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Simulink Model for Cost-effective Analysis of Hybrid System

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Abstract: *Utilization of non conventional sources of energy to meet the present day energy requirement has become very much essential in the era of fossil fuel crises. The present paper discusses the importance of PV-Diesel hybrid system to meet electrical requirement in remote areas. A model of a photovoltaic array with diesel battery was designed by MATLAB simulink. In this paper, the cost-effective analysis which includes the fuel consumed, the energy obtained per gallon of fuel supplied, and the total cost of fuel. Simulations done for Diesel generator system, diesel-battery system and solar PV with diesel-battery system using a one-year time period. Based on simulation results energy payback period for PV array, the simple payback time for the PV module calculated. Simulation analysis includes the comparison of system cost, efficiency, and kWh per gallon with those predicted by Hybrid Optimization Model for Electric Renewables (HOMER).*

Keywords: *Energy payback period, simple payback time, hybrid system, HOMER.*

I. Introduction

Hybrid power systems are intended for the generation of electrical power and are used in remote areas. Hybrid systems consists of a number of power generation devices such as photovoltaic, micro-hydro and/or fossil fuel (diesel) generators. Hybrid power systems range from 0.1kwh to 10 Mwh per day. Hybrid power systems to provide reliable power to the many remote areas in the developing countries where transportation costs of diesel fuel are very high. The use of non conventional power generation systems reduces the use of fossil fuels, allows for the cleaner generation and also improves the standard of living .The use of non conventional energy sources in remote areas could help reduce the operating cost through the reduction in fuel consumption, increase system efficiency, and reduce emissions[1],[2]. There are issues associated with storage of fuels. Therefore, photovoltaic and other renewable sources of energy are being integrated with DEGs to help reduce the fuel consumed by the DEGs.

The RTU provides the information for modeling of power system. Remote terminal unit processed by the simulink model. In this way, the RTU and the model can be used to optimize the performance of the hybrid power system.

MATLAB Simulink is used to model the system and distribute the electrical load distribution between the PV array and diesel-electric generator. Simulations are performed for three cases: 1) only diesel system 2) diesel with battery and 3) PV with diesel-battery system using a one-year time period. The Simulation results used to perform a cost-effective analysis and predict the ecological impacts of hybrid power system. The cost-effective part of the model calculates the fuel consumed, the energy obtained per gallon of fuel supplied, and the total cost of fuel. These results are then utilized to calculate the EPBT (Energy payback time), the SPBT (simple payback time) for the PV module.

II. Hybrid Systems Model

A hybrid system is a combination of one or more resources of renewable energy such as solar, micro or mini-hydropower and biomass with other technologies such as batteries and diesel generator. Particularly, the solar hybrid system developed with a combination of solar with battery and diesel generator. The hybrid system offers clean and efficient power that will in many cases be more cost-effective than individual diesel systems. As a result, renewable energy options have increasingly become the preferred solution for off-grid power generation. The system has been installed at the middle and top stations. Hybrid system supplies power for base load from non conventional energy resources whilst the peak load could be met via battery and diesel generator.

When two or more different power sources are connected to a common grid and operate hand in hand to give the desired load, the system becomes a hybrid electric power system. Simple block diagram of a hybrid power system is shown in Fig 2.1. The hybrid system consists of a diesel generator, a battery bank, a PV array. The diesel generator is the main source of power for many of the distant villages and around the world. The Diesel generator gives ac voltage as output, which supplies the load through transformer.

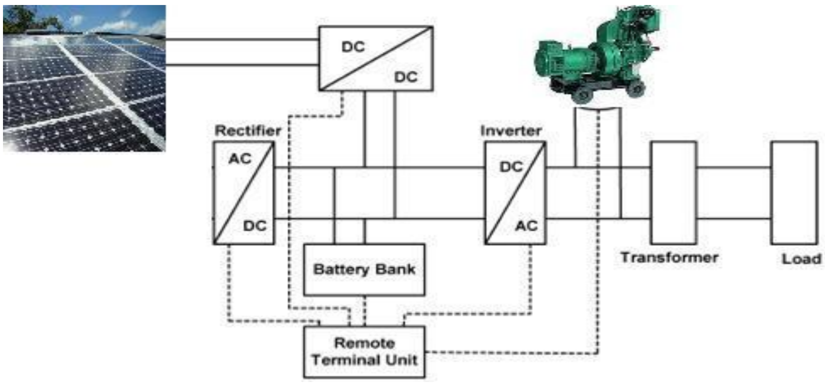

Fig.2.1

The battery bank, the PV array is interlinked through a dc bus. The RTU controls the flow of power to and from the different units, depending on the load. RTU plays main role in a hybrid power system to improve the performance of the system. The purpose of the RTU is to monitor and control the hybrid system The RTU is interfaced with many sensors and control devices located at different locations within the hybrid system. The RTU processes the data from these sensors and transmits it to a control center.

In this paper, the hybrid power system consists of 21- and 35-kW diesel generators, 100 kWh of lead acid batteries, and a 12-kW PV array. The PV array consists of 8 kW and 4 kW solar panels. A 30-kVA bidirectional power controller is used to supply power to and from the batteries and from the PV array. The use of renewable energy in the form of a PV array combined with regulated battery storage helps in constraining the use of the diesel generator while optimizing the efficiency and economics of the system.

A hybrid power station typically includes (a) Inverter unit (b) Diesel engines, which are 1.5 times the inverter rating with diesel generator control system. A fully automatic diesel generator control system enables automatic operation and automatic selection of power sources (c) A battery storage system (d) A solar PV array and solar regulator (e) A microprocessor based controller unit to monitor and manage the system automatically.

The solar hybrid power system makes use of the solar PV to produce electricity that can be supplemented by diesel generators. The configuration of solar hybrid system is analyzed for various photovoltaic array sizes with respect to a diesel generator to operate in tandem with the battery system. The power controller unit will determine the AC conversion of the DC power in relation to optimum diesel generator operation following the load profile. The charge controller will charge the batteries with energy from solar modules as well as from the diesel generator. The main objective of solar hybrid system is to reduce the cost of operation and maintenance and cost of logistic by minimizing diesel runtime and fuel consumption. To achieve this generator only runs as needed to recharge the battery and to supply excess load. It is started when the battery reaches a preset discharge level and is run at full capacity until the battery is fully recharged and then shut down. During day time, Solar PV panels used to generate the electricity while the generator is off mode. The output of PV arrays i.e., DC power converts to AC power using inverter. The additional generated power is stored in battery system. During Night Time, battery supplies the energy to load while the generator and PV arrays are both off. The inverter again converts the battery output power to AC power for the load. The battery will supply the load to its maximum discharge level. During shortfall, the battery reaches its maximum discharge level and therefore, the generator is on. At this time, the generator serves the load as well as charges the battery. The battery charge rate is adjusted to maintain the generator at full output. The operations, which activate or deactivate generator set and charging or discharging battery are managed and done by a micro-processor-based controller unit. The controller unit monitors and manages the load demand and energy supplied.

III. Simulation Model

The simulation models for three cases are shown below viz., Fig 3.1,Fig 3.2 and Fig 3.3.The Simulation model consists of nine blocks. The Input Parameters block consists of data files obtained from the site. The model receives the information from the Remote terminal unit after installation. Sensors collects the information from the location which includes the amount of sunlight insolation, incident upon the PV arrays, charge and discharge level of the batteries, and operating parameters of the diesel generator and passed to signal conditioning devices. These signals are then transmitted to A/D converter for processing. The data is then saved within the memory of the RTU[3]. The data which includes solar insolation values, electrical load, and temperature are useful to develop the model and also to find out efficiency and the amount of fuel used for the Diesel generator. These parameters sufficient to analyze any hybrid power system.

The PV Model block is the model of the 12-kW PV array to calculate the power available from the PV array, based on the intensity of sunlight. The -function written in MATLAB performs the following tasks.

1) The total power available from the PV array (aligned due south and tilted at a 15 degrees) is calculated using the solar insolation values which are collected from NREL, the total area of the collector from the manufacturer data sheet , and the efficiency of the solar collector. In this project, a collector efficiency of 12% is assumed.
2) The model compares the calculated PV power to the required load.

The Battery Model block consists of the battery bank and controller. The -function in the Battery Model block performs the following tasks. The total battery voltage is calculated using the number of battery cells and the voltage per cell as follows:

Battery volt = n*volt_per_cell

Where volt per cell is obtained from the output of the Input Parameters block. The model then compares the required load with the rated capacity of the two generators. If the required load more than the capacity of the two generators, then the model displays the message that the load can't be supplied. If the load is less, then the Simulink model checks for the available energy and the mode (charging or discharging) of the battery bank. If the battery bank energy is greater than 20% and the battery is in the discharging state, then the battery energy will be supplied to the load. If the available energy of the battery bank is less than 20% of its rated kilowatt-hours or if the battery bank is in the charging stage, then the energy from the diesel generator will be used to supply the load and charge the battery bank simultaneously.

The Generator Model block contains parameters like efficiency of the electric generator. The input power to the generator can be calculated as

$$Pi = \frac{P_1}{\eta}$$

Where P_1 is the load on the diesel generator.

The Generator Model block is designed in such a way that the diesel generators are always operating at 95% of their kilowatt rating while operating in conjunction with the battery bank and the PV array.

The Fuel Consumption Model block calculates the amount of fuel required by the diesel engine to supply the load. The fuel consumed by the engine depends on the load and the electrical efficiency of the generator. The plot for the fuel consumption obtained from the manufacturer's data sheet can be mathematically interpreted as follows:

$$F\,c = 0.5 * Pi + 0.5$$

$$Fc = \frac{Fuel\ consumed}{7.1}$$

Where P_i is the input power to the generator given in kilowatts; 7.1 is the factor that converts pounds (lbs) to gallons.

The Error block calculates the difference between the powers (supplied and required) .The error within the model is calculated by

$$Error = P_s + P_G + P_{pv} - P_L - P_D$$

Where Ps is the power supplied by the battery bank, P_G is the power supplied by the diesel generators, P_{pv} is the power supplied by the PV array, P_L is the power delivered to the load, and P_D is the power delivered to the dump load.

The rms value of error is given by

$$Error\ (r\,m\,s) = \sqrt{\frac{\Sigma\ (\text{Ins tan tan}\ eous\ value)^2}{n}}$$

The Other Parameters block calculates the parameters such as the total energy per gallon supplied by the generator, fuel consumed, the total cost of fuel (in U.S. dollars). The kilowatt-hours per gallon and total fuel cost are calculated as

$$\frac{k\,wh}{gallon} = \frac{k\,wh_{Gen}}{Fc}$$

And $$Total\ \cos t\ (USD) = Fc * \frac{\cos t}{gallon}$$

The Display Parameters block is used to display all the calculated parameters

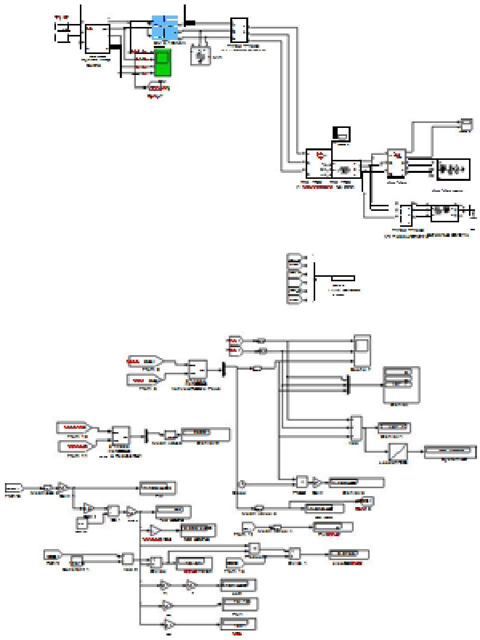

Fig 3.1 Remote diesel only System (Case-I)

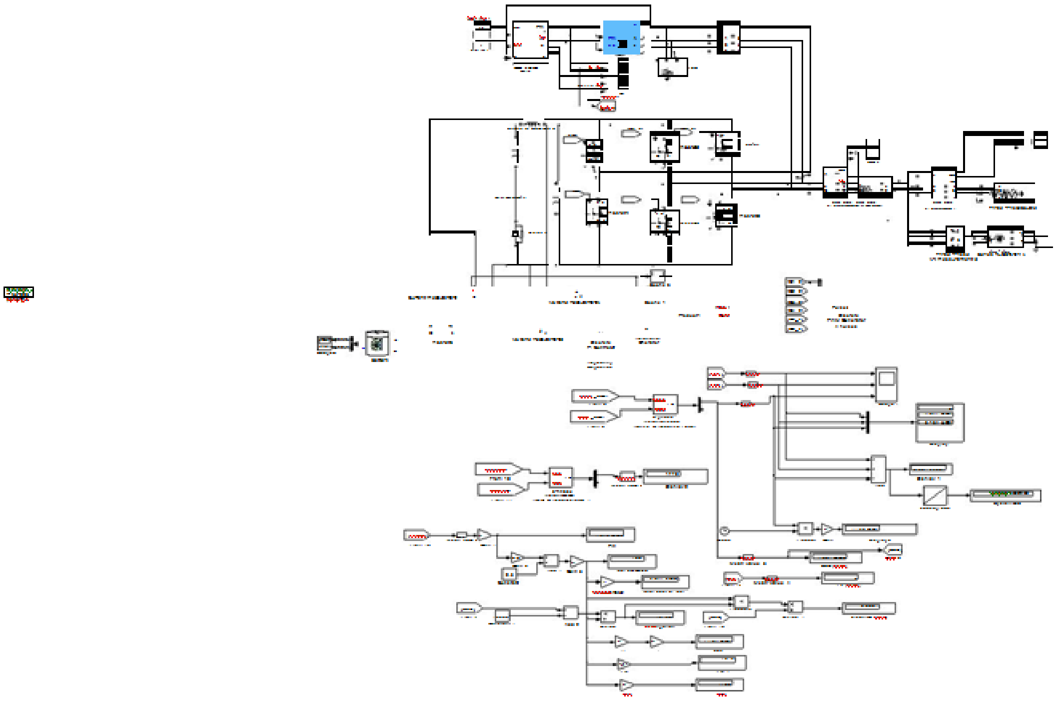

Fig 3.2 Remote diesel-battery System (Case-II)

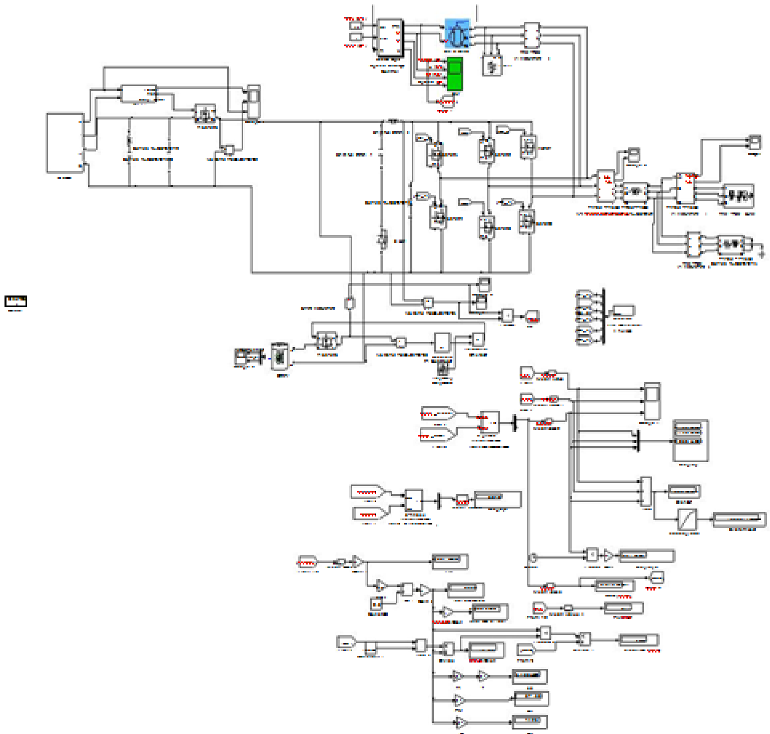

Fig 3.3 Remote PV diesel-battery System (Case-III)

IV. Simulations and Results

Simulations were performed for diesel system, diesel-battery system, and PV with diesel-battery system. The costs of the different components were obtained from the various manufacturers listed[4] in Table I. Due to the distance of the site, the cost for transporting the various components is relatively high.

Table II shows the results for diesel,diesel battery and pv with diesel battery cases. In this model, converters efficiency was considered as 90%. The solar collector efficiency for the PV array is assumed as 12%. As per HOMER, the density of fuel is assumed to be 840 Kg/m^3 and the heating value of fuel is assumed to be 48.5 MJ/kg, and Simulation results were utilized to analyze cost-effective which includes the simple payback time and energy payback time. The cost-effective analysis part of the simulation model involves calculation of the simple payback time (SPBT) and energy payback time (EPBT) for the PV module and array respectively. Usually, battery banks are used as back-up sources for power. Therefore, the PV with diesel-battery system is compared to the diesel-battery system in the analysis of SPBT. The Simple payback time is expressed as

$$SPBT = \frac{Excess\ \cos t\ \ of\ \ PV\ \ system}{Rate\ of\ \ saving}$$

From table 2, $SPBT = 18.11\ years$

In order to calculate the Energy payback time for the PV array, it is essential to know the energy required in the construction of the PV array is also called as embodied energy. In this method [5], the total energy required is the sum of energies required for raw materials and the energy required in the various processes involved to convert the raw materials into the PV array.

The embodied energy of a PV system is given by

$$Embodied\ energy\ = 5600 * Rated\ \ power\ of\ \ PV$$

And $$EPBT = \frac{Embodied\ \ energy}{E}$$

$$EPBT = 7.11\ \ years$$

The PV array is rated to produce 12 kW, and from Table II, the value for is 9445 Wh/yr.

Table III shows the comparison of the results using the Simulink model with those predicted by HOMER. It was observed that the efficiency of the diesel generator is higher using the Simulink model. This is because in the Simulink model, the battery bank has a longer charge/discharge cycle. So, the life time of the battery bank is less in the Simulink model as compared to that of HOMER.

In HOMER, the energy generated by the diesel engine is higher because the battery bank is designed to cycle between 40% and 82% of its energy rating rather than between 20% and 95% in the Simulink model. The converters are operating with much less efficiency in HOMER as compared to the Simulink model (about 20% difference). In HOMER, the Diesel generator is loaded anywhere between 6.3–21 kW, with the average load of 13.4 kW, and, hence, operates with a lower electrical efficiency than in the Simulink model. In the Simulink model, the battery bank acts as a source of power. So whenever the Diesel generator is ―on,‖ it operates at 95% of its rated power—therefore, with a higher electrical efficiency. If the load on the DEG is less than 95% of its rated power, the excess power is utilized to charge the battery bank. It can also be observed that the efficiencies for the DEG-battery and PV-DEG-battery are the same in the Simulink analysis. In the above analysis, HOMER has the advantage with a higher net present value (NPV) due to the longer life of the battery bank over the Simulink model. The battery bank is the most expensive component of the system.

After conducting the simulations for the three cases, it was observed that pv with diesel hybrid system provided better results in terms of fuel consumption for the diesel generator .It was observed that the diesel generator operates most efficiently for case 3, while the diesel-battery system has the highest kilowatt-hours per gallon. In diesel only system the entire load was supplied without the PV array and the battery bank, leaving the load to be supplied by the diesel generator. Since the diesel generator operates with the lowest load for the diesel-only system, it is the least efficient system and has the lowest kilowatt-hours per gallon. In diesel battery system, when the battery bank is discharged, the diesel generator is used to charge the battery bank, so finally, the entire load is supplied with the help of the diesel generator. In case 3, part of the load was supplied using the PV array. As a result, there is substantial saving in the fuel consumption by the diesel generator due to use of the battery bank and the PV array with the diesel-only system.

Table I : Installation costs for 3 cases (Diesel, diesel-battery and PV with Diesel battery)

Item	Cost per unit	No. of units	Diesel-only system	Diesel-Battery system	PV with Diesel-Battery system
35 KW diesel generator	$28,000	1	$28,000	$28,000	$28,000
21KW diesel generator	$18,500	1	$18,500	$18,500	$18,500
Switch gear to automatic control of both diesels	$16,000	1	$16,000	$16,000	$16,000
Rectification/ Inversion	$18,000	1	$0	$18,000	$18,000
New absolyte IIP6-90A13 Battery bank	$2,143	16	$0	$34,288	$34,288
BP 275 Solar	$329	105	$0	$0	$34,545
Siemens M55 Solar	$266	75	$0	$0	$19,650
Engineering		1	$3,000	$3,500	$4,000
Commissioning, Installation, Freight, Travel miscellaneous		1	$13,000	$14,000	$16,000
		Total	$78,500	$1,32,288	$1,88,983

Table II: Comparison results for 3 cases (Diesel,diesel-battery and PV with Diesel battery)

Parameter	Diesel-only system	Diesel-Battery system	PV with Diesel-Battery system
System cost	$78,500	$1,32,288	$1,88,983
System efficiency (%)	26.22	29.94	29.96
KWh/gallons (KWh)	10.61	12.1	12.1
Fuel consumed(gallons)	8410	7367	6583
Total cost of fuel(USD)	$33,640	$29,470	$26,340
System load(KWh)	89220	89220	89220
Energy supplied			

(a). DEG (KWh)	101900	100100	89500
(b). PV(KWh)	0	0	9455
Electrical efficiency of DEG (%)	87.56	89.13	90.17

Table III : Comparison of results with HOMER

Parameter	Simulink Model	HOMER
System efficiency	29.96	29
Fuel Consumed (gallons)	6,583	6,817
Kwh per gallon	12.1	11.84
Energy generated		
1) Diesel engine	82497	87064
2) Solar Panels	9445	9444
Energy Supplied to load (kwhr)	89220	89224
Operational life		
1) Generator(years)	5.4	4.62
2) Battery bank(years)	5.4	6.07
System Cost(USD)	188,983	188,983
Net present value(NPV) (USD)	547,322	585,012

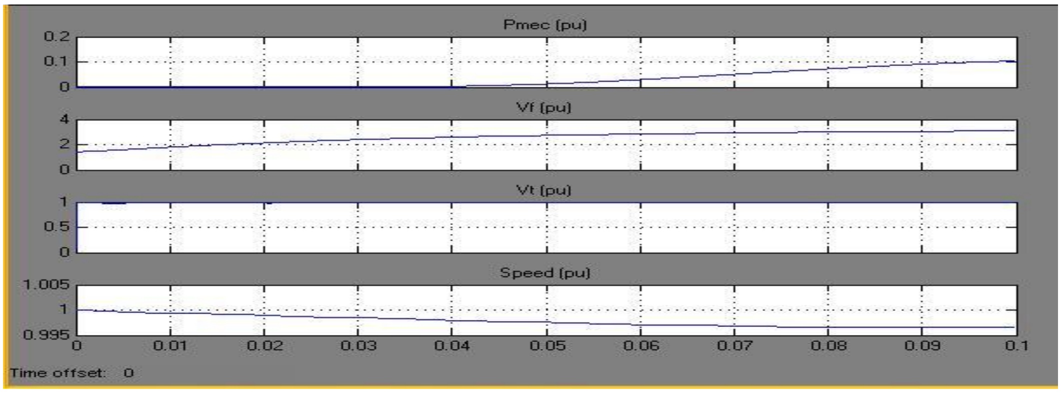

Fig 4.1 Diesel System output (Case-I)

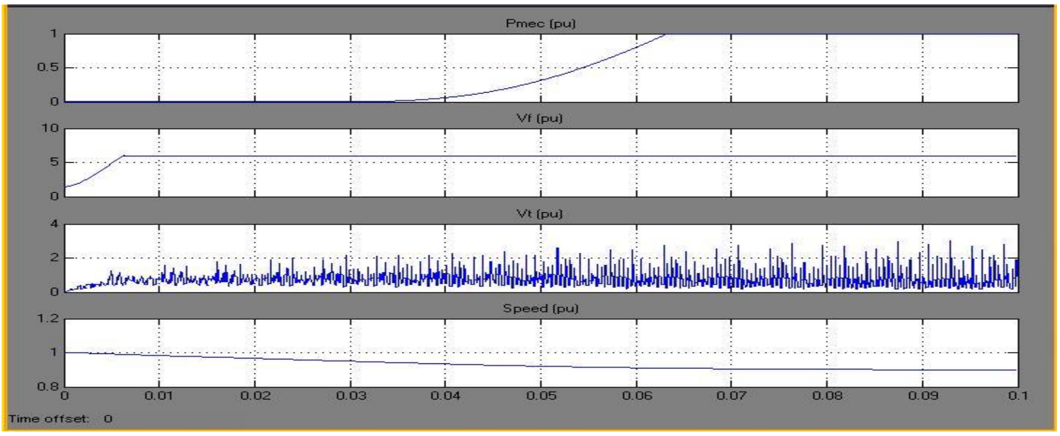

Fig 4.2 Diesel system output (Case-II)

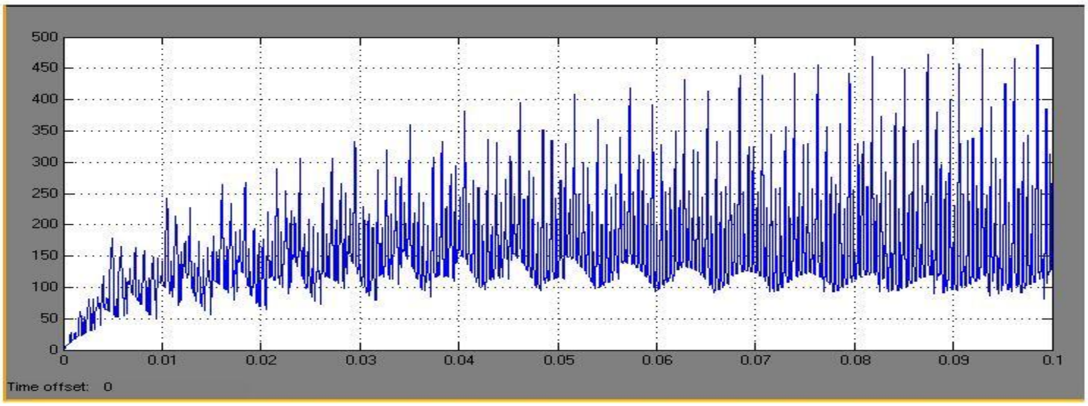

Fig 4.3 Battery system output voltage (Case-II)

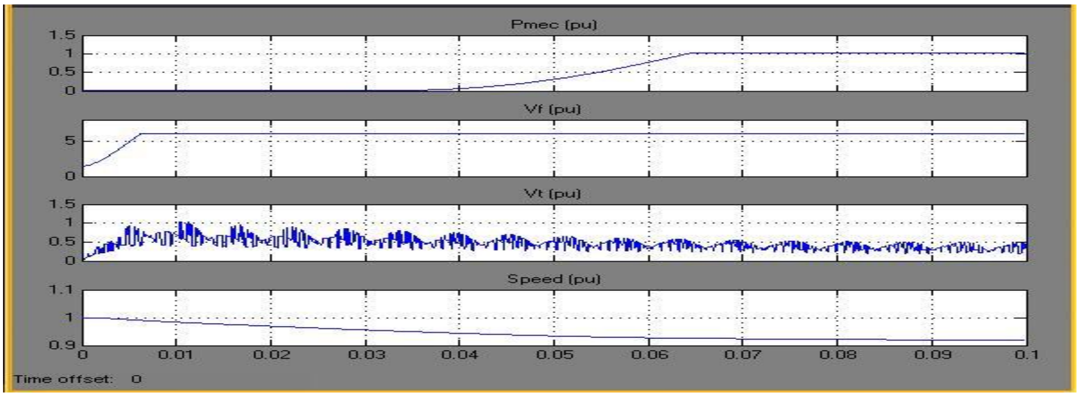

Fig 4.4 Diesel System Output (Case-III)

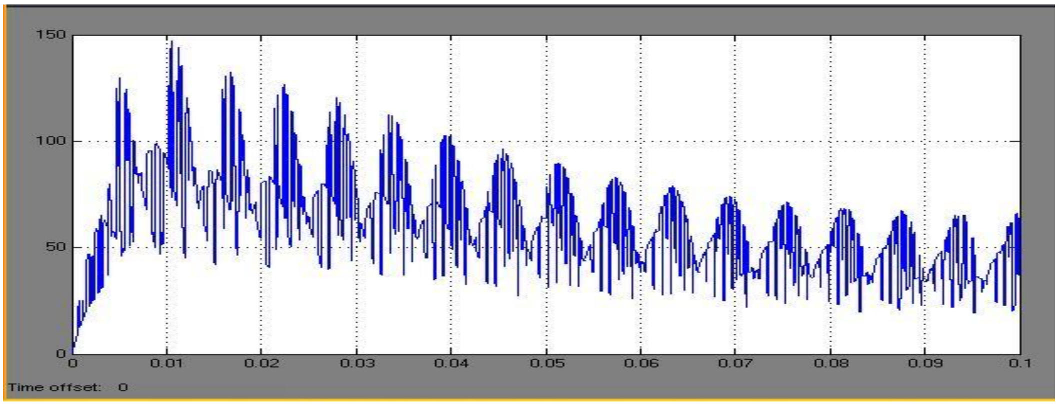

Fig 4.5 Battery Voltage (Case-III)

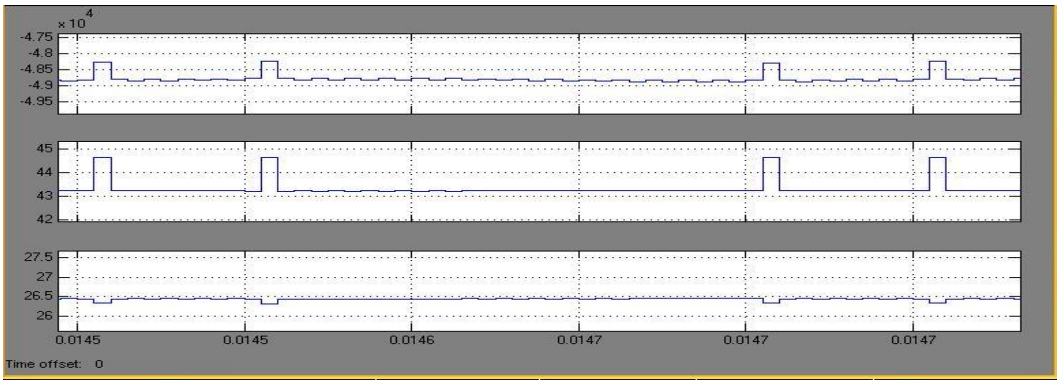

Fig 4.6 PV System Response (Case-III)

V. Conclusion

The preliminary results reported here demonstrate that the integration of a PV array into a diesel-battery stand-alone hybrid power system reduces the operating costs. A Simulink model of the PV with diesel-battery hybrid power system was developed in this project. The Simulink model can be used to study the performance of any PV with diesel-battery hybrid power system if the operating characteristics of the power system are known. With few modifications, the model can be extended to incorporate other renewable energy sources. The incorporation of additional renewable sources of energy, such as wind turbines in this system, could further reduce fuel consumption. The dynamic performance and the control system strategy of the power system can also be incorporated into the model. The model was validated by comparing the results for supplying an annual load profile with those predicted by HOMER. Although there is a significant capital investment to purchase a PV system for this application, the PV system may have acceptable 20-yr LCCs for many remote locations. Furthermore, over its life cycle, the PV hybrid power system will consume less fuel than the diesel-only system. If the external costs associated with emissions are taken into account, the PV system discounted payback period will further decrease. Hybrid energy systems, which result in more economical and efficient generation of electrical energy, would not only improve the capability of automated and precision generation systems, but would also help to extend the life of nonrenewable energy sources.

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