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Development of Efficient Operational Mode for Wind-Diesel Hybrid System

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Abstract

Hybrid wind Diesel stand-alone power systems are considered economically viable and effective to create balance between production and load demand in remote areas where the wind speed is considerable for electric generation, and also, electric energy is not easily available from the grid. In Wind diesel hybrid system, the wind energy system is the main constitute and diesel system forms the back up. This type of hybrid power system saves fuel cost, improves power capacity to meet the increasing demand and maintains the continuity of supply in the system. Problem we face in this system is that even after producing enough power through wind turbine system, considerable portion of this power needs to be dumped due to short term oversupply of power and to maintain the frequency within close tolerances. As a result remaining portion of total energy supplied comes from the diesel generator to overcome the temporal energy shortage. This scenario decreases the overall efficiency of hybrid power system. In this study, efficient Simulink modeling for wind-diesel hybrid system is proposed and some simulations study is carried out to verify the feasibility of the proposed scheme.

Key Words : Wind Turbine, Diesel Generator, Hybrid Power System, Operational Mode, Backup

1. Introduction

Continually increasing power demand has to be met through a proper planned power generation system. Renewable energy resources are playing an active role in dealing with threats of energy shortage, environmental pollution and decreasing fossil fuel resources. Wind energy has gained a large momentum during the past decades. Wind power is considered one of the best attainable approaches to fossil fuels [1-4] and energy production using this resource is increasing with the passage of time. Wind and diesel system is a reliable hybrid system. As wind is intermittent in nature, so diesel generator acts as a cushion for wind system to smooth power transfer as the load demand. These hybrid systems are being used as an electric power supply source in relatively small islands and remote areas. In [5] Wind/Diesel generator hybrid system, different strategies such as dump load, switched load control, superconducting magnetic energy system are being adopted to reduce the imbalance between production and demand. In our proposed system, Dump load is used to dump the extra power generated by wind turbine and to maintain the desired frequency within defined limits. The main problem which makes the hybrid system less profitable and inefficient is that even after generating much power through wind turbine system than the load demand; diesel generator needs to be operating to overcome the transitory energy deficiency. In this case [6] dump load is used to dump extra energy in form of heat and to maintain the frequency within permissible limits.

In this study, research work is being done to make hybrid system performance more efficient and energetic. More practical and efficient operational mode is developed by using state flow chart technique for wind diesel hybrid system. By using this technique we make controller system working more steady and reliable. Some simulations study is carried out to prove the feasibility of the proposed design.

2. Wind Diesel Generation System

Wind diesel generation system is the economic and systematic replacement of conventional power generation systems. This generation system is the hybrid of two mechanisms, i.e. diesel generator and wind turbine generator system. This hybrid system relies on power electronic interfacing for functioning and inter-

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facing between diesel and wind turbine generation units as shown in figure 1.

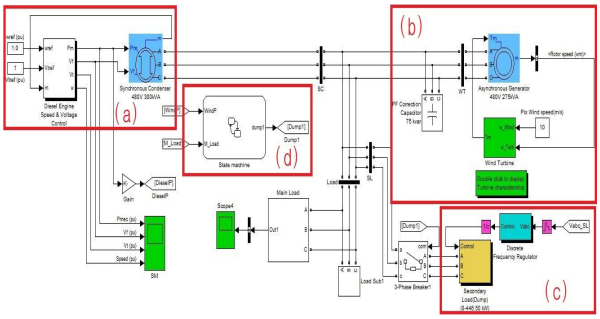

Fig. 1. Wind Diesel Hybrid System

Diesel generator, wind generator with dump load and state machine makes the whole hybrid system as shown in figure 1. Mainly to meet load demand power is generated using wind power generation system. In case if wind system is unable to complete load demand, diesel generator will start operating and supply the remaining power required for load. Usually even if the power generated by wind system in more than enough for load, a portion of this power needs to be dumped due to short term oversupply of power and the part of total energy supplied comes from the diesel generator to overcome the transitory energy shortfall. To make the system working performance better by solving this problem, state machine is being designed which will operate the whole system with different conditions as described in section 2.4 and minimize the power used by dump load to great extent. Here is brief discussion on the both power generation systems.

2.1 DIESEL GENERATOR MODEL

Diesel generator a conventional energy resource considered as controlled energy resource. It is a source that can supply power demand up to rated power at [7] constant frequency. This generator system consists mainly on two parts, i.e. diesel engine & governor and excitation system. A 300 kVA synchronous generator with different capacity loads is discussed here.

In diesel engine speed and voltage control block, diesel engine produced the mechanical power by combusting fuel which is then input to the synchronous generator. Initially the power produced by diesel engine is small as the synchronous generator connected with engine is in no load condition due to circuit breaker in open state. After operating breaker and coupling of load, machine speed decreases for a short time and input mechanical power to the generator terminals also decreases. System stabilize itself after a short period of time due to the operation of speed control system and input power to generator stabilizes to required level. Due to the operation of (excitation system) [8] voltage control system, voltages at the generator terminals also maintains as the load demand.

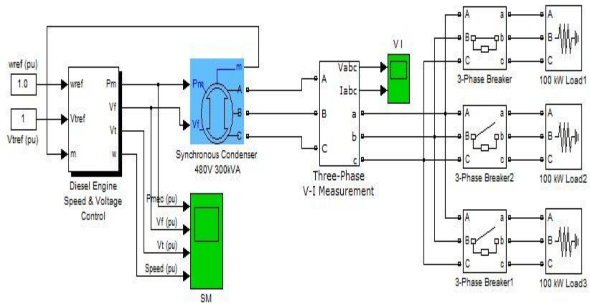

Fig. 2. Diesel Generator Model

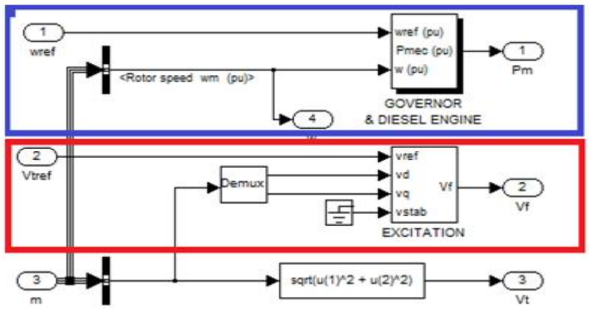

Fig. 3. Diesel Engine Speed and Voltage Control System

If the load demand is greater than the grid power, then it results in decrease in frequency of the output eventually. In the [9] governor & diesel engine block, reference rotor speed is already defined and using feedback system rotor speed of generator is also input to get the error value between two speeds to perform the function of controlling fuel combustion which results in power with desired frequency. In figure 4 the internal configuration of a diesel generator governor is shown.

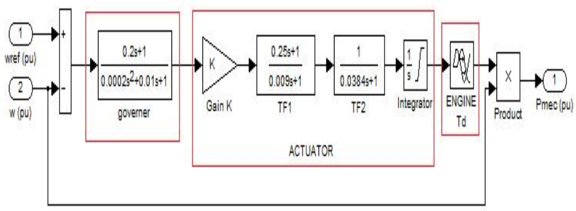

Fig. 4. Internal Configuration of Governor

To study the operating conditions of synchronous machine, we have to transform the three phase model to two phase (d-q) orthogonal model to understand the assembly of regulation system in better way. As shown, the output (Vf) of excitation block is input of synchronous generator. If the load needs much power than the product, we need to control the field voltages according to the load demand through the excitation system. In this case, reference terminal voltages (Vtref) are already defined. Vd and Vq are real stator voltage (Vt) components. By comparing the Vtref and Vt, we can get the error value to activate the excitation controller to produced required field voltage (Vf) and as a result reactive power as the load demands. The internal structure of excitation block is shown in figure 5.

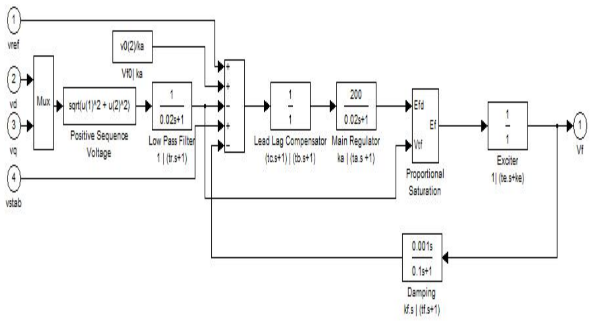

Fig. 5. Internal Configuration of Excitation Block

In excitation block, we can achieve Vt nearly equal to the Vtref by applying more current to rotor coil to create strong magnetic field to get the Vf as needed to produced required reactive power as load demand. Basic controlling principles of diesel generator are discussed here.

2.2 Asynchronous Wind Generator Model

Wind energy is clean, silent and reliable, with low maintenance costs and small ecological impact among the technologies using renewable energy resources. Along with these advantages, wind energy pose technical problems due to its intermittent nature. This is the reason that wind generation system in considered uncontrollable energy source.

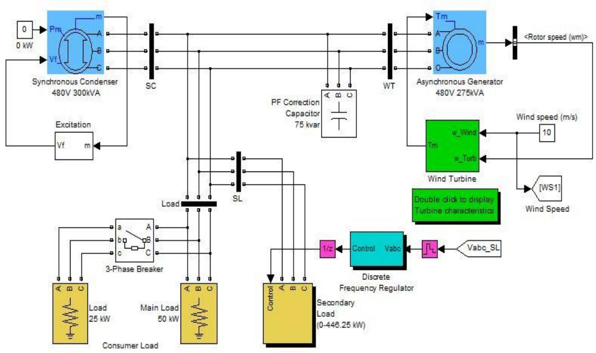

Fig. 6. Wind Turbine Model

A 275 kVA asynchronous generator with input power from wind turbine and different capacity loads is discussed here and shown in figure 6.

Turbine characteristics such as turbine operating speed with respect to output power and turbine generator rotor RPM is shown in figure 7.

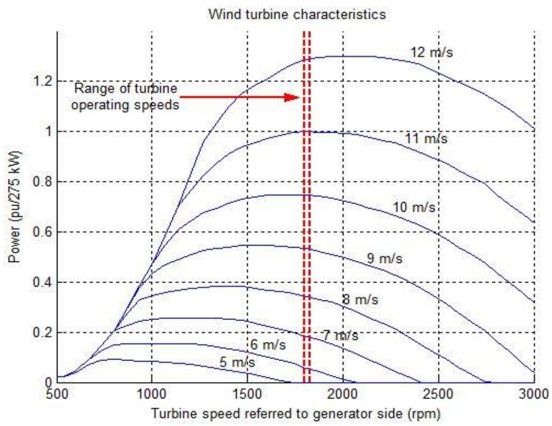

Fig. 7. Wind Turbine Characteristics

The Wind Turbine block [11] as shown in figure 8 uses a 2-D Lookup Table [10] to compute the turbine torque output (Tm) as a function of wind speed (w_Wind) and turbine speed (w_Turb). For example according to turbine characteristics, for a 10 m/s wind speed, the turbine output power is 0.75 pu (206 kW). In this block wind speed data and wind turbine rotor data from asynchronous generator is fed as input through feedback system. Using 2D lookup graph we can control the output torque of wind turbine which is the input of the generator. As a result, generator can produced the output power as the load demands.

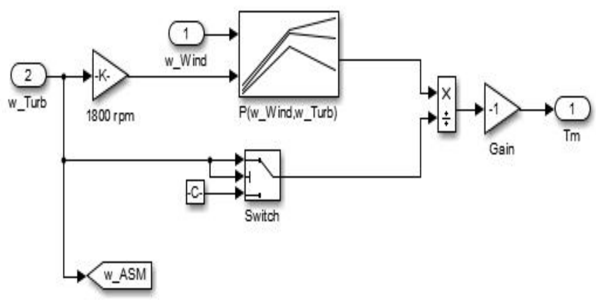

Fig. 8. Internal Configuration of Wind Turbine Block

2.3 Dump Load Controller

Dump load or secondary load [11] is installed to ensure the safe way to disperse surplus power produced by wind turbine to stabilize the system performance such as frequency of the output to desired limit. Load on wind turbine always is another feature of dump load. If there's no dump load to consume excess power, it decrease the load on turbine causes reduction in resisting torque and purpose the over speeding of turbine. In case of high wind speed, Generator will produce more power than the load demand. As a result the frequency of the output voltage will be disturbed compared to reference frequency point. Frequency can be maintained by dumping the extra power generated by generator to dump load. To manage the whole process, discrete frequency regulator block is used as shown below.

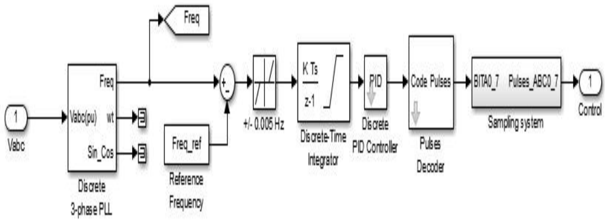

Fig. 9. Discrete Frequency Regulator Configuration

The frequency is controlled by the Discrete Frequency Regulator block. This regulator uses a standard three-phase Phase Locked Loop (PLL) system to measure the system frequency. The measured frequency is compared to the reference frequency (60 Hz) to obtain the error. The integrated phase error is then used by a Proportional-Differential controller to produce an output signal representing the required secondary/dump load power as shown in figure 9. The output signal is converted to an 8-bit digital signal which controls switching of the eight resistive loads inside secondary load. In order to minimize voltage disturbances, switching is performed at zero crossing of voltage.

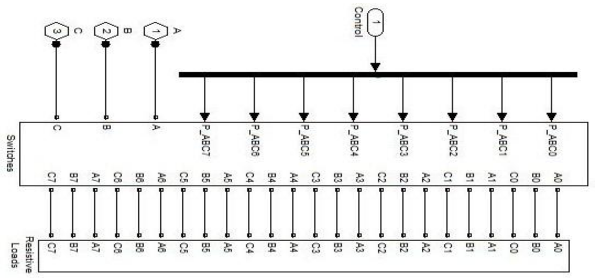

Fig. 10. Dump Load Internal Structure

The Dump load as shown in figure 10 consists of eight three-phase resistors connected in series with GTO (gate turn off) thyristor switches. The power of each resistor set can be control by a binary progression so that the load can be varied as required. The thyristors selectively switch on/off by the binary output from the PD controller to dissipate the power by dump load as determined. By following this binary progression, load can be varied from 0 to 446.25 kW (rated) by steps of 1.75kW.

2.4 State Machine For Efficient Power Control

Graphical and tabular interfaces are provided by state flow [12] for modeling system logic using state machines. In a state machine, system's modes of operation are modeled as states and represent the logic for switching between modes using transitions and junctions by comparing input data. Logic can be designed by defining conditions to be checked and desired actions to be performed as a result. State machine block we designed is shown in figure 11.

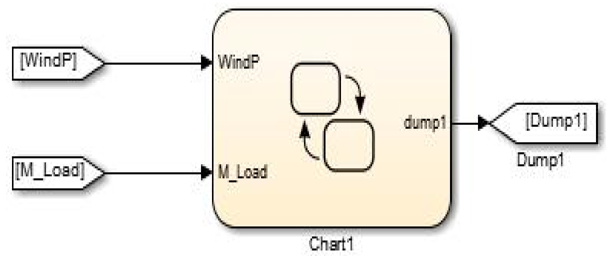

Fig. 11. State Machine Block

State machine inputs are wind power and main load while as output it will decide the power to be consumed by dump load. By designing this state machine we make our system performance more productive as a whole by controlling operation of diesel, wind generation system and less use of dump load eventually by consuming output power effectively. State machine design internal configuration with its states and conditions is as follow.

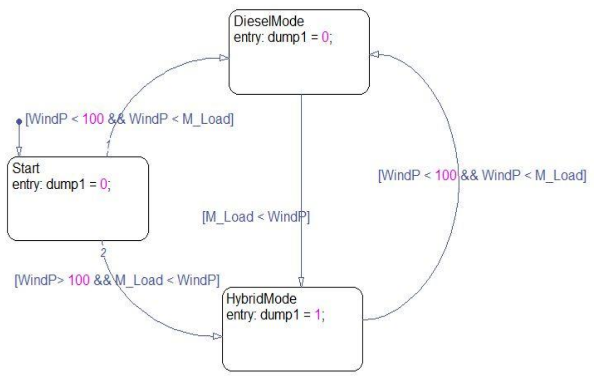

Fig. 12. Design of State Machine

Initially system is operating in wind mode with dump load in off condition. System will analyze condition 1 and 2 periodically. If system meets the condition 1, i.e. wind power less than 100 & main load, system operation mode will change to diesel mode state with dump load is in off mode. Hybrid system will provide output power generated by diesel and wind generation system. If system unable to meet condition 1, it will analyze condition 2 and will operate in hybrid mode with active dump load. The system will stay in this state until it fulfills the next condition, i.e. wind power less than 100 & main load. The system will go in diesel mode with off dump load and will operate in same state until it follows the next condition and the same procedure will go on. This conditional operation mode controlled by state machine makes the system performance efficient.

3. Simulation Study

Hybrid wind-diesel power generation system is discussed in section 2 in detail. Now the matlab simulations study of the whole system is examined.

3.1 Diesel Generator Simultion

Power System consists on diesel generator with different resistive loads and simulation block for indication of output characteristics is shown in figure 13.

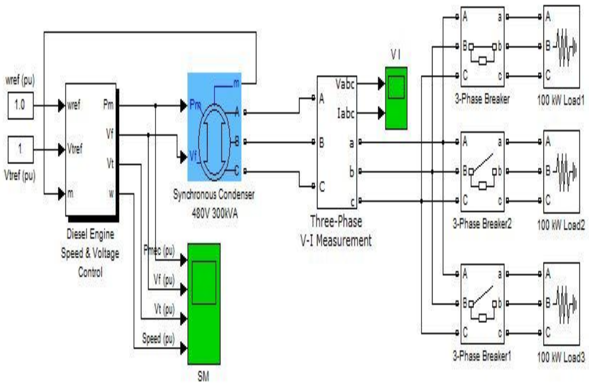

Fig. 13. System Consist of Diesel Generator and Resistive Load

Time variation of load demand scenario is defined in Table 1.The output of the diesel generator, synchronous generator excitation voltage and the grid frequency (power frequency) are shown in Figure 14.

Table 1. Main Load Simulation Scenarios

time(sec)	load(kW)
0~5	100
5~10	200
10~15	300
15~20	200

It can be seen that diesel generator system producing 100 KW power as the main load demand till 5 sec periods. After the addition of extra load as defined in scenario table 1, system generates output power of 200KW for period of 5-10 sec and the process further goes on. As the load increase frequency of output drops for short time but system stabilize the output frequency by increasing excitation voltages as shown in Vf block of figure 14.

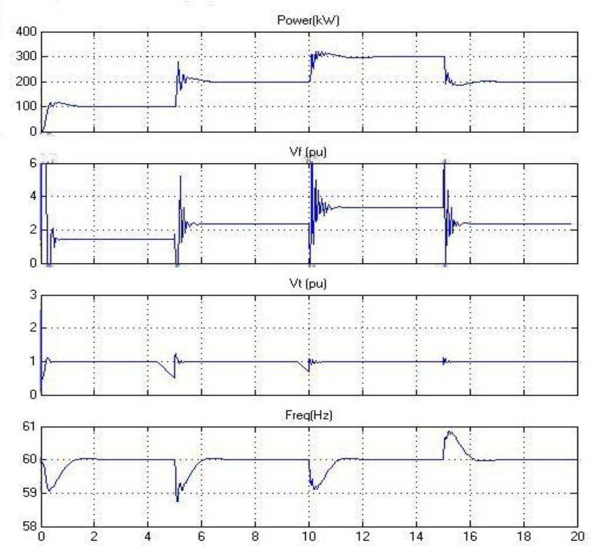

Fig. 14. Output Characteristics of Diesel Generator Load

3.2 Wind Turbine Generator Simulation

Power system consisting on wind turbine generator, resistive load, dump load and simulation block for the indication of output characteristics is shown in figure 15.

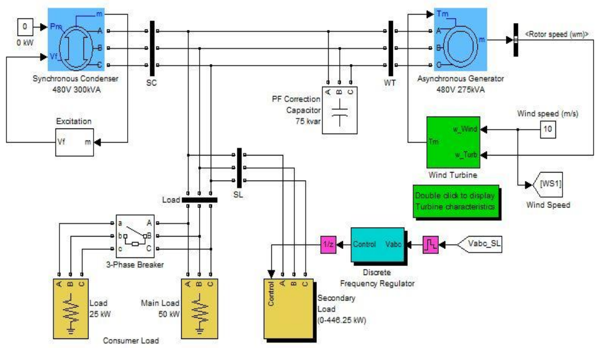

Fig. 15. Wind Generation System with Resistive and Dump Load

Figure 15 shows the wind turbine generator with capacity of 275 KVA and resistive load of 75 KW. When the output power is greater than the load demand, dump load is also installed in system to consume the surplus power with the maximum limit of 446.25 KW.

Time scenario for Changes in the load demand is same as in Table 2 and wind speed, output power, load demand; dump load represents the response of Figure 16. As already discussed wind speed is fixed to 10 m/s. For the time period of 0-5 sec wind generator output is 200 KW and the load demand is 50 KW. The surplus power (150 KW) is consumed by the dump load as shown in simulation result and the same process for the next time period according to table 2 scenario.

Table 2. Load Simulation Scenarios (Wind 10m/s Fixed)

time(sec)	load(kW)
0~5	50
5~10	75

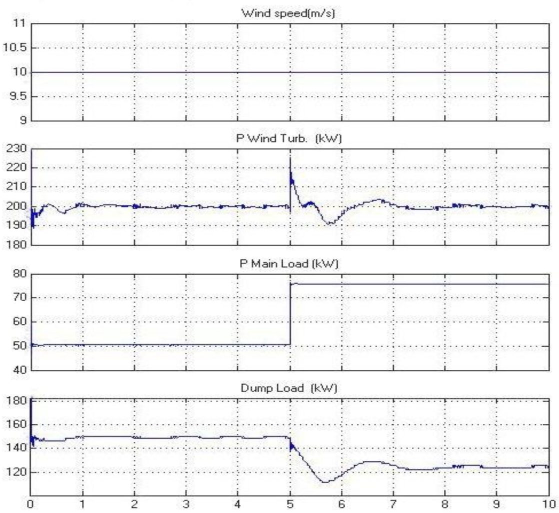

Fig. 16. Output Characteristics of Wind Generator Load

3.3 Hybrid System Response

Wind diesel hybrid generation system main load and wind speed graphs are shown in figure 17. System response is described as simulation graphs with and without efficient state machine.

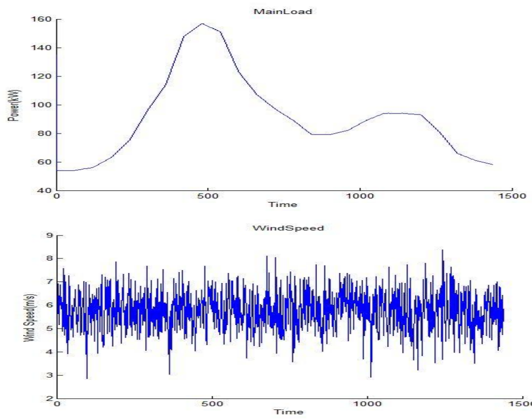

Fig. 17. Main Load & Wind Speed Data Simulation

3.3.1 Hybrid System Response Without State Machine

Due to the intermittent nature of wind, output power from wind turbine also varies and this problem cause imbalance between produced power and load demand. To compensate the less power, diesel generator is also need to be operated. In normal operations, even if the produced power from wind is enough for load still a portion of power is supplied by diesel generator while a specific portion of produced power is to be dumped to maintain the output power.

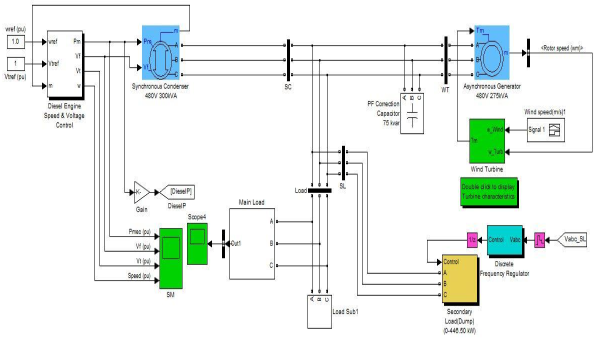

Fig. 18. Hybrid System Without State Machine

This undesirable behavior of both generating excess energy and dumping is main obstacle in improvement of system efficiency. Output simulations including wind speed, turbine power, diesel generator output, frequency and main load are shown below.

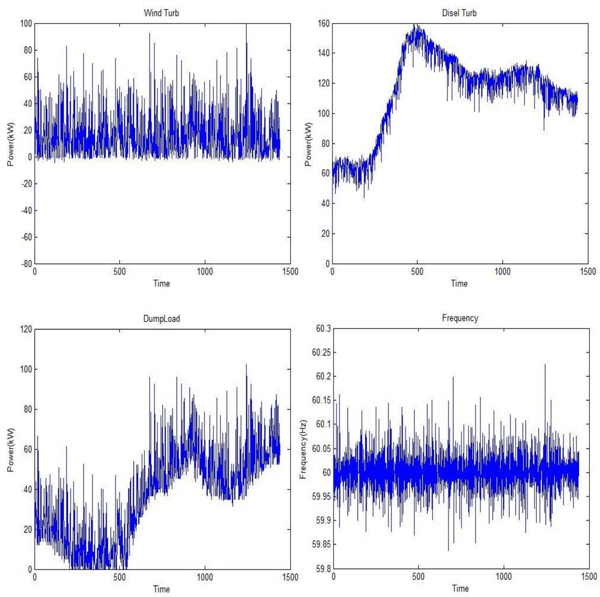

Fig. 19. Output Characteristics of Hybrid System Without State Machine

It can be seen from the simulation results that even most of the time wind system producing enough power for main load but still diesel generator is in operational mode to compensate the power shortage due to transient energy deficits to meet the load demand. As a result considerable portion of produced power is used by dump load which decrease the overall hybrid system efficiency.

3.3.2 Hybrid System Operation With State Machine

To solve the problem of excess output power dumping to dump load, state machine has been designed and simulations carried out to examine the system output efficiency.

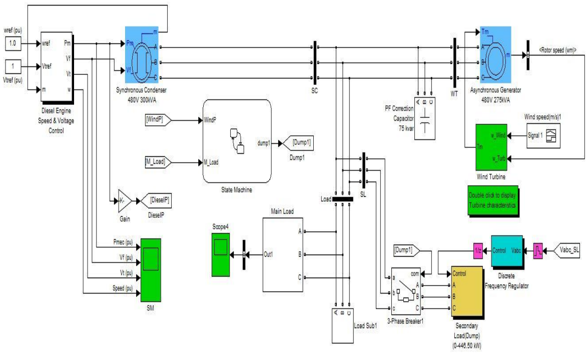

Fig. 20. Hybrid System With State Machine

By controlling the operation of diesel generator, wind generator and active switching of dump load using state machine scenario as defined in figure 12, system overall efficiency has been increased as shown in figure 21.
It can be seen that output power dumped is very less as compared to the power dumped in normal operation mode without state machine.

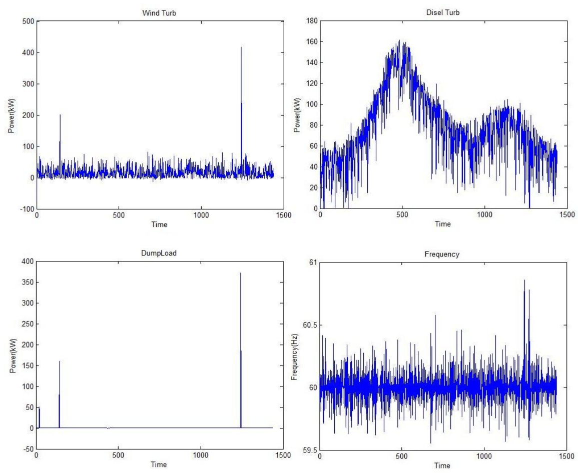

Fig. 21. Output Characteristics of Hybrid System With State Machine

4. Conclusion

In this study, hybrid wind-diesel system functioning and output characteristics are studied in normal condition and in proposed way with state machine. Simulation results show that higher efficiency can be achieved using the designed state machine shown in figure 21. State machine effectively controls the switching between operational modes of system, i.e. from wind to hybrid & back to wind and dump load to consume surplus generated power and increase the system efficiency to a great extent as witnessed by analyzing figure 19 and 21. Also it can be seen that system output frequency increases to a minor extent in state machine mode. The reason behind this little rise is the switched off period of dump load because in that period discrete frequency regulator block is unable to regulate or stabilize frequency same as during normal operational mode. But still after this insignificant rise in frequency, system output frequency is in range of 60 Hz with ±1% error assigned by Korea Electronics Standards.

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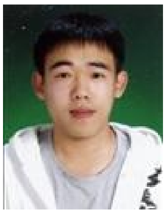

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