ANALYSIS AND SIMULATION OF ISOLATED WIND DIESEL HYBRID POWER SYSTEM

E. S. Raghav Chakravarthy, A. Bhargavi, K. Parkavi Kathirvelu and R. Balasubramanian
Department of Electrical and Electronics Engineering, SASTRA University, Thirumalaisamudram, Thanjavur, India
E-Mai: libchak@gmail.com

ABSTRACT

The present day energy scenario clearly shows the large potential demand for the electrification of remote rural places which can be met easily through the stand alone renewable energy systems. The hybridization of these stand alone renewable energy systems increases the reliability of self sufficient power supply for off grid locations [1]. This work describes the characteristic features of a standalone hybrid Wind-Diesel microgrid. The modelling and simulation of a standalone Wind/Diesel system with individual system components i.e., Diesel Set and Wind Set are simulated and described in detail. The effect of penetrative variations with change in wind speed and the impact of position and length of transmission line on reactive power compensation in the microgrid are effectively demonstrated by simulation results.

Keywords: wind diesel hybrid system (WDHS), point of common coupling (PCC), wind generation, synchronous condenser, asynchronous machine speed (ASM).

1. INTRODUCTION

The demand for energy has increased, resulting in the increase of the number of renewable energy generating sources. As per the Renewable's 2013 Global status report [2] depicted in the graph shown in Figure-1, almost 45GW of wind power capacity came into operation in 2012, thereby increasing the global wind capacity by 19% resulting a total capacity of 283GW. Also the annual growth rate of cumulative wind power capacity in the years 2007-2012 averaged 25%. The installation of wind energy is both consumer and eco-friendly and also requires a very short span of time for installation of the plant compared to other conventional generative sources.

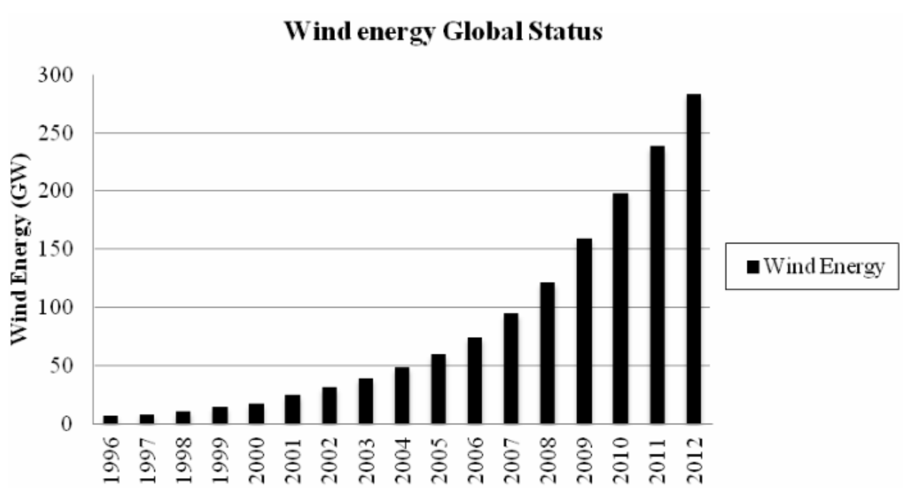

Figure-1. Bar graph showing global status of wind energy.
(Source: REN21 Renewables'13 Global Status Report)

The effective and hybrid use of these sources are very essential for the optimized power generation. The Wind-Diesel power generation system is a hybrid combination consisting of Wind and diesel as power generating sources. These types of hybrid system are designed to increase potential of generation and proportionally to reduce the cost of production. The existence of the Wind - Diesel generation system started in the later part of 20th century. The integration of two generating system relies mainly on complex controls to make certain of proper sharing of discontinuous wind energy and handy diesel generation to meet up the demand which usually variable in nature. It is also a major concern to reduce the environmental impact of diesel generation which is advantage of the Hybrid Wind Diesel power generation. The transportation cost of the fuel to the remote locations can be limited by effective use of this hybrid system by the optimal operation of the generations together.

The power quality concern in renewable energy based micro grid is also an important factor which has to be taken into consideration. In isolated system the reactive

VOL. 9, NO. 7, JULY 2014 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

power has to be supplied to the load, the frequency of the system has to be maintained within the confines, so as to ensure the reliability in quality of the power supply [3].

The major advantage of WDHS is that it can be operated based on the requirement which is constrained with wind source. The Synchronous machine of Diesel Generation set can be used a synchronous condenser in Wind mode to enable the reactive power compensation of the system without installation of any ancillary equipment which is economic benefit in this type of system.

The WDHS is being classified based on the Wind energy penetration level [4] which is defined as:

Energy Penetration (EP) =

$$\frac{\text{Wind Tubrine Annual Energy Output (KWh)}}{\text{Annual Primary Energy Demand (KWh)}} \quad (1)$$

The WDHS is classified as low penetration when EP < 20% and as medium penetration when 20% < EP < 50%. If the wind generation is capable of shutting down the diesel generation then it is called High Penetration [5]. Many works have been carried out on dynamic simulation of WDHS. In [3] a WTG to the DG isolated grid is being simulated touching quite a few perturbations. In [6] a variable speed flywheel energy storage system based on hydrostatic transmission is been included in WDHS system. In [7] simulation of an isolated WDHS system with BESS has been simulated. This paper focuses mainly on the performance of the WDHS system considering the restraint of variable wind speed and also the effect of transmission line with respect to its position in the system. This article comprises of the following sections, Simulation Schematics and Methodology in which the description of the simulated MATLAB design and the methodology has been specified followed by the Observations and analysis which had been drawn out from the results obtained in and the conclusion which emphasize the outcome of the result.

2. SIMULATION SCHEMATICS AND METHODOLOGY

The circuit diagram employed for modelling medium penetration WDHS is shown in Figure-2. The wind generation system is modelled as an asynchronous generator connected to a wind turbine block, customized from MATLAB Simulink library. The wind generation system is connected to a synchronous machine operating at no load, with its excitation system controlling the operation of the synchronous machine. The three phase RLC load is the primary load which is being connected to the PCC of wind generation system and synchronous condenser blocks. The dump load acts as a secondary load to consume the extra generated energy and to maintain the frequency of the system within the confines. The transmission line is introduced in the system in some case studies to analyze the performance of the system.

The voltage and current measurements blocks are connected at the wind generation system, synchronous condenser and at load, to observe and analyze the results pertaining to the real power (P_w) produced by the wind generation system, the reactive power (Q_d) compensated by the synchronous condenser, the power consumed by the primary load (P_m), the power consumed by the secondary load (P_s), the frequency of the system and the speed of the wind turbine generator in p.u. (ASM).

The power produced by a wind turbine is a function of the wind speed input to the system. In general, the minimum wind speed for generation of power is 6m/s and a maximum of 15 m/s. The mechanical power produced by a wind turbine is given by the equation (2).

$$P_m = C_p(\lambda, \beta) * \frac{\rho A}{2} * v_{wind}^3 \quad (2)$$

Where, P_m is the mechanical power output of the wind turbine, ρ is the air density in Kg/m^3, in general taken as 1.229 Kg/m^3, C_p is the performance coefficient of the wind turbine; υ_{wind} is the input wind speed in m/s, A is the area swept by the turbine blade in m^2, λ is the ratio of the rotor blade tip speed to wind speed and β is the blade pitch angle in degrees. Since the pitch angle of the wind turbine is kept constant the value of β is considered as zero, so C_p is only a function of tip speed ratio.

The wind turbine is connected to asynchronous generator rated as 275kVA, 440 V_{rms} operating at 50Hz. The asynchronous machine operation as generator or as motor is based on the sign of the mechanical torque. If mechanical torque is positive, the machine acts as a motor and for negative value it acts as a generator.

The synchronous machine is connected to an exciter which controls the excitation of the synchronous machine and maintains the grid voltage at a stipulated value. The excitation system also controls the Diesel engine connected to synchronous machine rated at a value of 300 kVA, 440V_{rms} at an operating frequency of 50Hz. The synchronous machine acts as a synchronous condenser at no load.

The system performance has been observed and analyzed for two case studies of variable wind speed input to the wind turbine and for the impact of presence of transmission line in system.

ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

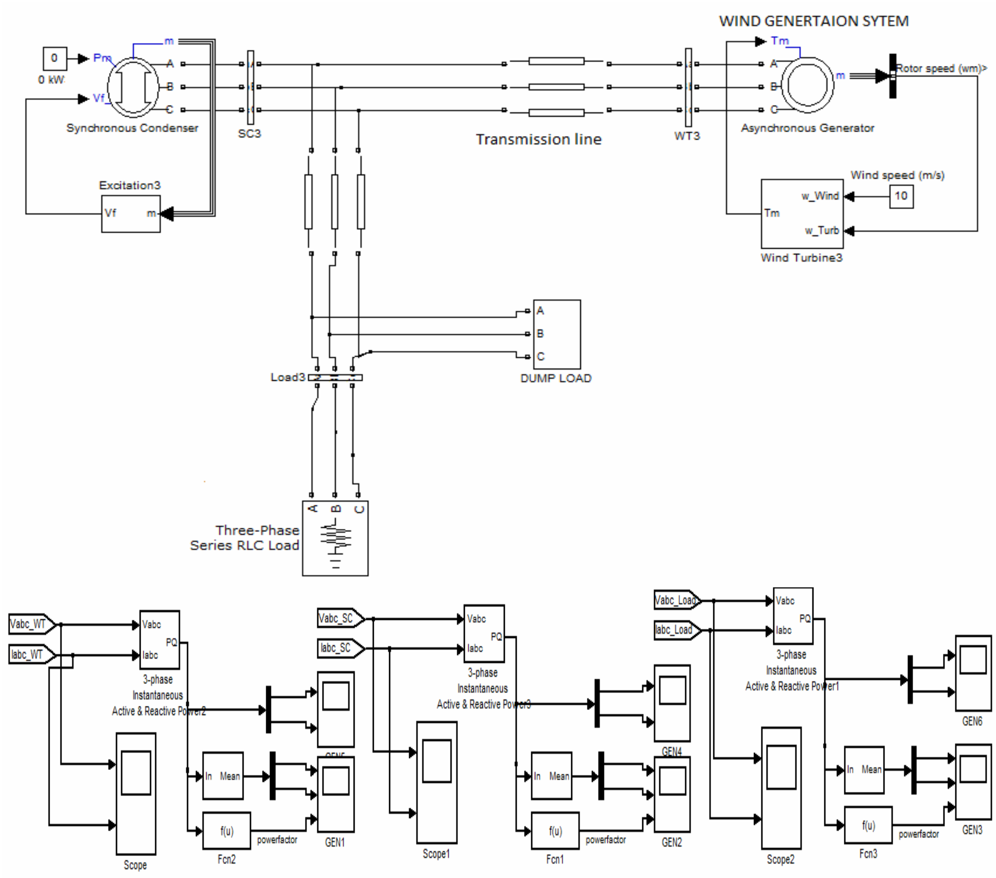

Figure-2. Isolated wind - diesel hybrid system.

3. OBSERVATIONS AND ANALYSIS

CASE-I: For variable wind speed input

The input wind speed to the wind turbine is varied by considering three different values of wind speed as 10m/s, 8 m/s and 6m/s. The resulting wave forms for the wind real power (P_w) compensated reactive power (Q_d), primary load power consumption (P_m), secondary load power consumption (P_s), system frequency and the speed of the asynchronous generator in p.u. have been observed and analyzed for the variable wind speed input.

(N.B: For the graphs depicted for all the case studies the following colour code is considered)

Wind speed (m/s)	Colour code
10	Blue
8	Green
6	Red

It can be observed from Figure-3 that the Wind real power output is dependent on wind speed input. The rated power output of the asynchronous generator can be achieved only if the wind speed input to the wind turbine is above a rated value of 10m/s. For wind speed input of 10 m/s the expected output power of wind turbine is 206 kW. Due to losses in the asynchronous machine, the output power is obtained as 200 kW. At wind speed input of 10m/s, the primary load consumes 50 kW (3 Ø R load) and the dump load absorbs remaining generated power of 150 kW maintaining a constant system frequency as observed from Figures 4 and 5. The reactive power compensated by the synchronous condenser is variant based on the real power output of the wind turbine and is equal to 100kVAR. Since the asynchronous machine operates in generator mode, the generator rotor speed is slightly above the synchronous speed (1.011 p.u.) as noticed from Figure-4.

For a rated wind speed input of 8m/s, the wind real output power is drastically decreased to half of the rated value i.e., to 100 kW and for the wind speed input of 6 m/s, it considerably decreased to a value less than 50 kW, where the real power produced by the wind turbine is inadequate to meet the primary load demand of 50kW. The power consumption of the secondary load is decreasing with decrease in the wind speed input as observed from Figure-5. The important aspect which has to be taken into account is that the system is driven out of stability when the wind speed is 6 m/s due to a drastic drop in the system frequency.

VOL. 9, NO. 7, JULY 2014 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

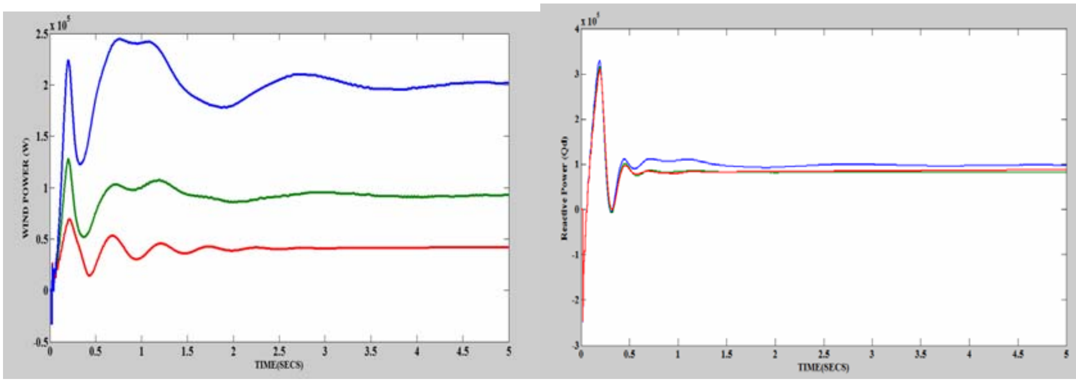

Figure-3. Real power produced by wind generation (left): Reactive power compensated by synchronous condenser (right) for Case-I.

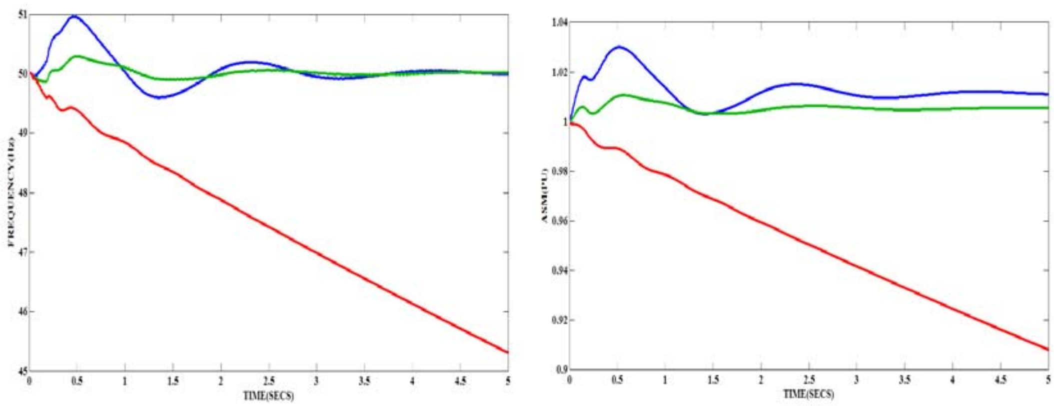

Figure-4. System frequency (left): Asynchronous machine speed ASM (p.u.) (right) for Case-I.

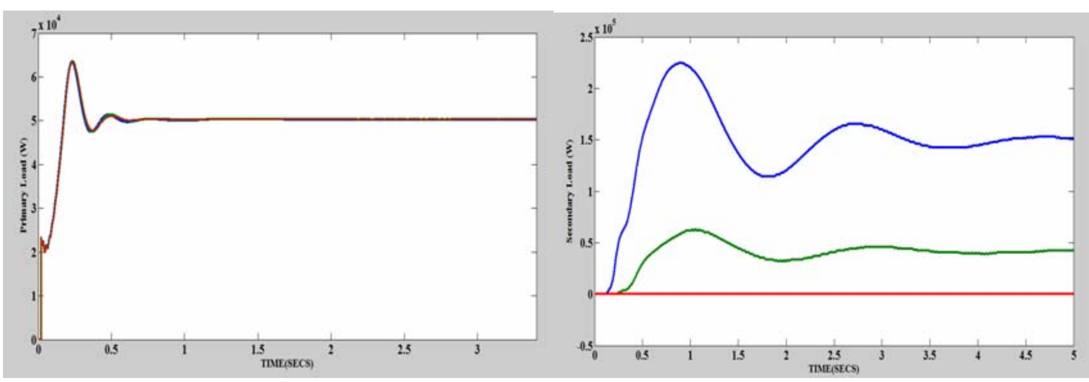

Figure-5. Power consumption of primary load (left): Secondary load (right) for Case-I.

CASE-II: Impact of transmission line on system performance

To analyze the performance of the system further in detail, transmission line of 1 km distance is introduced in the designed wind diesel hybrid system. The introduction of transmission line is considered for three cases:

a) Transmission line connected between wind generation system and synchronous condenser, where the load is connected near the synchronous condenser.

b) Both the wind generation system and synchronous condenser are placed close to each other and the transmission line is connected in between the point of common coupling (PCC) of wind generation system, synchronous condenser and load.

c) The Transmission line is connected in between wind generation system and synchronous condenser and in between point of common coupling and load.

Case-II(a)

VOL. 9, NO. 7, JULY 2014 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

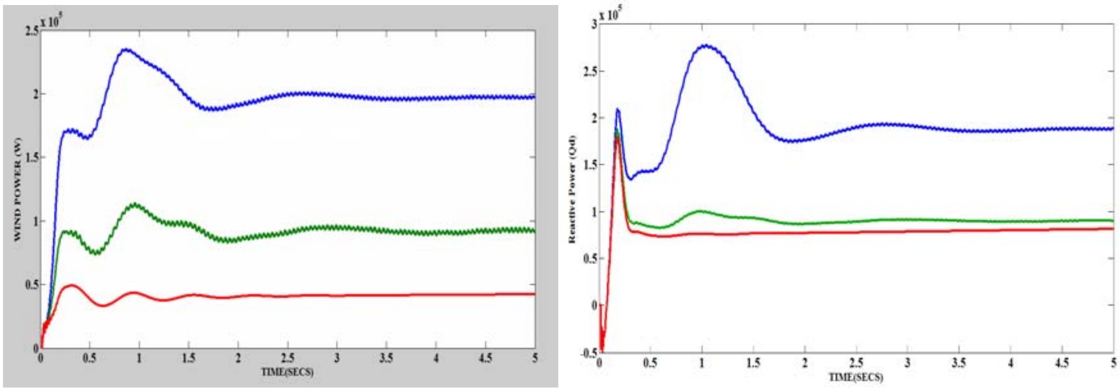

Figure-6. Real power produced by wind generation (left): Reactive power compensated by synchronous condenser (right) for Case-II(a).

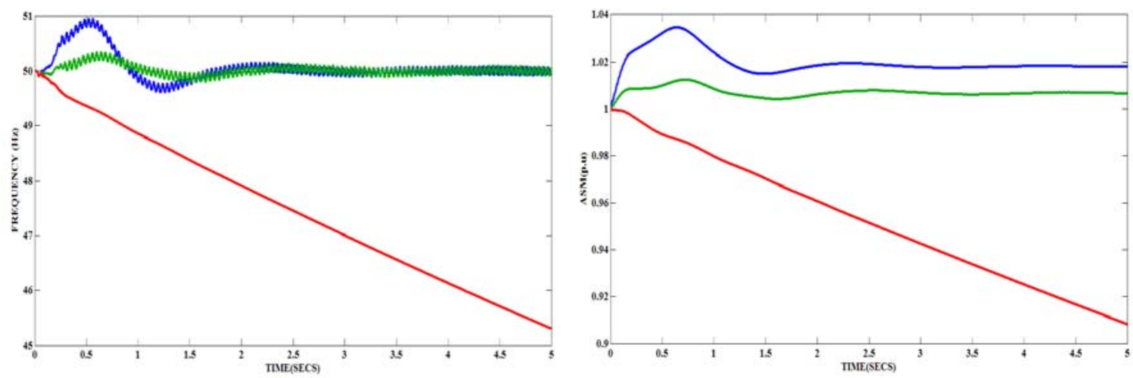

Figure-7. System frequency (left): Asynchronous machine speed ASM (p.u.) (right) for Case-II(a).

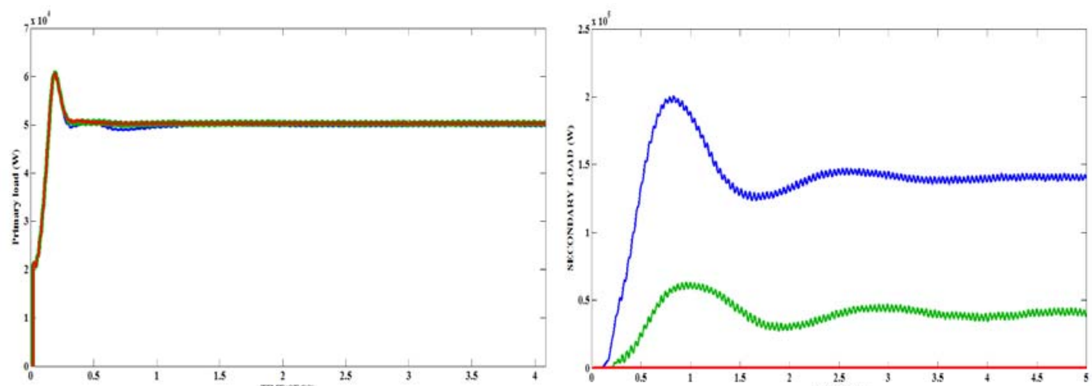

Figure-8. Power consumption of primary load (left): Secondary load (right) for Case-II(a).

The wind power output for different wind speed is similar to that of the results obtained in the case-I, but due to the introduction of transmission line, uncertainty in the wave forms is observed. The reactive power demand has considerably increased by 100 kVAR to a value to 200 kVAR approximately shown in Figure-6. This reactive power demand is to compensate the real power loss occurring through the transmission line. The uncertainty in the graph of frequency can also be observed in Figure-7, due to the presence of transmission line.

The wave forms pertaining to speed of the asynchronous machine, primary load and secondary load are similar to that of case-I as noticed from Figures 7 and 8, but uncertainty in the wave form can be observed in the case of power consumption of primary and secondary load.

Case II-(b)

 ISSN 1819-6608

ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

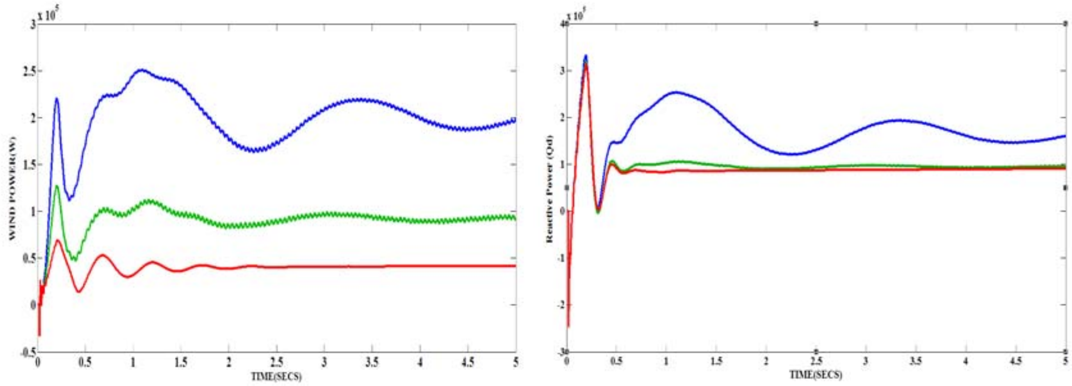

Figure-9. Real power produced by wind generation (left): Reactive power compensated by synchronous condenser (right) for Case-II (b).

The real power output of wind turbine for a wind speed input of 10 m/s is taking more time to obtain steady state (approximately 3.5s) compared to that of Case-II(a), as observed from Figure-9. The reactive power demand for the wind speed input of 10 m/s has considerably decreased and the primary load power consumption is decreased below the rated value of 50 kW for the same wind speed of 10 m/s compared to that of Case-II(a) which can be observed from Figures 9 and 11.

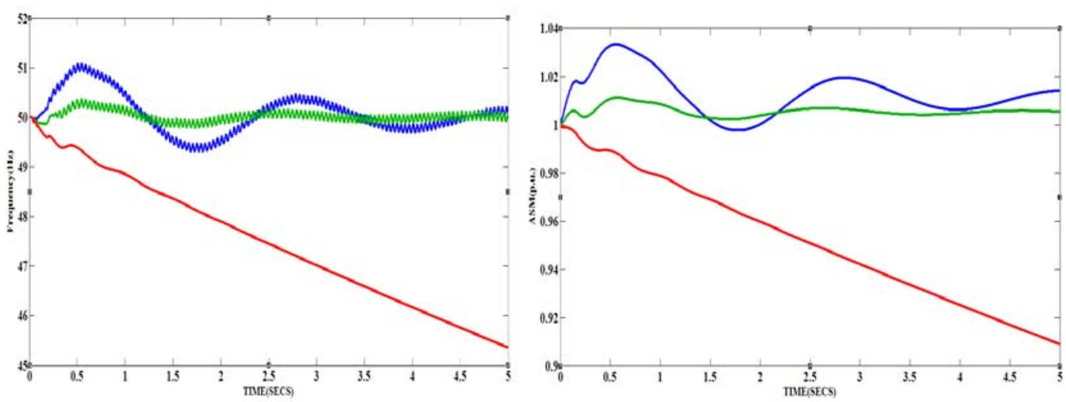

Figure-10. System frequency (left): Asynchronous machine speed ASM (p.u.) (right) for Case-II(b).

The distortion in the frequency for the wind speed of 10 m/s is also observed in this case. The deviation in asynchronous machine speed is observed for the wind speed input of 10 m/s and 8 m/s, but when compared to both wind inputs the machine speed in case of 10 m/s it is taking a time period of 4secs to obtain steady state, whereas in case of 8 m/s it is taking a time of 1.5secs to obtain steady state, as observed from Figure-10. The remaining wave forms left unexplained for the observed scopes are similar to that of Case-I.

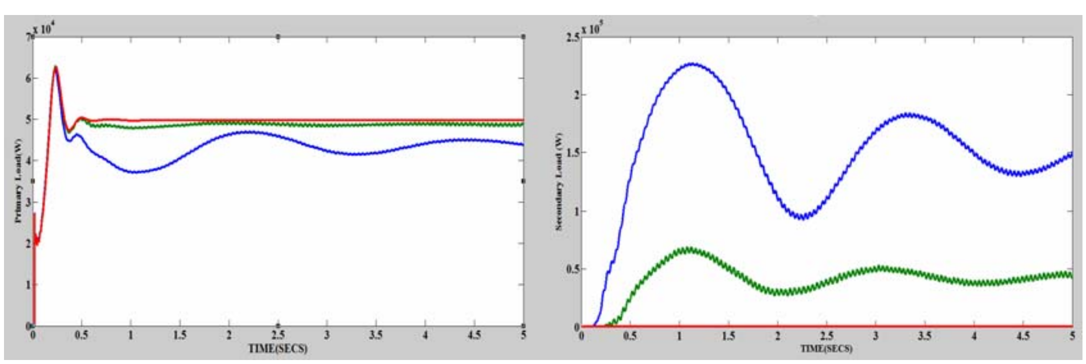

Figure-11. Power consumption of primary load (left): Secondary load (right) for Case-II(b).

VOL. 9, NO. 7, JULY 2014 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

Case-II(c)

Due to the presence of transmission line at both the places in the system the losses has been drastically increased at the same instance increasing the reactive power demand to a value of 250 kVAR compared to the previous Case-II(a) and Case-II(b) and it can be clearly noticed from Figure-12.

The remaining graphs pertaining to other values of the system in this case shown in Figures 13 and 14 are similar as mentioned in the previous case studies.

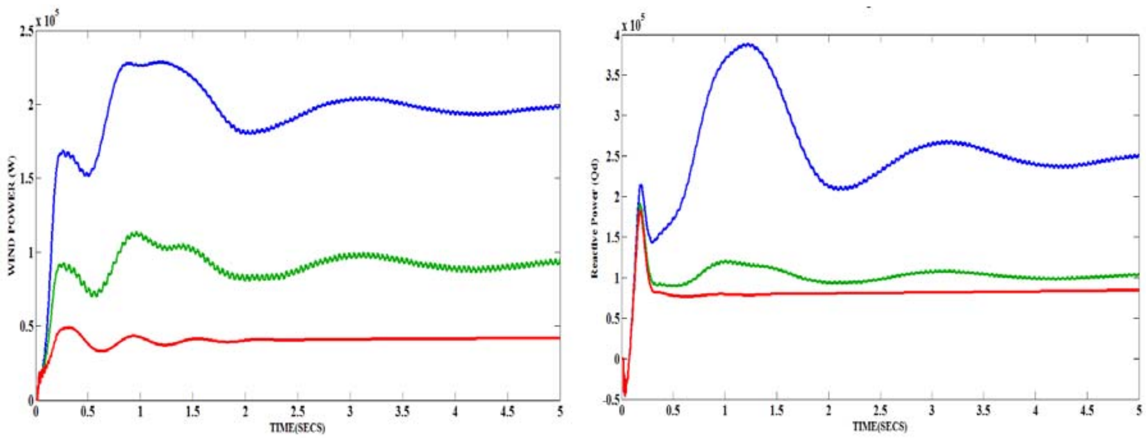

Figure-12. Real power produced by wind generation (left): Reactive power compensated by synchronous condenser (right) for Case-II(c).

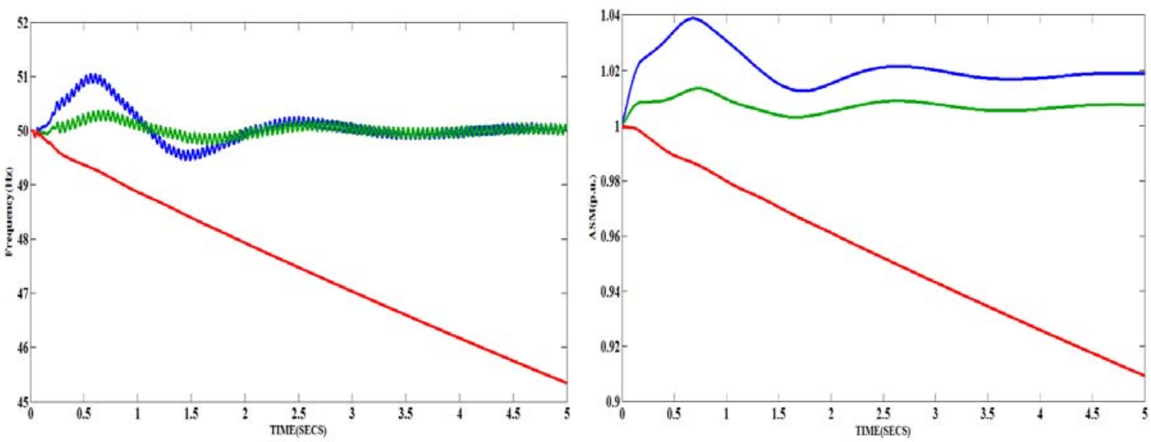

Figure-13. System Frequency (left): Asynchronous machine speed ASM (p.u.) (right) for Case-II(c).

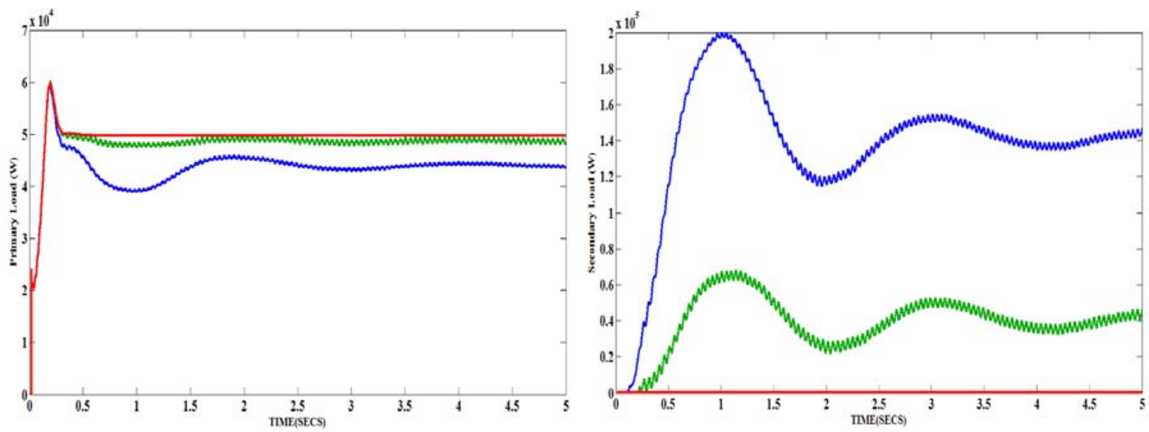

Figure-14. Power consumption of primary load (left): Secondary load (right) for Case-II(c).

4. CONCLUSIONS

The work has involved the MATLAB based simulation for performance analysis of a hybrid power system formed by combination of wind generation set and diesel generation under various conditions of real time situations. It is a major advantage of this type of hybrid system for enabling the electrification of remote locations where grid cannot be reached, optimized use of hybrid power system for economic and eco-friendly benefits.

It can be observed that the essentiality for the stability of the system frequency requires a fast acting dump load, which indicates that the excess of energy produced at a location can even be transferred to the nearby places to meet the energy demand or even can be preserved in a storage device to meet the energy crisis at the time of requirement.

It was noticed that the impact of variation in the wind speed input was on real power produced by the wind system and also the power flow between the wind system and synchronous condenser. It can be clearly observed that the system is out of stability for the lower wind speed input.

The impact of presence and position of transmission line in the system has been observed. In all the three cases of transmission line which has been considered, it is noticeable that the frequency of the system is not precise due to common transmission line effect. The Case-II(c) is not suitable due to increase in the transmission loss and also for reactive power compensation. Case-II(a) and Case-II(b) are nearly similar compared with the results with stability of the system in the case has to cautious but the Case-II(b) is preferable as the compensating reactive power demand is comparatively less to that of Case-II(a).

REFERENCES

[1] K.A. Kavadias. 2012. Stand alone Hybrid Systems. Reference Module in Earth Systems and Environmental Sciences, from Renewable Energy. 2: 623-655.

[2] REN'21: Renewable Energy Policy Network for the 21st Century. http://www.ren21.net/ren21activities/globalstatusreport.aspx.

[3] Eduard Muljadi H. and Edward McKenna. 2002. Power Quality Issues in a Hybrid Power System. IEEE TRANS. on Industry Applications. 38(3).

[4] S. Drouilhet. 1998. High penetration AC bus wind-diesel hybrid power systems. Village Power' 98 Technical Workshop, Washington DC., USA.

[5] R. Sebastian and R. Pena Alzola. 2011. Simulation of an isolated Wind Diesel System with battery energy storage. Electric Power Systems Research. 81(2): 677-686.

[6] C. Carrillo, A. Feijóo and J. Cidrás. 2009. Comparative study of flywheel systems in an isolated wind plant. Renewable. Energy. 34(3).

[7] R. Sebastian and R. Pena Alzola. 2010. Effective active power control of a high penetration wind diesel system with Ni-Cd battery energy storage. Renewable Energy. 35(5): 952-965.

[8] Apoorva Kanthwal and Aman Ganesh. 2012. Hybrid Wind-Diesel Generation System. International Journal of Applied Engineering Research. 7(11).

[9] R. Sebastian. 2009. Simulation of the Trasition from Wind Only Mode to Wind Diesel System. IEEE Latin America Transactions. 7(5).

[10] Marcos S. Miranda Renato O.C. Lyra and Selenio R. Silva. 1999. A Alternative Isolated Wind Electric Pumping System Using Induction Machine. IEEE Transactions on Energy conversion. 14(4): 1611-1616.