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Simulation and Study of Standalone Hybrid Grid (Involving Biogas, Solar, Wind and Biodiesel -based Generation)

R.L. Chakrasali[*1], H.N. Nagaraja[#], V.R. Sheelavant[*],
H. Vijay Murthy[*] and B.S. Shalavadi[*]

Abstract *– The demand for electrical power is increasing constantly for several applications due to its flexibility and efficiency. The utilities are unable to cope up with this requirement from the existing captive generation using conventional sources. The recent liberalization policy encourages exploring Independent Power Production (IPP) avenues and use of renewable energy sources. Hence attention must be turned to generate power from locally available resources like biogas, solar, wind, biodiesel, micro hydro etc. The power available is fluctuating when all the above are implemented as standalone system. But the integrated operation of all these sources leads to a reliable, robust and cost effective system to provide sustainable power. The paper discusses the task involved in design, implementation of standalone sy stems and integration of the renewable energy sources. The design of power electronic circuitry for superior and trouble free performance is a challenging engineering issue. The simulation study of standalone hybrid grid is carried out to confirm the integration of the sources and is validated by the simulation results.*

Keywords – Biodiesel, biogas, hybrid grid, solar, wind and sustainable power.

1. INTRODUCTION

Energy is vital for sustaining life on earth expresses the economic stability of a nation. It is needed to improve the quality of life by exploiting the natural resources. Continuous electric supply for the people in remote areas is a challenge to the power sector, where extension of power line from central grid is not feasible in our country. The government of India has set the target to provide power to all by 2012. As per the recent data available, out of 587,556 total villages only 474,982 villages have been electrified (% electrification is 86%). This situation still leaves 80000 villages and about 80 million households without electricity. Out of the above un-electrified villages, 25,000 villages will have considerable infrastructure problems to connect with electricity grid. There is an immediate need to focus on the development of cost effective system for remote places and in urban areas to reduce burden on conventional sources. The renewable sources can play a major and prominent role in rural electrification. The development of renewable energy sources is necessary for sustainable development of any country due to depleting fossil fuel level, increasing fossil fuel prices across the world. It is an established and accepted fact that renewable sources will play an increasingly important role in the future as they are cleaner, easier to use and environmentally benign. These are economically more viable with increased use. India is blessed with abundant solar energy, equivalent to 5000 trillion kWh/yr besides several indirect forms of solar energy manifesting as hydro power, ocean energy, wind energy, bio energy etc.

Thus, hybrid energy systems generally integrate renewable energy. Hybrid grids consist of two or more energy conversion devices, an energy storage system, power conditioning equipment and a controller [1]. A hybrid energy system may or may not be connected to the grid. They are generally independent of large centralized electric grids and are used in rural/remote areas. The study evaluates the feasibility of utilizing solar, biogas, biodiesel and wind energy to meet the electricity requirements. Hybrid energy systems are well suited for remote/rural areas. Hybrid systems for rural electrification can be configured in three different ways: grid connected off-grid with distribution system and off-grid for direct supply. The design of the system should minimize the total cost per year, subject to constraints on resources availabilities and load demands. The criteria for the design include [2], [3], [14]:

- Finding the most economical solution in terms of lifecycle costs
- Making the best use of existing equipment
- Optimizing the system performance for the load profile
- Lowering the operating and maintenance costs
- Assessing the impacts of the design on the environment and the community
- The villages should be in a cluster, remote but reasonably accessible.
- The villagers should be keen for electricity, ready to participate and should have strong community cohesiveness
- There should be scope for income/employment generation

A standalone hybrid systems offer several advantages and quite a few are as listed below.

*Department of Electrical Engineering, SDM College of Engineering and Technology, Dharwad-5 80002, India.

#Department of Electrical Engineering, Angadi Institute of Technology, Belgaum 590 008, India.

[1]Corresponding author; Tel: (0836)244-7465, Fax: (0836)246-4638.
E-mail: pratisatu@yahoo.co.in.

- It is a viable alternative solution for energy needs
- Laying of expensive grid line, transmission and distribution losses can be eliminated
- Eliminates expensive mains cable installation costs
- It also has longer life cycle. In particular, the integrated approach [1]-[4] makes a hybrid system to be the most appropriate for isolated communities of a rural /remote area.
- No pollution and no recurring fuel costs; Most eco-friendly and clean source of power
- Reasonably reliable and consistent quality power supply
- The use of distributed energy systems in remote standalone systems could help reduce the operating cost through the reduction in fuel consumption, increase system efficiency and reduced noise and emissions [4]-[6]. In many remote villages stand-alone power systems are often more cost-effective than utility grid extensions mainly due to the high cost of transmission lines.

2. CONFIGURATION OF STANDALONE HYBRID GRID:

It is clear from the literature that lot of work has been carried out for modeling of hybrid energy systems involving up to three different sources [1]. Though the models have been developed and simulated, realization of models at decentralized level is limited. The simulation study is carried out here by integrating four energy sources viz solar, wind, biodiesel and biogas. Thus the proposed work is carried out here with the objectives of

- Simulating a standalone hybrid grid involving solar, wind, biogas and biodiesel sources using Matlab simulink.
- Demonstrating possibility of sustainable power from fluctuating power.
- Educating and creating awareness in the public about IPP (Independent Power Production) and energy conservation

The block diagram of the proposed standalone hybrid grid is shown in Figure 1. The system consists of solar, wind, biogas and biodiesel generators, inverters, electrical isolation, ac bus and load.

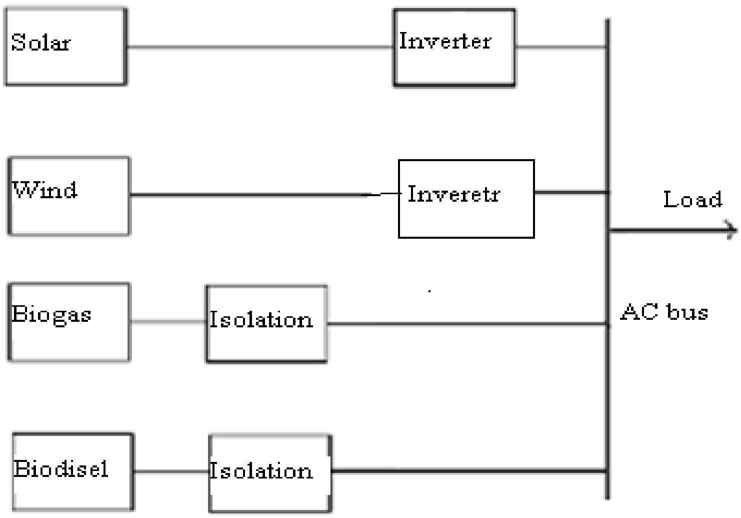

Fig. 1. The configuration of standalone hybrid grid.

3. METHODOLOGY

In this study, a hybrid grid is developed for single phase system. The voltage of the solar PV module is connected to a sine wave inverter. The output of the inverter is 230 volts. The wind uses a dc generator because the variation in velocity of wind is within the manageable limit in this region. Therefore low speed permanent magnet dc generator is coupled to the wind turbine. This is chosen as it is more technically and economically viable in rural/remote areas. The voltage from the generator terminals is applied across the sine wave inverter which is designed to give output of 230 volts. The biogas and biodiesel generation makes use of ac generators. The excitation and input are so adjusted to get the generated voltage of 230 volts. Then all the four sources are synchronized at an AC bus. The power generated from all the sources supply the load. This provides sustainable power though all sources generate fluctuating power when operated independently. This small scale generation technology holds the potential to help basic electricity services to the people who are living in remote / rural areas, who don't have an access to grid connectivity. Thus the locally available resources can help becoming energy independent. The resource assessment from primary information collected in the field and secondary data available from different sources is encouraging to choose installation of standalone hybrid grid.

3.1. Mathematical Modeling and Simulation

There are quite a few number of models have been proposed and are available, *e.g.* model formulation based on linear programming, mixed linear programming, hybrid optimization model for electric renewable, *etc.* including cost optimized models. In this work mixed linear programming model is used. Many software tools viz HOMER [7], PVSYST [8], SOMES [9], RAPSIM [10], SOLSIM [11], INSEL [12], PV-Design Pro [13] *etc.* are available and are capable of simulating, optimizing and determining sizes of equipment in hybrid energy systems. A mathematical model for each source is source is derived and simulated. Finally all the sources are integrated. The energy available from all the generators can be managed to serve the load by operating the generators as per the predefined schedule to fit the load curve under consideration. However, there is a flexibility to change the operating schedule to make it compatible with the load curve at hand.

3.2. Modeling and Simulation of Solar PV Plant

The irradiance is measured in units W/m^2 [1]. The PV system power output (dc) linearly varies with the irradiance. Using the irradiance data, the energy output of PV generator at given time, on a tilted surface is calculated using the following expression.

$$E_{solar}(t) = G(t) x A x \eta_{solar}$$

where G (t) is irradiance in kW/m^2

A = surface area of the PV module in m^2

It is assumed that PV generator is working at maximum power point tracking i.e. η_{solar} = 1 and the energy losses in PV generator, connection losses and other permissible losses are neglected. It also assumes that the temperature effects are neglected. Figure 2 shows the details of simulation of solar PV plant.

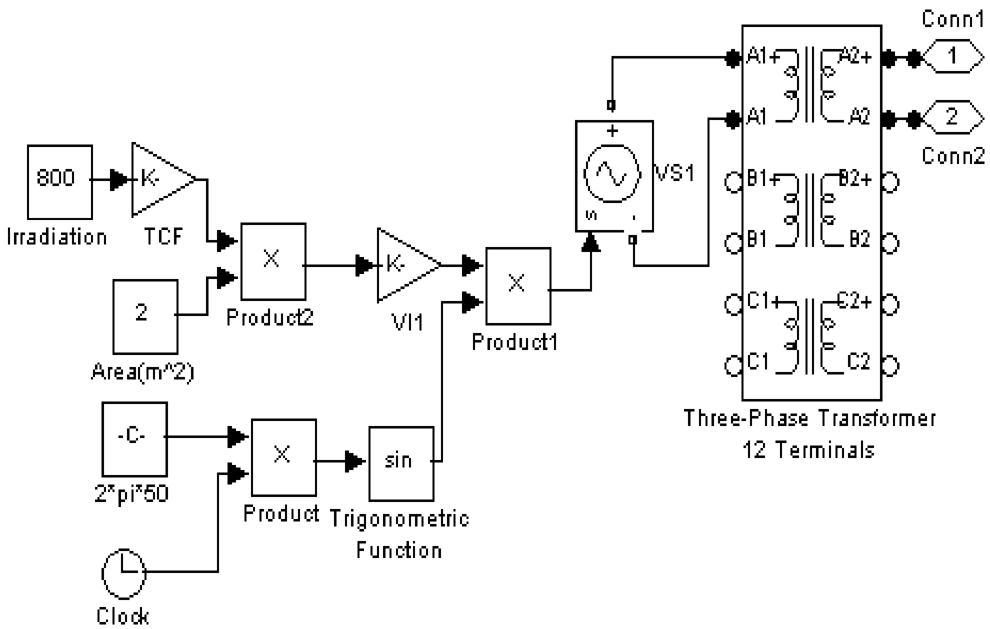

Fig. 2. Simulation of Solar PV plant.

3.3. Modeling and Simulation of Biogas Plant

The energy output (E_{bg}) of a biogas based system with the rated power output (P_{bggen}) of the generator depends on its capacity utilization factor (CUF). Assuming a conversion efficiency of 27% from biogas to electricity [1], it is modeled using the following expression: Annual energy output

$$E_{bg}= P_{bggen}(8760 x CUF)$$

The power is generated by using an ac generator coupled to a dual fuel diesel engine. The available volume of the gas depends on the digester capacity. The simulation shown in Figure 3 is run under the specified conditions to calculate the power, sine wave function generation and ac voltage compatible to the load specifications. The ac supply for the specified load voltage is obtained using sine wave function generation and transformer.

3.4. Modeling and Simulation of Biodiesel Plant

The model is designed in such a way that the generator is always operating between 80-90% of their kW rating (P_{bd}) when working in conjunction with other renewable generators. The biodiesel fueled engine will also work approximately in the same range of efficiency. Energy generated ($E_{biodiesel}$) in an hour 't' by the generator is expressed by the following equation:

$$E_{bd} (t) = P_{bd} (t) x \eta_{gen}$$

where: η_{gen} = diesel generator efficiency

The power is generated by using an ac generator coupled to a kerosene engine that starts with petrol. The fuel used is blend of biodiesel derived from castor oil or used edible oil. The proportion of the blend is 80% kerosene and 20% biodiesel. The combustion properties are taken in to account for the calculation of power and exhaust effects. The simulation shown in Figure 4 and is run under the specified conditions. The power is calculated knowing the quantity of fuel required to generate unit energy. The generator used in the simulation consumes 1.25 liters of fuel to produce 1 kW of power in one hour. Assuming overall system efficiency of 80% from biodiesel to electricity [1] the power is estimated.

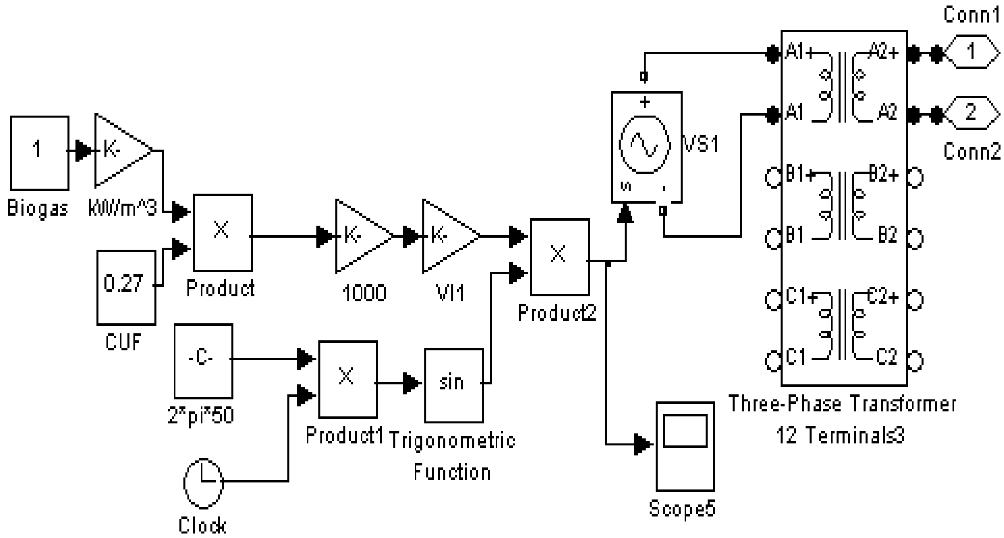

Fig. 3. Simulation of biogas plant.

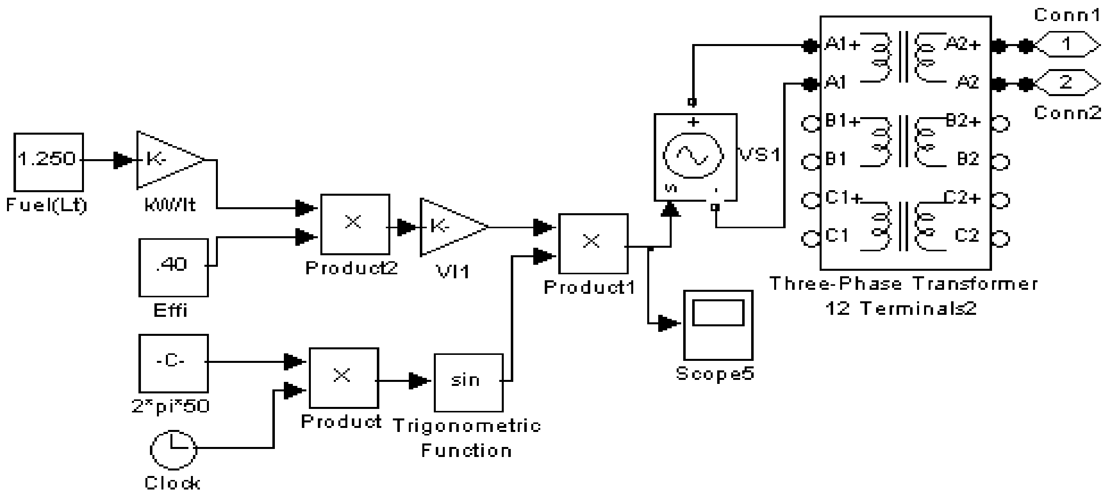

Fig. 4. Simulation of biodiesel plant.

3.5. Modeling and Simulation of Wind Power Plant

The principle of converting wind energy into useful form is "slowing down of wind". If slowed down too much i.e. when wind is fully blocked then wind velocity becomes zero. This means wind ceases to flow hence energy in wind becomes zero. That's why extraction of all the power available in wind is not possible. The actual power that can be extracted from the wind is nearly 56% available power P_a and is known as Betz criterion. This is defined as ratio of power extract to the power available in wind. The maximum value of power coefficient C_p=0.593. For micro power wind turbine C_p=0.45. Wind power equation:

Considering a wind propeller of diameter D meters, swept area A in m^2 and wind velocity V m/s, with the mass of wind sweeping across the blades is m kg, Then the kinetic energy (KE) available in wind is given by

$KE = 1/2 \times m \times V^2$ joules

Amount of air passing per unit time through an area A with a velocity $V = A \times V\ m^3$

The mass of this air = density × volume

$= \rho \times A \times V$ Kg/sec

This is the mass of air travelling the area A swept by the rotating blades of a wind mill.

The KE available per unit time in the air =1/2×mass/unit time×velocity^2=1/2× ρ×A×V×V^2. Power available in the wind P_a =1/2 ρAV^3 watts. Assuming conversion efficiency of 35%, power output of wind generator (P_{wind}). $P_{wind} = P_a \times \eta_{con}$

The power is generated by using dc generator coupled wind turbine. The simulation is carried out assuming wind velocity of 6 m/s which is the speed of wind at the installed site. The simulation shown in Figure 5 and is run under the specified conditions.

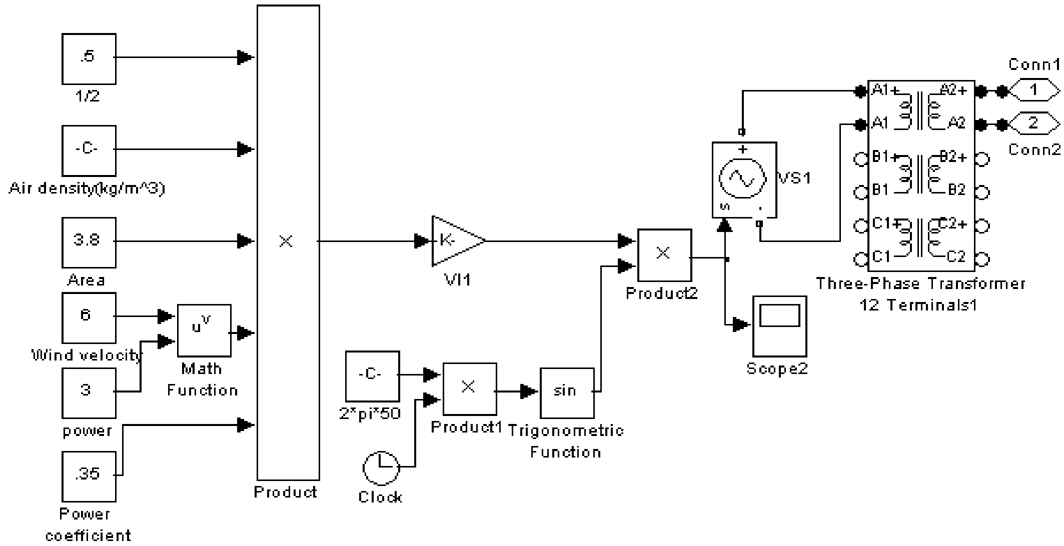

Fig. 5. Simulation of wind power plant.

4. SIMULATION OF STANDALONE HYBRID GRID

In this work four sources are integrated to form hybrid grid to which load is connected. The sources when operated independently will provide variable power but by integration, it becomes feasible to get fairly reasonable sustainable power. Such standalone hybrid grids are well suited for village/remote areas where it is difficult to provide power from central grid. The simulation of standalone systems have been explained above. The integration of all four sources is simulated as shown in Figure 6 and the power is tapped from the common AC bus.

Details of the Sub Systems

The details of the subsystems of individual source have been explained above. The dc power is generated from both solar and wind. The inverter operation is achieved by simulating it in terms of sine wave function generation unit and a transformer. The sine wave function generator unit makes use of a clock which helps in synchronizing the sources. The ac power is generated from biodiesel and biogas plants. Hence no inversion is required. However, to get proper synchronization and the required load voltage, the sine wave function generation unit and transformer is used and is simply considered as electrical isolation. The meters and oscilloscopes are used for measurement and displaying of the wave forms. The simulation is carried out here with the available tool box which has certain limitations.

5. SIMULATION RESULTS

The simulation is tested for the generated voltage at common points where all the sources are connected. It is observed that there is perfect synchronization of the sources and no local current paths are found. The voltage wave form obtained at the grid terminals is as shown in Figure 7.

The rated unity power factor load of 2996 watts is connected and the currents supplied by all the sources are measured and waveforms are recorded. The observation of the current waveforms reveals that all sources are sharing the load proportional to their rated capacities. The current waveforms for the rated condition are depicted in Figure 8.

The practical load is not always constant. Therefore the performance and load sharing is evaluated for one more load condition at half the rated power. It is observed that the sources are sharing the load. The magnitudes of the currents supplied by the sources at half the full load are shown in Figure 9.

There is no appreciable change in the terminal voltage for both full load and half the full load. Thus the system voltage regulation is well within the permissible limits. The same is observed by looking at the load voltage at half the full load condition shown in Figure 10.

Load Sharing

The current waveforms from the simulation results clearly indicate that the sources are supplying power proportional to their capacities. Thus, power supply to the load centre is asserted by the integrated system. The work in this paper is limited only to the integration of the sources, however, simulation for some fault conditions and intermittency effect of renewable sources (*e.g.* wind and solar) on the output would be taken up in due course to have complete insight of the system.

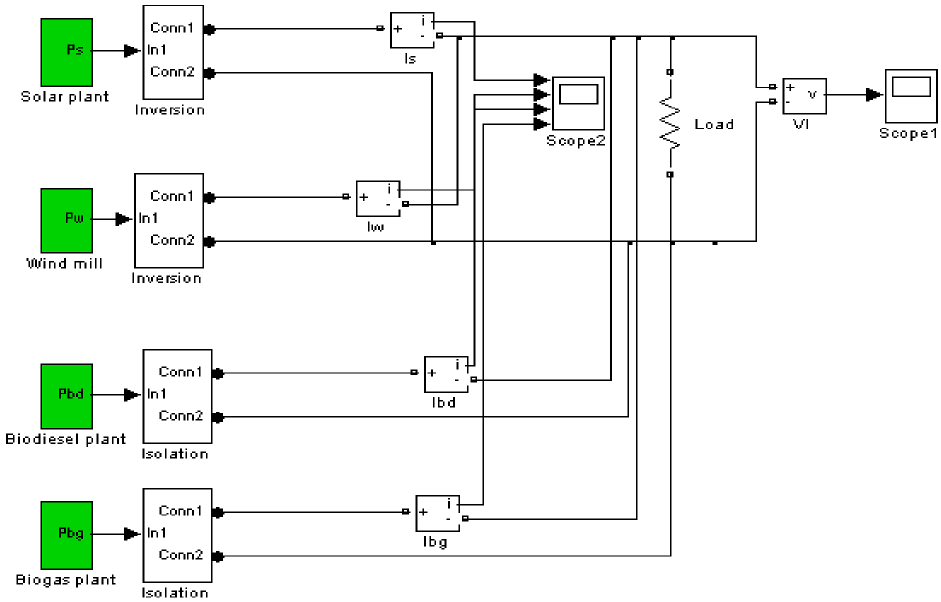

Fig. 6. Simulation of hybrid grid.

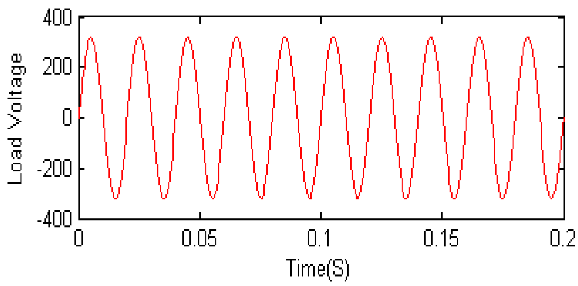

Fig. 7. Load voltage waveform.

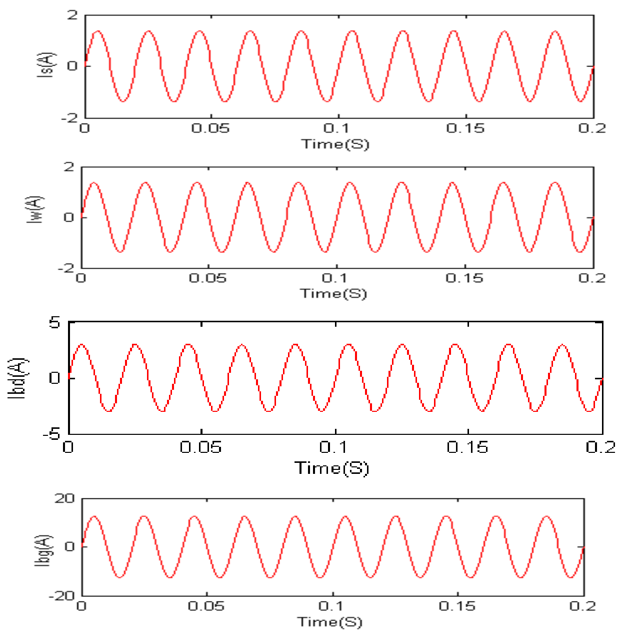

Fig. 8. Waveforms of load currents shared by all the four the sources at rated power.

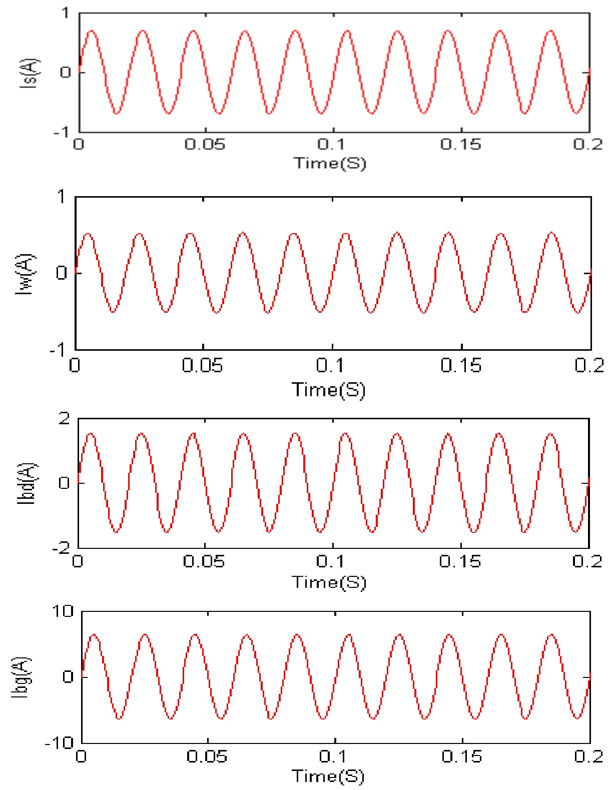

Fig. 9. Waveforms of load currents shared by all the four the sources at half the rated power.

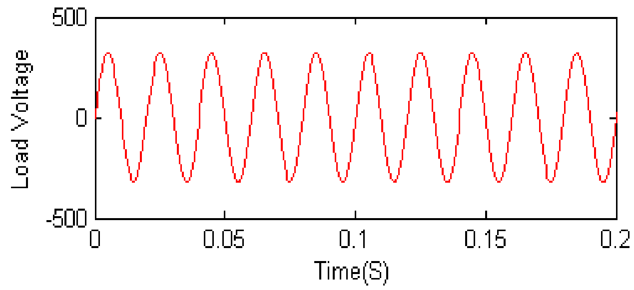

Fig. 10. Load voltage waveform at half the rated power.

6. CONCLUSION AND FUTURE SCOPE

In the present scenario, the power requirements can be met by independent power generation making use of locally available resources. The simulation and installation of individual sources reveals that the power is variable when operated independently. The integration of the sources leads to fairly sustainable power which is clear from the results obtained from the simulation. The demonstrative model installed is well suited for village/remote areas. The model is suitable to supply power to a typical farm house with a connected load of 3 kW. The testing is done here with the resistive load. However, the same can also supply the motor load.

The work in this paper is limited only to the integration of the sources, however, simulation for some fault conditions and intermittency effect of renewable sources (*e.g.* wind and solar) on the output would be the further scope to work in this area to have complete insight of the system.

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