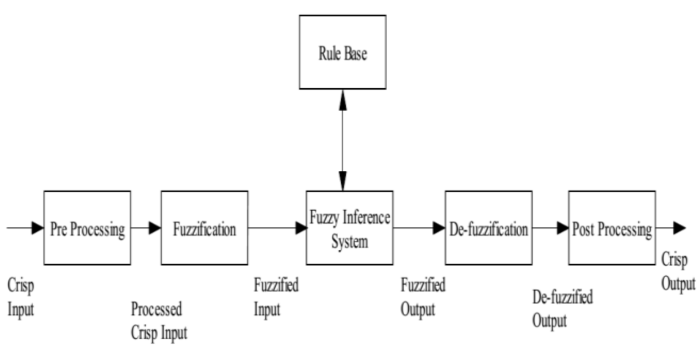

Fig.44.Block diagram of fuzzy control system

Fig.4 shows the block diagram of fuzzy control system. The crisp inputs are supplied to the input side Fuzzification unit. The Fuzzification unit converts the crisp input in to fuzzy variable. The fuzzy variables are then passed through the fuzzy rule base. The fuzzy rule base computes the input according to the rules and gives the output. The output is then passed through defuzzification unit where the fuzzy output is converted to crisp output.

IV Simulation Discussion:

Performance of the system only with wind energy output results are shown in below

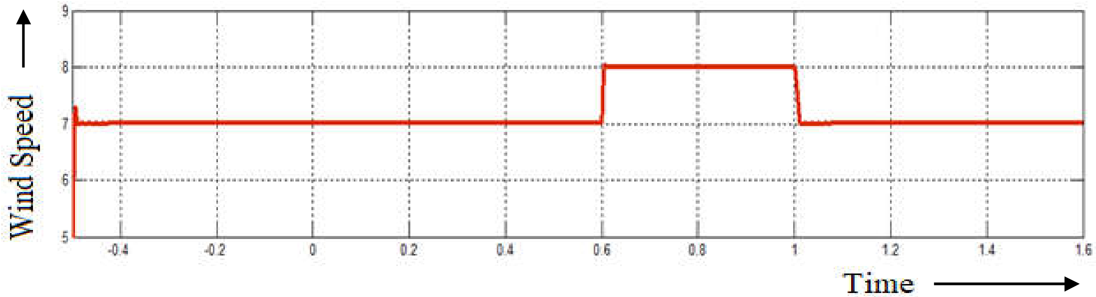

Fig.5 Wind speed

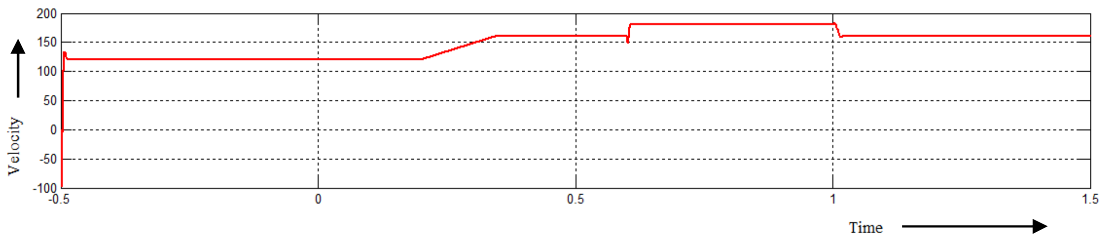

Fig.6 WT velocity

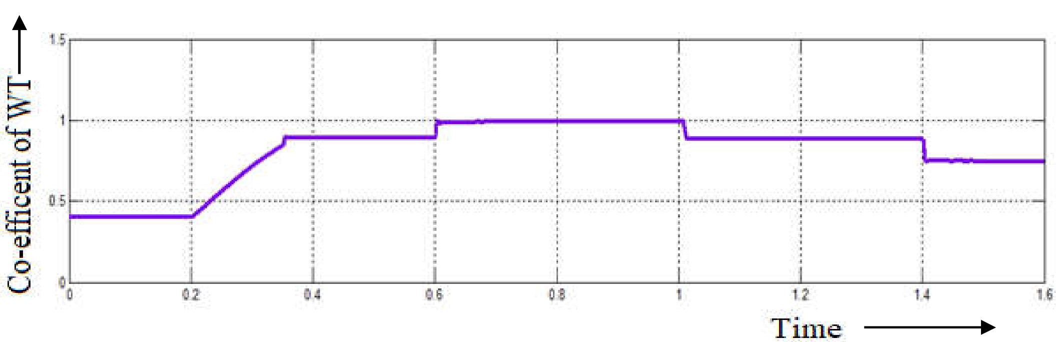

Fig.7 Co-efficient performance of WT

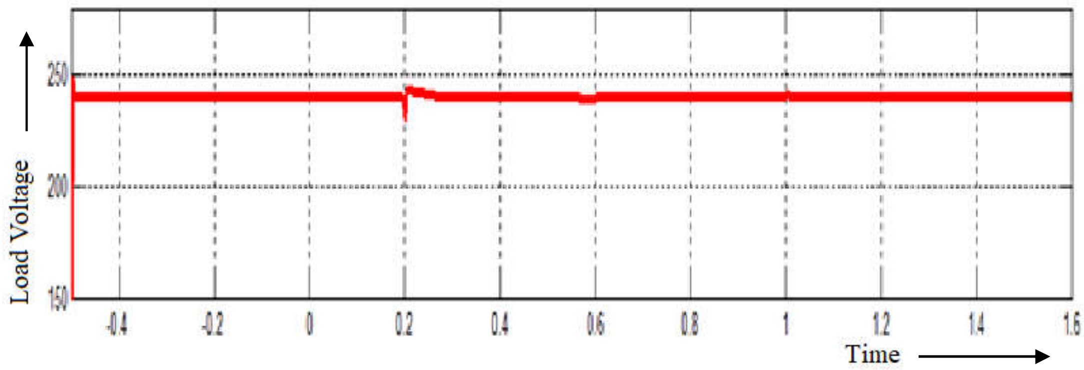

Fig.8. Load voltage

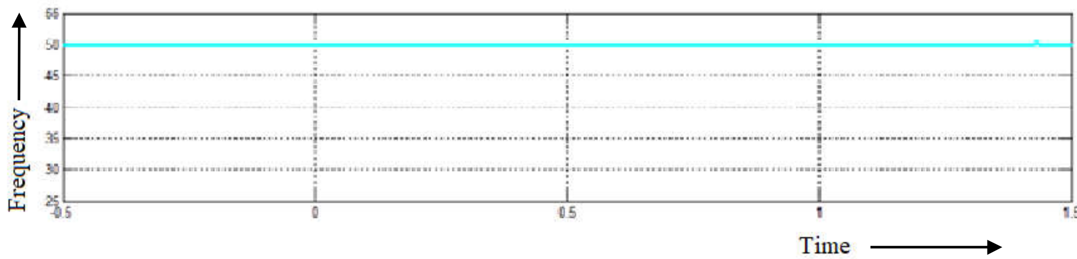

Fig.9. Frequency

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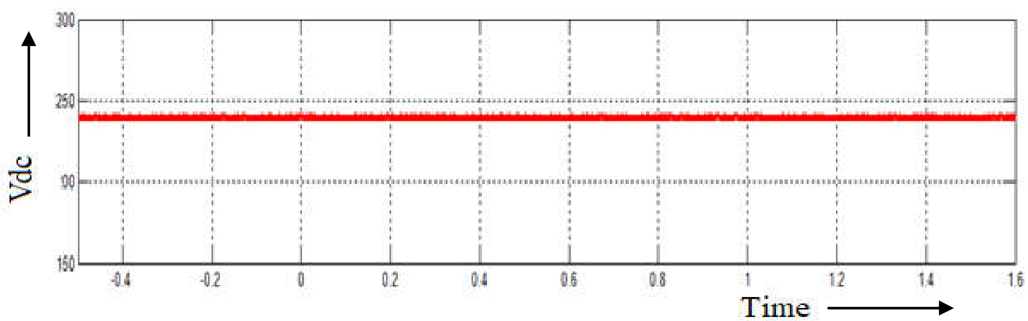

Fig.10 Voltage available at DC link

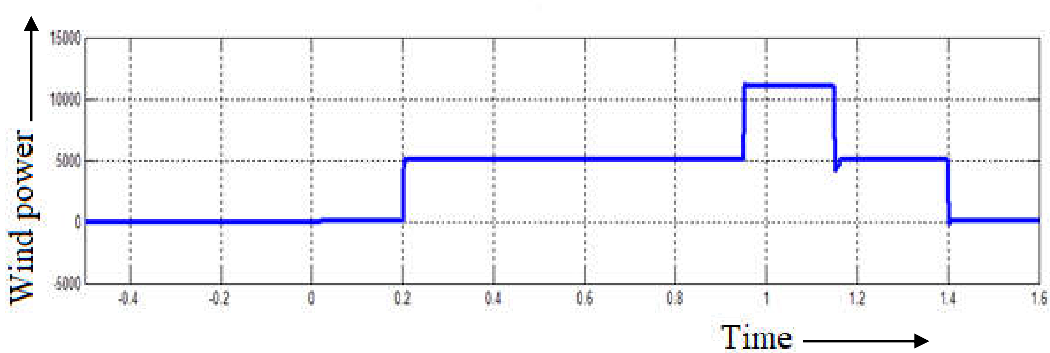

Fig.11 Production of Wind power

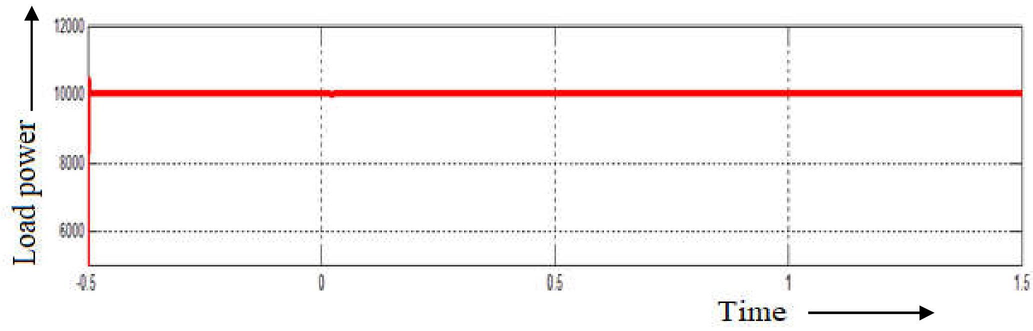

Fig.12 Load power

Performance of the system only with solar energy output results are shown in below

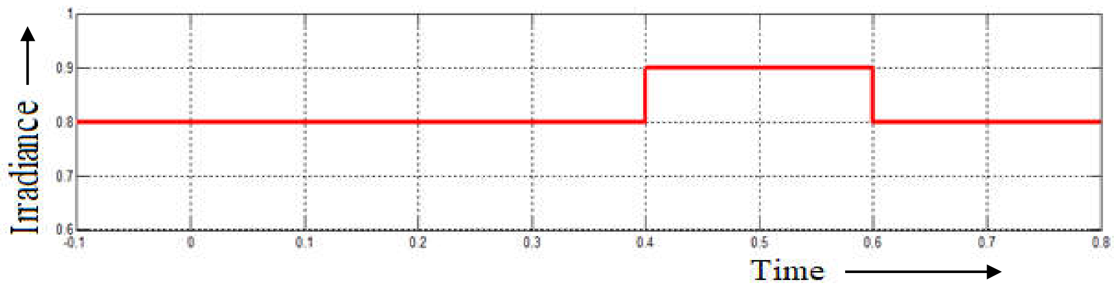

Fig.13 Irradiance (G)

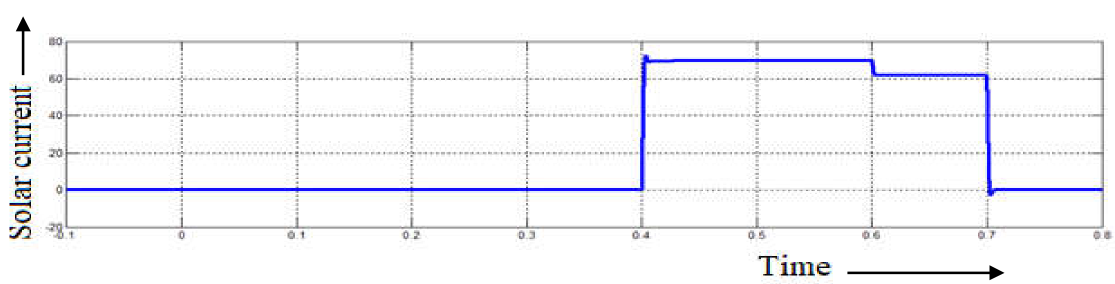

Fig.14 Solar current

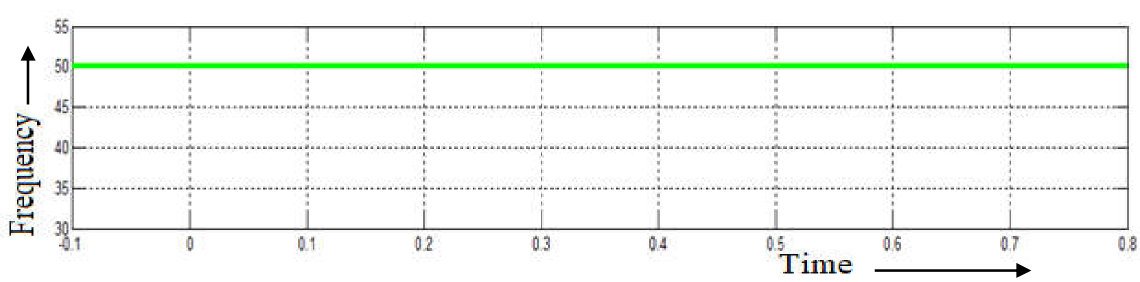

Fig.15 Frequency

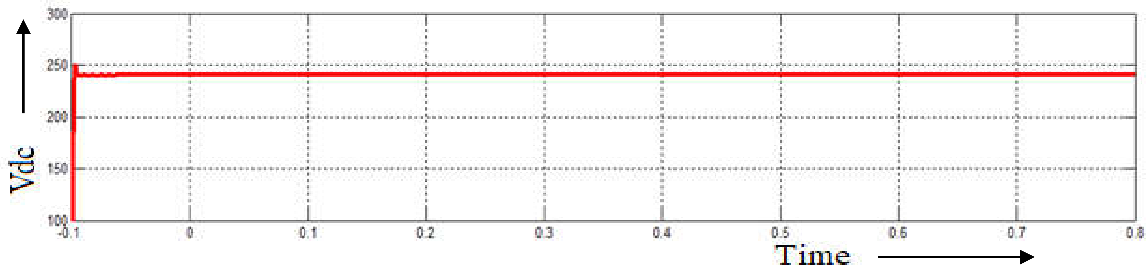

Fig.16 Voltage available at DC link

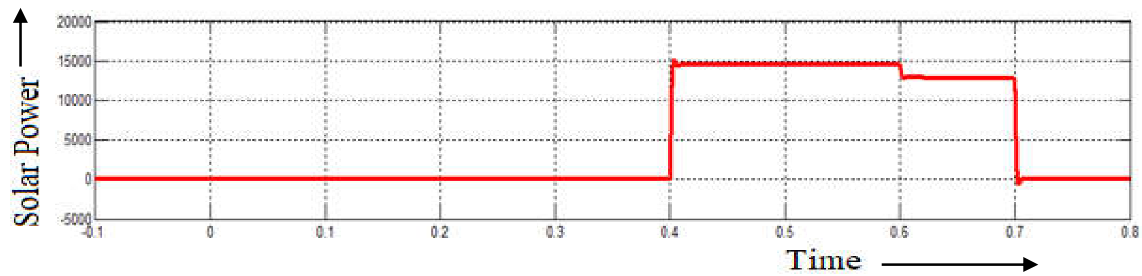

Fig.17 Generated solar power

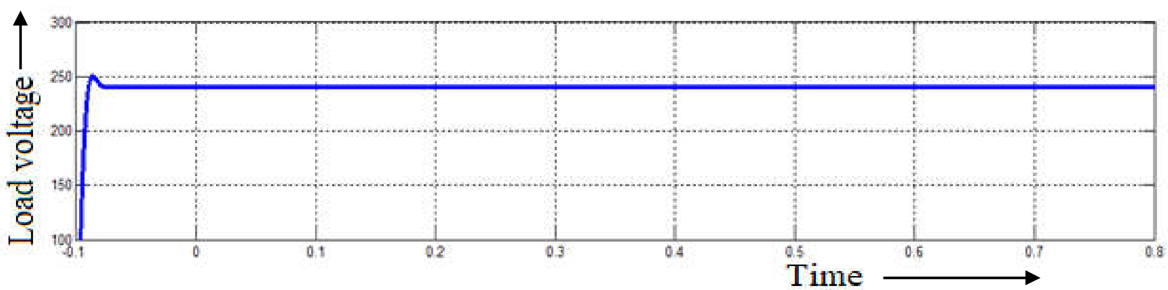

Fig.18 Load voltage

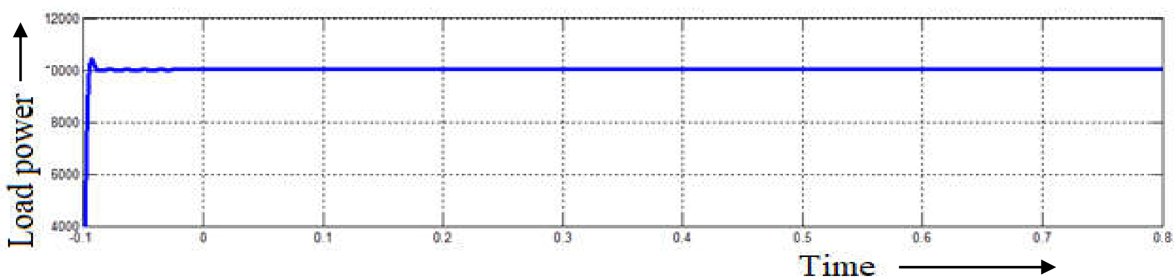

Fig.19 Load power

V. CONCLUTION

The proposed micro-grid system fed from REGS has been found suitable for meeting load requirement of a remote isolated location comprising few households. REGS comprises of wind and solar energy blocks, which are designed to extract the maximum power from the renewable energy sources and at the same time, it provides quality power to the consumers. The system has been designed for complete automated operation. This work also presents the sizing of the major components. The performance of the system has been presented for change in input conditions for different type of load profiles. Under all the conditions, the power quality at the load terminals, remains within acceptable limit. The effectiveness of the system is also presented with test results with prototype in the laboratory. The system has also envisaged the external battery charging by utilizing the rotor side converter and its sensors for achieving rectifier operation at unity power factor.

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