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Analysis of a Hybrid Wind Power Generation System in Isolated Mode

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Abstract—The energy demands increment, perishing resources of fossil fuels and growing pollution levels encourage more electricity generation using renewable energy sources such as wind, solar, geothermal, tidal etc. Generation of electricity using high speed wind seems a viable and environment friendly solution to meet energy crisis. However, due to variable nature of wind speed, it is difficult to supply constant power demands. In this paper, a hybrid energy generation using combination of wind turbine driven generator and Permanent Magnet Synchronous Generator (PMSG) driven by microturbine has been proposed, which is quite effective in supplying constant power loads. The two generation systems have been interfaced by power electronic interface. A simulation model of the hybrid generation system has been designed using MATLAB/SIMULINK and its various characteristics have been observed..

Keywords— Hybrid generating system, Micro turbine, PMSG, Wind energy.

I. Introduction

Today's power system mostly depends upon thermal generations which causes lots of carbon emissions leading to pollution of atmosphere. This has posed the danger of global warming and climate changes. Therefore, present world energy scenario is shifting towards the renewable resources of energy. These resources are environment friendly and free of pollution. However, renewable resources may depend on the natural factors which are out of human control. As in case of Wind Energy conversion plant, power generation is possible until there is sufficient wind speed available to operate the wind turbine. So, to improve the reliability of the system, renewable resources have to be clubbed with the conventional resources.

For the above purpose, a Hybrid Generation System is presented which generally consists of renewable sources such as Wind Power, Solar Power etc. and traditional energy sources. The high-performance control strategies for a novel Current Source Converter (CSC)-based wind turbine-Superconducting Magnetic Energy Storage (SMES) hybrid system have been proposed which improves the operating performance for the wind farm in the grid-connected operation and in islanding mode.

In Iran, a hybrid generation system for stand-alone application have been proposed which considers Wind-Turbine Generators (WTG), Photovoltaic (PV) systems, battery banks and diesel generator as power sources. The hybrid operation of fuel cell with other conventional DG system in utility interconnected mode and a linear state modelling of a diesel generator have been proposed. A PSCAD simulation model of the isolated micro-grid with wind-solar-dieselbattery hybrid power generation have been proposed based on the operating mode. Optimization through linear programming ahead generation scheduling of the windphotovoltaic- battery hybrid power system have been considered. The PI controller based frequency regulation of hybrid distributed generation system for sudden variation in load demand and wind have also been proposed. A hybrid renewable energy system consisting of solar photovoltaic and fuel cell for continuous power supply to the load have been proposed. The simulation and design models of the hybrid systems have also been developed.The modeling and simulation of Ramea hybrid power system that consists of mathematical models of diesel generators, wind turbines, electrolyzer, hydrogen generator and storage are also proposed. An interval optimization is integrated with the Markovian approach which divides the generation level of a conventional unit into a Markovian component and depends on the local state. A heuristic dynamic programming based controller is developed for the doubly-fed induction generator based wind farm to improve the system transient stability under fault conditions. An optimization technique based on a Multi-Objective Genetic Algorithm (MOGA) have been proposed that employs a techno-economic approach to determine the system design optimized by considering multiple criteria including size, cost, and availability. The methods for mitigating subsynchronous interaction between Doubly Fed Induction Generator (DFIG) based wind farms and series capacitor compensated transmission systems have been presented. The capability of Unified Power Flow Controller (UPFC) in attenuating sub-synchronous reactance in wind farm integrations is also proposed. A Remote Area Power Supply (RAPS) system consisting of a Permanent Magnet Synchronous Generator (PMSG), a hybrid energy storage, a dump load and a mains load is also considered. A wind generation is also modeled as a discrete Markov process based on historical data, to minimize the total commitment cost of conventional generators and their total dispatch cost. Analysis approach is done based on both trajectory and frequency domain information integrated with evolutionary algorithm to achieve the optimal control of doubly-fed induction generators based wind generation. A methodology for evaluating the reliability, considering demand side management and reliability information system for a grid constrained composite power system including wind turbine

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generators have been proposed . Integration of wind farm energy storage systems within microgrids where voltage and frequency control of the microgrid is shared by the wind generators through droop characteristics have been considered. A modeling and control strategy for a sustainable microgrid powered by wind and solar energy have also been proposed. An analytical stability study have been done, where speed is directly driven permanently, excited by 2MW wind generator connected to ac grids of widely varying strength and very weak grids. Analysis of sub synchronous resonance phenomena in doubly fed induction generator based wind farms interconnected with series compensated networks have also been proposed to analyze the induction generator effect and torsional interaction in system. The effectiveness of the commercial relay functioning in a local passive anti-islanding process for a permanent-magnet synchronous generator (PMSG)-based wind farm which is interfaced with a radial distribution network is also proposed. Impact of renewable power resources such as wind and photo-voltaic with storage systems in microgrid has been introduced.

Out of various renewable resources, wind energy generation seems to be a major solution due to availability of high speed winds near seashore. However, wind speed is quite fluctuating in nature. In case of low speed wind, power generation may be affected and it may not be possible to provide uninterrupted power supply to consumers. Hybrid energy generation may be the solution for such problem. This paper proposes a hybrid energy generation where wind energy generator is synchronized to PMSG driven by microturbine, through power electronic interface. Proposed scheme is able to supply almost constant power to consumers.

II. Hybrid Wind-Microturbine Generation System

Various advancements in the field of Wind Energy lead us to the design of a Hybrid Generation System comprising Wind Energy conversion system and Microturbine generation system. The major concern is to present the concept of hybrid generation system for increasing the usage of Wind Energy and further improving its reliability and efficiency. While using distributed generation source like Wind (considered renewable energy source in the system) there are two main problems for electric power generation:-

1. The unpredictable nature of the wind which disturbs the continuity of supply and hence raises the requirement of standby supply system.
2. The use of asynchronous generator as an electric generator.

These machines have merits that they can be driven on variable speeds that are well suited for random wind speeds, but have demerits that they need support of reactive power from utility or to the network from which they are connected. So, the continuity of supply depends on successful incorporation of renewable sources with conventional sources of energy.

In case of insufficient wind energy to meet the requirement, a backup supply system is required to be developed. In this paper, a combination of wind energy generation system and microturbine generation system is proposed. In this hybrid generation system, both the systems are complementary to each other. Such system act as virtual grid and could be operated either in isolated (stand-alone) mode or grid connected mode. While using hybrid systems, a power electronics interface is required to keep their voltage and frequency within prescribed limits.

Hybrid Wind-Microturbine generation systems shown in figure 1 have four main components:

1. Wind Energy Conversion System
2. Microturbine generation System
3. Power Electronics Interface
4. Energy Storage System

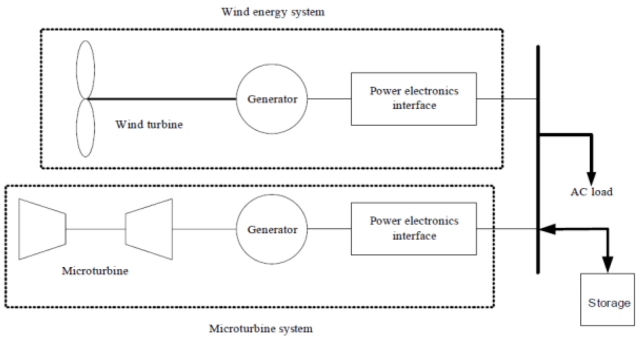

Figure 1. A Hybrid Wind-Microturbine Generation System

III. Simulation Model Of The Microturbine System

The block diagram of the Microturbine generation system is shown in the figure 2.

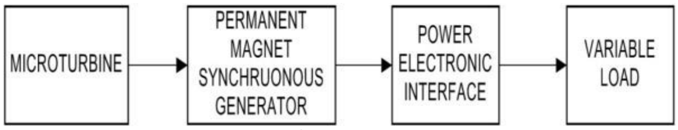

Fig. 2. Block diagram of Microturbine generation system.

The simulation model of the Microturbine with its whole system representation, along with its control system interconnections is shown in figure 3.

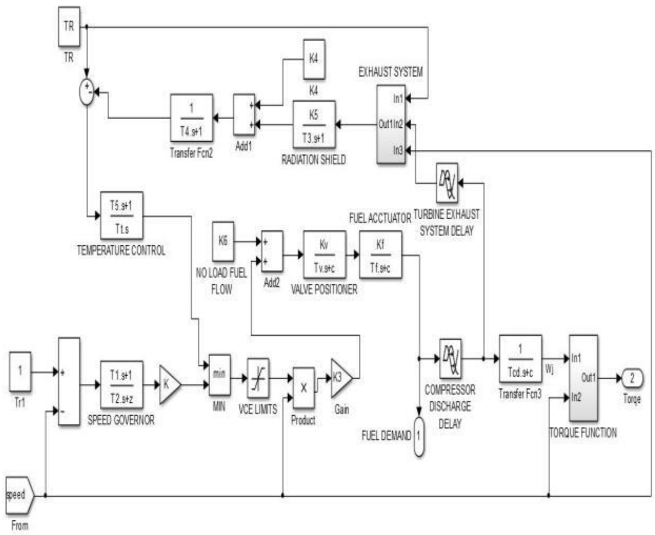

Fig. 3. Simulation model of a micro-turbine.

Bhanu Partap Singh, Monika Balgotra, and Meghna Sharma, "Analysis of a hybrid wind power generation system in isolated mode," *International Journal of Scientific and Technical Advancements*, Volume 2, Issue 4, pp. 179-186, 2016.

A. Modeling of Microturbine Generation System

The Microturbine generation system has the following main components required for its simulation in MATLAB environment.

1. Microturbine system
2. Permanent Magnet Synchronous Generator
3. Power Electronics interface
4. Variable Load

Parameters of the various components of Microturbine generation system are given in the following tables.

TABLE1. Parameters used for the simulation of PMSG

Stator Phase Resistance R_S (ohms)	0.0125
Armature Inductance (H)	165×10^{-6}
Flux Linkage (wb)	0.2388
Number of poles	4
Inertia (kg-m^2)	0.011

TABLE 2. Parameters used for the simulation of power electronics interface

VOLTAGE REGULATOR	K_P	0.4
	K_i	500
PWM GENERATOR	Carrier frequency (Hz)	2000
	Sampling Time (sec)	2μsec

B. Modeling of Hybrid Generation System

The hybrid generation system is modeled using a Microturbine generation system and wind generation system. Both the generation systems are connected to the load with a Power Electronics interface on Microturbine side.

Simulation model of the hybrid generation System is shown in figure 4. This system contains three subsystems Microturbine, Power Electronics Interface, and Wind Energy Conversion System. The simulation models of power electronic interface and wind energy conversion system have been shown in figures 5 and 6, respectively. The Wind Energy Conversion System and Microturbine Generation System are connected to the load through their respective buses. The current and voltage measurements from these buses are fed to the power computation block to calculate their respective powers.

TABLE 3. Parameters of microturbine system.

Speed Controller	Controller Gain (K)	25
	Governor Lead Time Constant (T1)	0.4
Parameters	Governor Lag Time Constant (T2	1
	Constant Representing Governor Mode (Z)	3
Fuel System Parameters	Valve Positioner Gain (Kv)	1
	Fuel System Actuator (Kf)	1
	Valve Positioner Gain Time Constant (Tv)	0.05
	Fuel System Actuator Time Constant (Tf)	0.04
	Constant (c)	1
	Gain (K3)	0.77
	Gain (K6)	0.23
Compressor Turbine Parameters	Combustor Delay (TCR)	0.01
	Combustor Discharge Delay (TCD)	0.2
	Turbine Exhaust System Delay (TTD)	0.04
	Coefficient (KHHV)	1.2
Temperature Control Parameters	Radiation Shield Constant (K4)	0.8
	Radiation Shield Constant (K5)	0.2
	Radiation Shield Time Constant (T3)	15
	Thermocouple Time Constant (T4)	2.5
	Temp. Controller Integration Rate (Tt)	450
	Temp. Controller Time Constant (T5)	3.3
	Reference Temperature (TR)	950

Bhanu Partap Singh, Monika Balgotra, and Meghna Sharma, "Analysis of a hybrid wind power generation system in isolated mode," *International Journal of Scientific and Technical Advancements*, Volume 2, Issue 4, pp. 179-186, 2016.

The Power Electronics Interface is used to convert high frequency output from the Microturbine generation system to 50 Hz. This system uses uncontrolled diode rectifier to convert AC to DC. This DC is filtered with the help of inductor and capacitor and fed to the Insulated Gate Bipolar Transistor (IGBT) inverter. IGBT inverter is controlled using a Pulse width Modulated (PWM) generator and Voltage regulator as shown in figure 5. Voltage regulator is supplied with three phase voltage (in p.u) from voltage measurement block and this voltage is compared with a reference voltage of 1 p.u on a base voltage of 380V. The supplied per unit voltage is converted to their respective d-q quantities (using abc to d-q transformation block) with a 50 Hz reference phase angle from Phase Lock Loop (PLL). Then PI controller performs the voltage regulation and the dq to abc transformation is done.

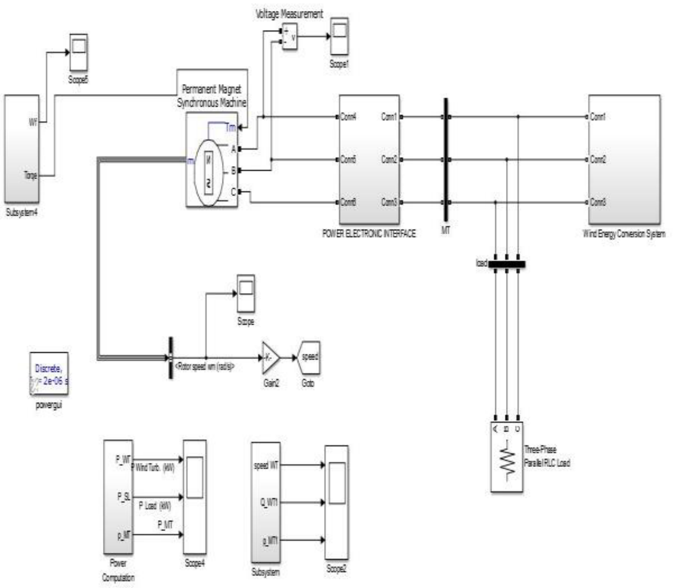

Fig. 4. Simulation Model of the hybrid generation system

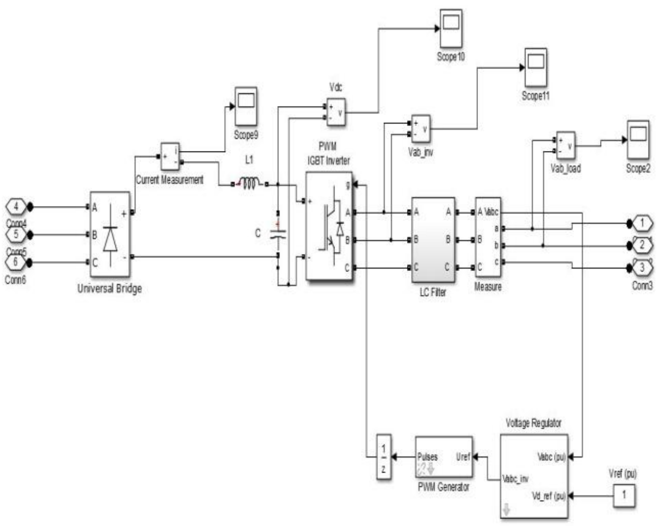

Fig. 5. Simulation of the power electronic interface.

Finally, this signal is fed to the PWM generator which generates the switching pulses for the IGBT inverter at a carrier frequency of 2 KHz. This interface is very important to match the system frequency and voltage with the other system with which interfacing has to be done. The other subsystem of the hybrid generation system is wind energy conversion system. This is the renewable system used as the main generation source in the hybrid system. This system runs on the variable wind inputs to the wind turbine producing useful torque required for running asynchronous generator. Feedback of the generator speed is given back to the wind turbine. Wind turbine runs on the constant pitch angle of 10°. A capacitor is connected after the asynchronous generator to improve the power factor of the system. The simulation model of the wind energy conversion system is shown in Figure 6.

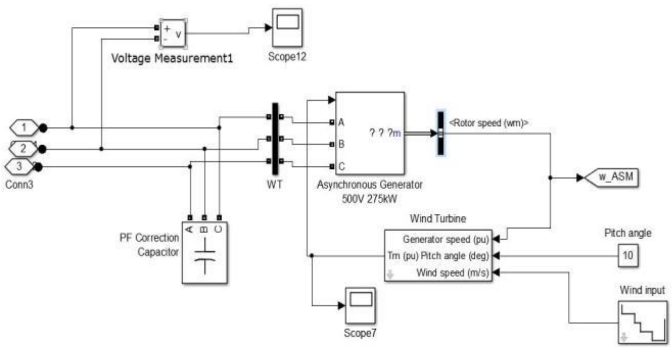

Fig. 6. Simulation model of the wind energy conversion system

The parameters for asynchronous generator of Wind energy conversion system is shown in Table 4.

TABLE 4. Shows parameters for simulation of asynchronous generator.

Asynchronous Generator	Nominal Power (kVA)	275
	Nominal Voltage ‘Vrms’ (volts)	380
	Frequency (Hz)	50
	Stator Resistance ‘Rs’ (p.u)	0.016
	Stator Inductance ‘Ls’ (p.u)	0.06
	Rotor Resistance ‘Rr’ (p.u)	0.015
	Rotor Inductance‘Lr’ (p.u)	0.06
	Mutual Inductance ‘Lm’ (p.u)	3.5

IV. RESULTS

Simulation of hybrid Wind-Microturbine generation system is performed using MATLAB/SIMULINK. The system runs under variable wind conditions, and characteristics of both the generation systems are studied. The system is run for 10 seconds under variable wind data as shown in figure 7. At t=0 seconds wind speed is 25 m/sec and varying at t=3, 4, 6, 8 seconds. The system is operating under constant pitch angle of 10°. The output voltage of the asynchronous generator operating by the torque supplied from the wind turbine is shown in the figure 8. The output voltage of microturbine generation system has been shown in Figure 9.

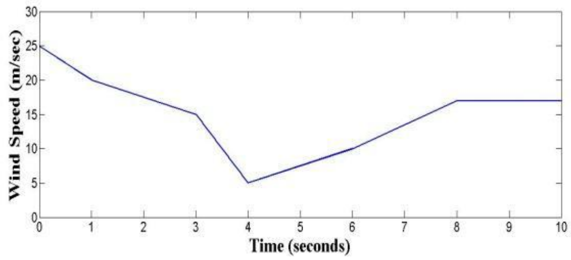

Fig. 7. Wind speed input to the wind turbine.

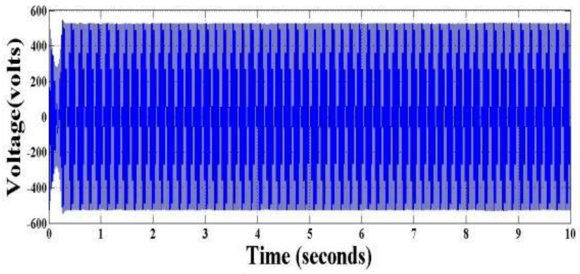

Fig. 8. Output voltage of the wind energy conversion system.

Figure 8 and 9 shows that the output voltage and frequency of both the generation systems is equal for full simulation time.

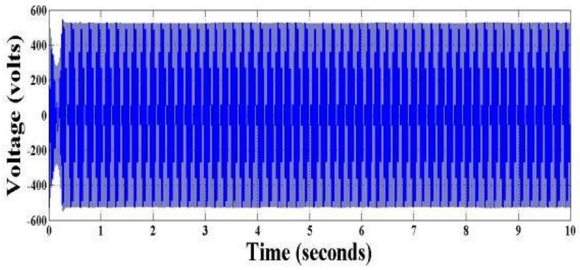

Fig. 9. Output voltage of the Microturbine generation system.

The output voltage of the Microturbine generation system is obtained by using a rectifier inverter circuit. Inverter is controlled by voltage regulator and PWM control circuit. The waveforms of the system are shown in figure 10, 11 and 12.

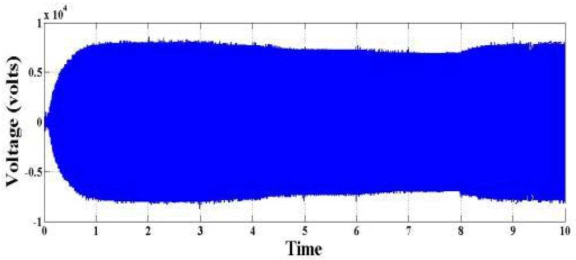

Fig. 10. Stator terminals voltage of PMSG.

Figure 10 shows the high frequency voltage output of the permanent magnet synchronous generator. Due to such a high frequency of the order of 1600 Hz, the system is provided with the rectifier-inverter circuit. Inverter is controlled by the voltage regulator converting this output voltage to 380V and 50 Hz.

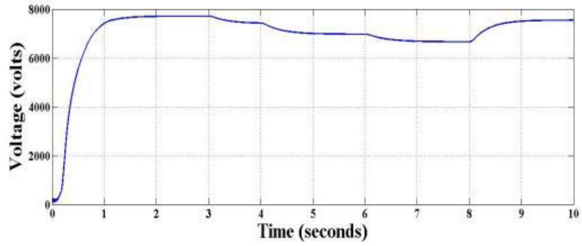

Fig. 11. DC link voltage of the power electronics interface

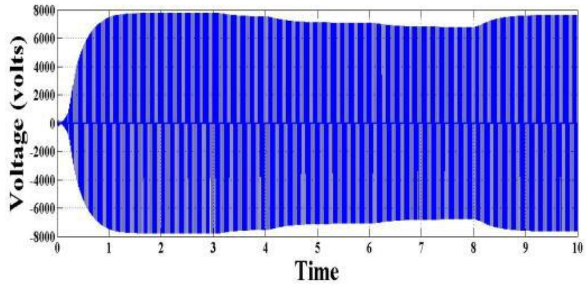

Fig. 12. Inverter output voltage of power electronics interface.

Figure 10, 11 and 12 shows the stepwise conversion of high voltage i.e. 8000V, and high frequency 1600 Hz. Figure 13 and 14 shows the variation of power supplied by the wind energy conversion system with the speed of the asynchronous generator. The system power decreases with the decrease in generator rotor speed.

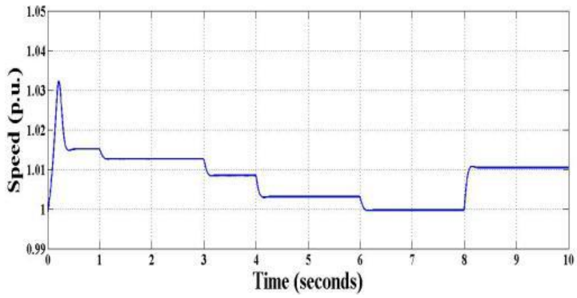

Fig. 13. Rotor speed of the asynchronous generator.

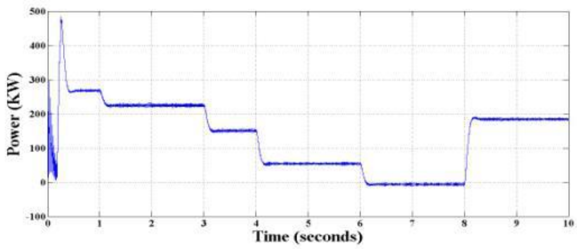

Fig. 14 Power extracted from the wind energy conversion system.

Bhanu Partap Singh, Monika Balgotra, and Meghna Sharma, "Analysis of a hybrid wind power generation system in isolated mode," *International Journal of Scientific and Technical Advancements*, Volume 2, Issue 4, pp. 179-186, 2016.

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Figure 15 shows power extracted from microturbine system. Power consumed by the load has been shown in Figure 16. Figure 14, 15 and 16 shows that both the generation systems are unstable till t=0.4 seconds. At t=0.4 seconds the Wind Turbine is supplying the major portion of power and Microturbine power share is about 30 kW. But, as the wind speed is reduced to 20 m/sec at t=1 second, wind power is not sufficient to fulfill the load demand. At this time, the Microturbine starts producing the deficient power. In the same way the Microturbine increases or decreases its output power according to the output of the wind power.

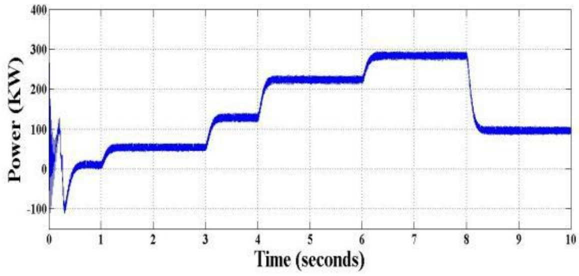

Fig. 15. Power extracted from the Microturbine generation system.

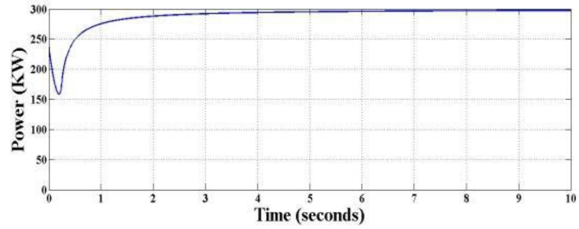

Fig. 16. Power consumed by the load.

Figure 17 represents the rotor speed of the permanent magnet synchronous generator. In this figure, the rotor rotates at rated speed at no load and speed of generator decreases as the load increases. This rotor speed is converted to per unit and sent to Microturbine system to control its fuel demand.

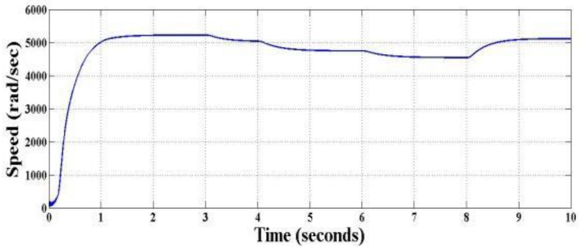

Figure 17. Rotor speed of the PMSG

Figure 18 shows load demand of microturbine system. It is seen from Figure 18 that the system requires fuel little more rated value for the purpose of starting and after that fuel demand varies with the rotor speed input. As the speed of the rotor decreases the fuel demand increases and vice versa. The asynchronous generator also requires the reactive power supply for excitation purpose during starting. This reactive power is supplied by the micro-turbine.

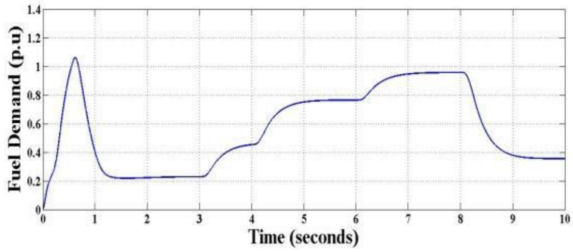

Fig. 18. Fuel demand of the Microturbine system.

Figure 19 and 20 shows that the reactive power requirement of the asynchronous generator during starting is compensated by the Microturbine generation system. After starting, the 75kvar capacitor connected in parallel to the asynchronous generator supplies the most of the reactive power and if more required; it is supplied by the Microturbine system.

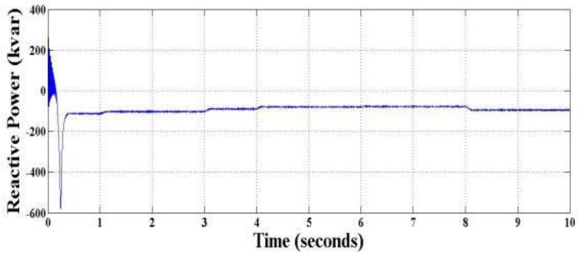

Fig. 19. Reactive Power characteristics of Wind energy conversion system.

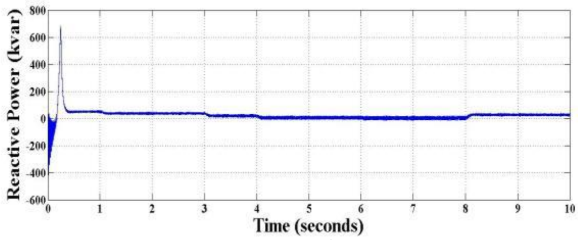

Fig. 20. Reactive Power characteristics of Microturbine generation system.

V. CONCLUSION

In this paper, a simulation model of a hybrid generation system comprising Microturbine generation system and wind energy conversion system is presented. This model is tested for evaluating the performance of the proposed hybrid generation system under varying wind speeds. Simulation results of the system show that the system is able to supply a constant power to the load irrespective of the wind speed input. This system also varies its fuel demand according to the load variations, resulting in low consumption of fuel. The system is also capable of meeting its reactive power demand, as asynchronous generator requires reactive power for excitation purpose. The hybrid Wind-Microturbine generation system is suitable for isolated mode (stand-alone) operation as both the generation systems very well coordinate with each other. Future research is required to be made to study the behavior of the hybrid generation system for connection to grid.

Bhanu Partap Singh, Monika Balgotra, and Meghna Sharma, "Analysis of a hybrid wind power generation system in isolated mode," *International Journal of Scientific and Technical Advancements*, Volume 2, Issue 4, pp. 179-186, 2016.

REFERENCES

[1] Zheng Wang, Bo Yuwen, Yongqiang Lang and Ming Cheng, "Improvement of operating performance for the wind farm with a novel CSC-type wind turbine-SMES hybrid system," *IEEE Transactions on Power Delivery*, Vol. 28, No. 2, pp. 1017-1022, April 2013.

[2] Pirhaghshenasvali M. and Asaei B. "Optimal modelling and sizing of a practical hybrid wind/PV/diesel generation system" *in Proc. IEEE 5th International Conference on Power Electronics, Drive Systems and Technologies Conference*, Tehran, Iran, pp. 506-511, February 2014.

[3] Nayak S.K. and Gaonkar D.N. "Fuel cell based hybrid distributed generation system- a review" *in Proc. IEEE 8thInternational Conferenceon Industrial and Information Systems*, Peradeniya, Srilanka, pp. 525-530, August 2013.

[4] Theubou T., Wamkeue R. and Kamwa I., "Dynamic model of diesel generator set for hybrid wind-diesel small grids applications," *in Proc. 25th IEEE International Canadian Conference on Electrical & Computer Engineering*, Montreal, Canada, pp.1-4, May 2012.

[5] Cai Guanglin, Chen Rouyi, Chen Jianbin, Wang Ke, Lin Yong, Wu Liexin and Zhang Yongjun, "Research on simulations and model of the isolated Wind-Solar-Diesel-Battery hybrid micro-grid" *in Proc. IEEE International Conference on Electricity Distribution*, Shanghai, China, pp. 1-4, September 2012.

[6] Lili Li, Qia Ding, Hucheng Li and Maohua Dan, "Optimal dispatching method for smoothing power fluctuations of the windphotovoltaic-battery hybrid generation system" *in Proc. IEEE Conference on Innovative Smart Grid Technologies*, Tianjin, China, pp.1-6, May 2012.

[7] Jayalakshmi N.S. and Gaonkar D.N., "Performance study of isolated hybrid power system with multiple generation and energy storage units" *in Proc. IEEE International Conference on Power and Energy Systems*, Chennai, India, pp.1-5, December 2011.

[8] Mahalakshmi M. and Latha S. "Dynamic modelling and simulation of hybrid generation systems" *in Proc. IEEE International Conference on Recent Advancements in Electrical, Electronics and Control Engineering*, Sivakasi, India, pp.371-376, December 2011.

[9] Ibrahim H., Lefebvre J., Methot J. F., and Deschenes J.S. "Numerical modelling wind-diesel hybrid system: Overview of the requirements, models and software tools," *in Proc. IEEE Electrical Power and Energy Conference*, Winnipeg, Canada, pp. 23-28, October 2011.

[10] Maruf-ul-Karim M. and Iqbal M.T. "Dynamic modelling and simulation of a remote wind diesel hydrogen hybrid power system" *in Proc. IEEE Conference on Electric Power and Energy*, Halifex, Canada, pp. 1-6, August 2010.

[11] Yaowen Yu, Peter B. Luh, Eugene Litvinov, Tongxin Zheng, Jinye Zhao and Feng Zhao, "Grid integration of distributed wind eneration: hybrid Markovian and interval unit commitment," *IEEE Transactions on Smart Grid*, Vol. 6, No. 6, pp. 3061-3072, November 2015.

[12] Yufei Tang, Haibo He, Jinyu Wen and Ju Liu, "Power system stability control for a wind farm based on adaptive dynamic programming," *IEEE Transactions on Smart Grid*, Vol. 6, No. 1, pp. 166-177, January 2015.

[13] Mohammad B. Shadmand and Robert S. Balog, "Multi-objective optimization and design of photovoltaic-wind hybrid system for community smart DC microgrid," *IEEE Transactions on Smart Grid*, Vol. 5, No. 5, pp. 2635-2643, September 2014.

[14] Ulas Karaagac, Sherif O. Faried, Jean Mahseredjian and Abdel-Aty (Aty) Edris, "Coordinated control of wind energy conversion systems for mitigating sub-synchronous interaction in DFIG-based wind farms," *IEEE Transactions on Smart Grid*, Vol. 5, No. 5, pp. 2440- 2449, September 2014.

[15] Sajjad Golshannavaz, Farrokh Aminifar and Daryoush Nazarpour, "Application of UPFC to enhancing oscillatory response of series compensated wind farm integrations," *IEEE Transactions on Smart Grid*, Vol. 5, No. 4, pp. 1961-1968, July 2014.

[16] Nishad Mendis, Kashem M. Muttaqi and Sarath Perera, "Management of battery-supercapacitor hybrid energy storage and synchronous condenser for isolated operation of PMSG based variable-speed wind turbine generating systems," *IEEE Transactions on Smart Grid*, Vol. 5, No. 2, pp. 944-953, March 2014.

[17] Peter B. Luh, Yaowen Yu, Bingjie Zhang, Eugene. Litvinov, Tongxin Zheng, Feng Zhao, Jinye Zhao and Congcong Wang, "Grid integration of intermittent wind generation: a Markovian approach," *IEEE Transactions on Smart Grid*, Vol. 5, No. 2, pp. 732-741, March 2014.

[18] Yufei Tang, Ping Ju, Haibo He, Chuan Qin and Feng Wu, "Optimized control of DFIG-based wind generation using sensitivity analysis and particle swarm optimization," *IEEE Transactions on Smart Grid*, Vol. 4, No. 1, pp. 509-520, March 2013.

[19] Jaeseok Choi, Jintaek Limand Kwang Y. Lee, "DSM considered probabilistic reliability evaluation and an information system for power systems including wind turbine generators," *IEEE Transactions on Smart Grid*, Vol. 4, No. 1, pp. 425-432, March 2013.

[20] Meghdad Fazeli, Greg M. Asher, Christian Klumpner, Liangzhong Yao and Masoud Bazargan, "Novel integration of wind generatorenergy storage systems within microgrids," *IEEE Transactions on Smart Grid*, Vol. 3, No. 2, pp. 728-737, June 2012.

[21] Sungwoo Bae and Alexis Kwasinski, "Dynamic modeling and operation strategy for a microgrid with wind and photovoltaic resources," *IEEE Transactions on Smart Grid*, Vol. 3, No. 4, pp. 1867-1876, December 2012.

[22] Nicholas P. W. Strachan and Dragan Jovcic, "Stability of a variablespeed permanent magnet wind generator with weak AC grids," *IEEE Transactions on Power Delivery*, Vol. 25, No. 4, pp. 2779-2788, October 2010.

ISSN: 2454-1532

Bhanu Partap Singh, Monika Balgotra, and Meghna Sharma, "Analysis of a hybrid wind power generation system in isolated mode," *International Journal of Scientific and Technical Advancements*, Volume 2, Issue 4, pp. 179-186, 2016.