International Journal of Trend in Scientific Research and Development (IJTSRD)
International Open Access Journal | www.ijtsrd.com
ISSN No: 2456 - 6470 | Volume - 2 | Issue – 6 | Sep – Oct 2018

Frequency Regulation and Active Power Control in Wind-Diesel Based Hybrid Power System Using BESS

Mohd Azrul
M.Tech Scholar, Electrical Engineering Department YIET,
Gadhauli, Yamunanagar, Haryana, India

ABSTRACT

Hybrid power systems must be self-sufficient in terms of frequency and voltage control due to their islanded operation. A control strategy to combine the operation of a wind generator, a diesel generator, a battery energy storage system and a dump load for frequency regulation is proposed in this thesis. The proposed strategy partitions the control task into two subtasks: a) choosing the element to be operated on, b) providing frequency regulation. A global controller, based on an IF-THEN inference engine, chooses the element to operate. The frequency regulation is provided by separate individual controllers. In this thesis, a hybrid power system has been modelled and the proposed control strategy has been tested. By monitoring the system's power management and frequency, it is shown that the proposed control strategy operates efficiently. The proposed strategy also reduces the number of measurements required and facilitates the integration of renewable energy sources.

Keyword: *Battery energy storage system, Micro grid, Frequency control, Single-phase inverter*

I. INTRODUCTION

In the current context of globally promoting the integration of renewable energy sources (RES) in small, medium and large-scale power systems, with the power grids expanding and becoming more complex, the development of new technologies for better RES integration and utilization is a current concern worldwide. Many countries are focusing to achieve the RES targets, to reduce the greenhouse gas emissions and to make the societies less energy-consuming [1]. However, the RES power variations and their unpredictable nature decrease the grids' reliability by making them more sensitive to voltage and frequency stability issues, the power reserve estimation becomes more difficult and the security of supply can be affected. Therefore once the RES penetration level increases the related standards are continuously revised [2].Within this context, a new power system structure has emerged, namely the micro grid (MG), which was initially developed to supply remote consumers with electricity. A MG consists of one or more micro-generators (of the same type or different)and consumers, defining all the equipments and infrastructure required to operate a small-scale power system [3]. The MG is meant to be mainly supplied by RES, whereas specific control devices (e.g. energy storage systems) maintain the required power quality.

Despite of the potential benefits, the development of MGs suffers from technical difficulties, lack of standardization, economical challenges, and administrative and legal barriers [4,5]. Recently, the smart grid (SG) evolved towards a new concept, where the MG represents the main building block [6,7]. Multiple MGs, linked through power and communications lines, can be seen in the SG as the equivalent power generators in the conventional power systems. The MG can operate islanded, feeding power to the local consumers from the in site power generators, or it can be interconnected with other grids. The power quality issues in an autonomous MG are rather similar to those from a classical power system (voltage, frequency, security of supply). The main MG weakness comes from the limited power supply capacity, especially when the RES penetration level is high. The majority of technical resources are based on power electronics converters, which are the critical distinguishing feature of the MGs, along with intelligent control and communication [8, 9]. Besides the generators, storage elements and other equipments needed for a normal operation, the MG may also include a centralized control system (the equivalent of a grid dispatcher), known as the micro grid central controller (MGCC) [10,11]. All the decisions regarding the MG resources handling are fulfilled by the MGCC, which provides the appropriate commands for each MG unit.

The frequency control process represents a main component within the control system of a MG. Giving the fact that the MG is characterized by small rigidity in comparison with the classical grid, the RES generators and the loads power variations are the main sources of instability. Ensuring an adequate power quality largely depends on maintaining the grid frequency within a certain range (e.g. ±2%), regardless of the generation and consumption levels. Unlike the voltage, which is a local power quality parameter of a network, and which usually depends on the reactive power flow, the steady-state frequency of a certain synchronous area represents a global indicator of the active power balance between the generation and consumption (including the system losses). The unpredictable RES power variation decreases the system's stability and security, making the power reserve estimation a difficult task[12].While in the large power grids the pumped hydro power plant represents the most efficient energy storage solution, in the case of MGs combining battery energy storage systems (BESS), smart loads, gensets and implementing a hierarchical control of the resources provide a solution to the frequency control challenges[13–16]. Due to the rapid active power response, the BESS may compensate the fluctuations produced by RESs, and the generation rate constraints of conventional generators [17, 18]. The energy storage resource may come from stationary units based on different battery technologies (e.g. lead-acid, vanadium redox flow, etc.) [19,20] or from electric vehicles as recent studies suggest [21,22].

II. MODELLING OF HYBRID POWER SYSTEM

Hybrid power systems are considered an environment-friendly option to provide power service to remote areas where grid connection in unavailable. As previously described, a hybrid power system combines a renewable, weather-dependent, energy source with fuel based energy source. In addition to fuel-based sources, other balancing mechanisms have been added to increase the use of renewable energy. An energy storage system can absorb excess power during high wind conditions and use the stored energy during low wind conditions, hence reducing the use of fuel based generation. Similarly, a variety of dump loads have been implemented to consume excess power available in the system and thus avoiding overcharging the battery or surpassing the battery's instantaneous absorption limit.

As their name suggests, the balancing mechanisms are used to balance the real power in the hybrid power system. In this study, a diesel generator (DG), a battery energy storage system (BESS) and a dump load (DL) are used as balancing mechanisms.

When more than one balancing mechanism is used, their operation must be coordinated. The balancing mechanisms are coordinated according to the operator's dispatch strategy. Some dispatch strategies are briefly described next sections.

A. Diesel Generator

The DG consists of a Diesel engine (DE) driving a SM which is connected through clutch for the different modes of operation. Since we have considered WD mode so it is taken as there is no clutch and DE is connected directly to the SM. The DE takes fuel as input and rotational speed as output, which is mechanical power and it is supplied to the SM. The speed of DE is constant and it is done by the help of speed governor. The working of speed governor is to sense the DE speed and according to this, it controls the valve of fuel so that the output speed of the DE is constant. SM takes the mechanical power as input and delivers the active and reactive power to the grid. Voltage of the SM is controlled by the automatic voltage regulator (AVR). In the first place the AVR monitors the output voltage and controls the input voltage for the exciter of the generator. By increasing or decreasing the generator control voltage, the output voltage of the generator increases or decreases accordingly. The AVR calculates how much voltage has to be sent to the exciter numerous times a second, therefore stabilizing the output voltage to a predetermined set point. When two or more generators are powering the same system (parallel operation) the AVR receives information from more generators to match all output. The whole mechanism of the DG is shown in Fig. 1.

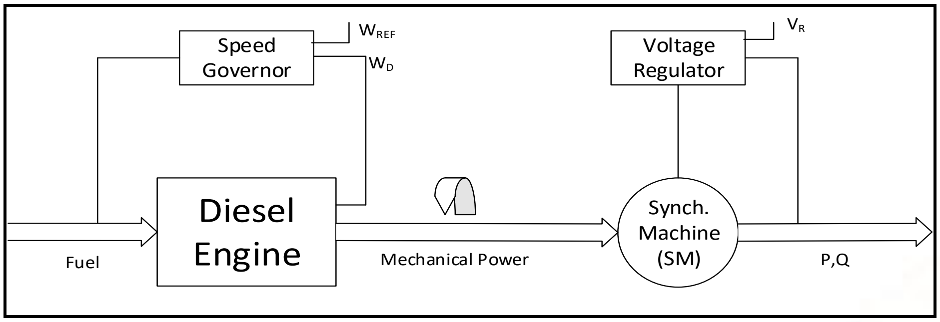

Figure 1 Basic block diagram of diesel generator

B. Excitation system

Excitation system is used to control the terminal voltage of synchronous generator. The input of the excitation system block is reference voltage, direct stator voltage (Vd) and quadrature stator voltage (Vq) and stability voltage (Vstab). Vd and Vq is obtained from the measurement signal of synchronous generator. Reference voltage is given as rated voltage and stability voltage is grounded. The output of the expectation system is Vf. The diagram of the Excitation system is given in the figure. The type of the excitation system is IEEE Type 1 synchronous machine voltage regulator and this excitation system block is easily available in the simulink library.

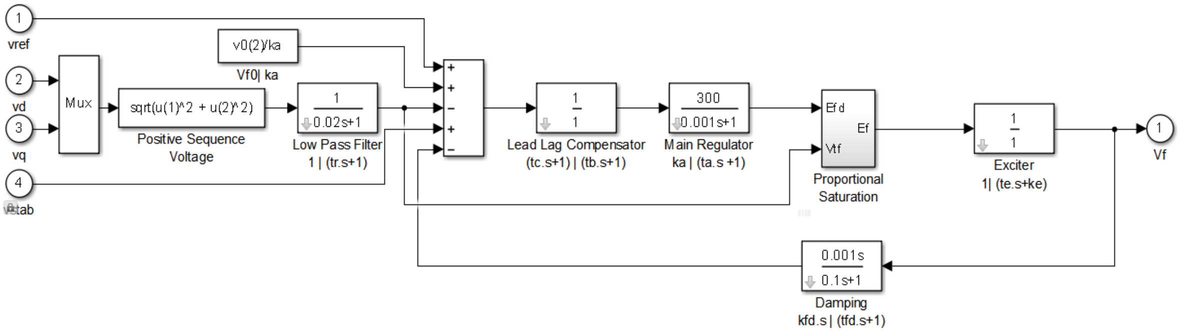

Figure 2 Simulink built in model for the excitation system type DC1A

C. Wind Turbine Generator

The WTG consists of a Wind Turbine driving an asynchronous Generator (induction generator) directly connected to the autonomous grid with a capacitor bank conforming a constant speed stall-controlled WTG which has no pitch control. The mechanical power produced by WT is:

$$P_{T-MECH} = \frac{1}{2}\rho A v^3 C_p \qquad (1)$$

Where ρ denotes air density, v denotes wind speed, A denotes swept area by the turbine blades and Cp denotes power coefficient of wind turbine. Cp is the function of tip speed ratio (λ) and blade pitch angle (β).

$$C_p = f(\lambda, \beta) \qquad (2)$$

In this paper there is no any pitch control i.e. β=constant, so Cp is only a function of Tip speed ratio.

$$C_p = f(\lambda) \qquad (3)$$

From the above equations (3) it shows that WTG produced active power P_T behaves as an uncontrolled source of active power. Capacitor bank is used for compensate the power factor as induction generator consumes reactive power.

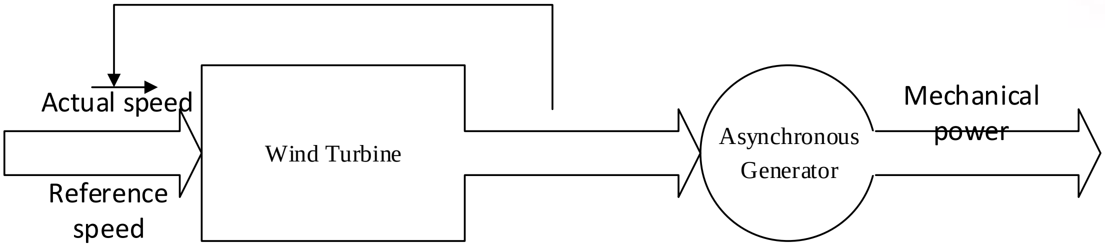

Figure 3 Basic block diagram of wind energy conversion system

D. Battery Energy Storage System

A BESS [11],[15] is connected to the grid with the help of a LC filter, an IGBT three-phase bidirectional Current Controlled Inverter (CCI) of rated power $P_{S\text{-}NOM}$ = 150kW and a 150 kVA elevating transformer. The type of BESS is Ni-Cd of 240V and its model consists of a DC voltage source function of the state of charge (SOC), based on the discharge characteristic of the battery, and an internal resistance of constant value. Ni–Cd batteries are preferred than the other type of battery (lead acid, Ni-MH) for isolated WDHS [14]. The energy stored in the battery is 93.75 kWh, which corresponds to a capacity of 390.625 Ah (93.75 kWh/240V=390.625Ah). A LC filter is connected to the BESS to determine the charging and discharging [16] time constant. The elevating transformer isolates the three phase power inverter and the battery bank from the autonomous grid [12]. Its rated line to line voltage in the grid/inverter sides are 480/120V AC (transformation ratio=4). The CCI receives its active power reference PS-REF from the power sharing block. PS-REF is used for inverter mode operation or rectifier mode operation. The CCI can control the reactive power it produces/consumes its reference reactive power is set to 0. BESS can be used as the dump load at the time of charging and it can be used as source at the time of discharging, it can be used as either active power source or reactive power.

There are various types of battery. In this matlab simulation, we have used Ni-Cd battery. The nominal voltage of the battery is 240V and rated capacity is 390.625Ah and initial state of charge is 50%. We can also use the other types of the batteries which will be discussed below.

Types of battery:

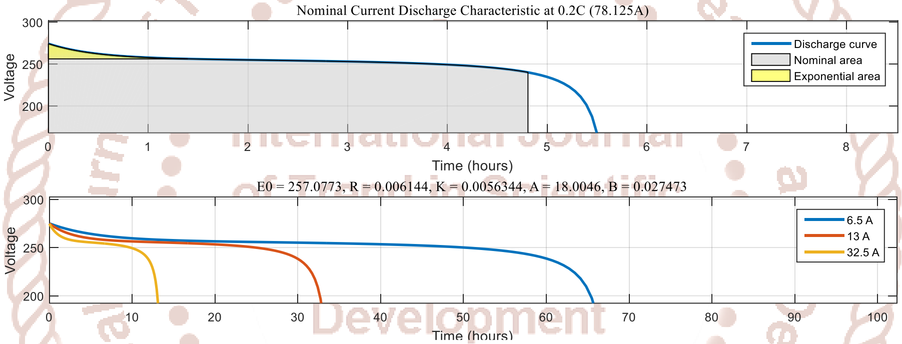

Figure 3Battery mathematical model against manufacturer's curves

III. CONTROL STRATEGY

There are various control strategy for stabilize the Wind diesel hybrid system. The control strategy is used for maintain the terminal voltage, active power, frequency within prescribed limits. These are:

A. Distributed Control System

The BESS and DL in WDHS is implemented to DCS and CAN bus used for each operation mode. For communication network, A DCS consist of several central processing unit (CPU) based electronic control units which is physically distributed and linked. Electronic control unit is also known as nodes and communication network is known as communication bus.

Three nodes of DCS:

1. For measure the DG shaft speed and active power of SM is called a sensor node (N_W).
2. For controls the DL is called actuator node (N_D).
3. For controls the BESS is called actuator node (N_S).

All above three nodes exchange their information by message passing to each other. The sensor nodes (NW) communicate to P_{REF} with a periodic message. The sensor node will take help from other two actuator nodes (N_D & N_S). Both actuator nodes receive almost same P_{REF} data at that instant.

The sensor node (N_W) calculates the P_{REF} depending on its measurements. The positive power P_{REF} ($P_{REF}> 0$) is supplied to the DL and BESS and negative power ($P_{REF}< 0$) is supplied by the BESS to the grid. Power sharing between DL and BESS is also calculated by the sensor node. The relation between power sharing of BESS and DL is shown in Eq. (4, 5, 6):

$$P_{REF} = P_{S-REF} + P_{D-REF} \tag{4}$$

$$0 \le P_{D-REF} \le P_{D-NOM} \tag{5}$$

$$\left| P_{S-REF} \right| \le P_{S-NOM} \tag{6}$$

Where, $P_{D\text{-}NOM}$ denotes the DL rated power, $P_{S\text{-}NOM}$ denotes BESS rated power, $P_{D\text{-}REF}$ denotes power sharing to DL, $P_{S\text{-}REF}$ denotes power sharing to BESS. The value of P_{REF} depends on the operating modes of WDHS. In WD mode P_{REF} is calculated as Eq. (7).

$$P_{REF} = K_{P-WD}.e_F + K_{D-WD}\frac{de_F}{dt} + P_{INV} \quad (7)$$

Where,
$K_{P\text{-}WD}$ is the proportional gain.
$K_{D\text{-}WD}$ is the derivative gain.

P_{INV} is the power that DL and BESS must consume to avoid a DG power inversion when $P_L < P_T$ ($P_{INV} > 0$).

WDHS dynamics is improved by implementing proportional-derivative (PD) controller. When the frequency is above the nominal frequency then proportional controller makes the BESS & DL to act as a load. When the frequency is below the nominal frequency then proportional controller makes the BESS to act as a source and it is improved the system stability and transient. The integral controller is minimized the steady state frequency error. The derivative term improves the speed response and system stability and PD control is also compatible with the diesel only mode. The it is activated when the DG power is less than the minimum allowable DG power $P_{DG\text{-}MIN}$ and calculated as an integral control in the following way.

$$P_{INV} = K_{INV}.\int e_{DG}dt \;;\; P_{INV} > 0 \quad (8)$$

Where,

$$e_{DG} = \begin{cases} 0 & if, P_{DG-MIN} \le P_{SM} \le P_{DG-MIN} + offset. \\ P_{DG-MIN} - P_{SM} & if, P_{DG-MIN} > P_{SM} \\ \left(P_{DG-MIN} + offset\right) - P_{SM} & if, \left(P_{DG-MIN} + offset\right) < P_{SM} \end{cases}$$

Where, P_{SM} denotes the SM active power (positive when produced) and K_{INV} denotes a constant gain. So P_{INV} increases when $P_{SM} < P_{DG\text{-}MIN}$ ($e_{DG} > 0$) and decreases when $P_{SM} > P_{DG\text{-}MIN}$ + offset (with a 0 lower limit).

IV. RESULTS AND DISCUSSION

A. Wind Only mode

In wind only mode, WT is connected to the consumer load and the variations in load cannot be compensated by only WT. As the load increases, there is deficiency in the active power as output of WT is dependent on WT only which further depends on wind speed. Figure5.1. Shows the consumer load requirements.

Two cases have been studied in this work;
1. Constant consumer load.
2. Variable consumer load

Figure4. Showing the waveform of the consumer load. The load is initially at 175 kW. At time 3 sec. load is increased to 300 kW.

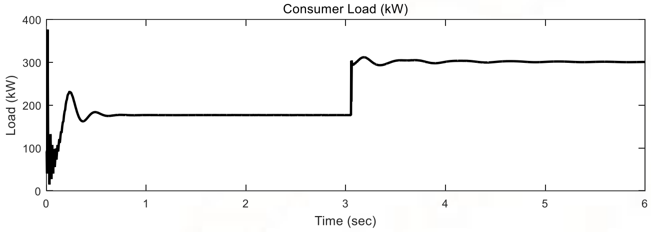

Figure4. Consumer load requirement (kW)

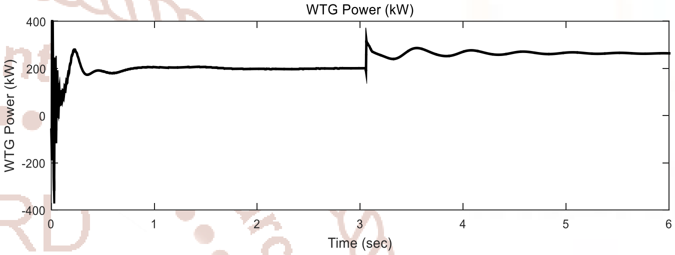

Figure 5 WT output power (kW)

As the load increases, the WT stsrt operating at its rated condition. The rating of the WT is 275 kW. So the WT cannot supply 300 kW load and its speed start reducing until it get stop.

The excess energy available after supplying load will go to the dump load. Initially when the load is less than the output of the WT, excess energy is dump out in dump load. In Figure 6 it can be clearly seen that around 20 kW of the extra energy is going to the dump load. When the load requirement of the customer is increased beyond the generation, dump load will not get any extra energy which can be seen in Figure 5.3.

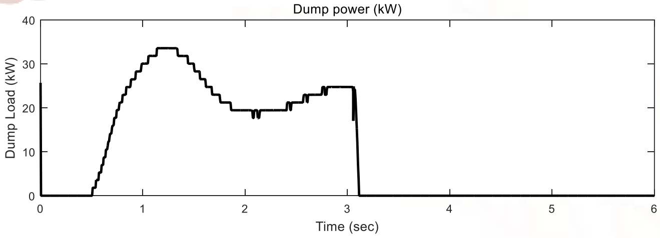

Figure6. Dump load consumption (kW)

The consumer load selected in this study is only resistive type. Therefore no requirement of reactive power. Figure7. Show the reactive power waveform which is zero all the time, weather the load is constant or variable.

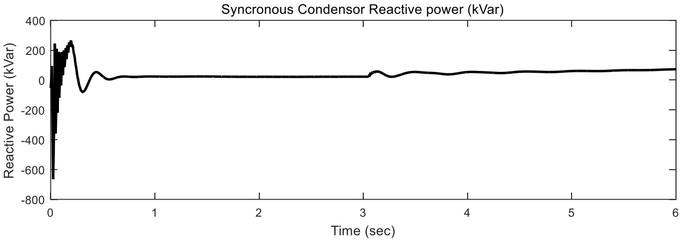

Figure7 Reactive power demand (KVA)

Because there is mismatch between the load and supply, there will be variations in the frequency. When the load is less than the requirement, there is surplus energy available and to stabilize the frequency, this surplus energy is dump out in dump load. But if the supply is less than the demand, the speed of the WT start reducing and consequently the frequency start reducing which can be seen in Fig. 8. and Figure 9 respectively.

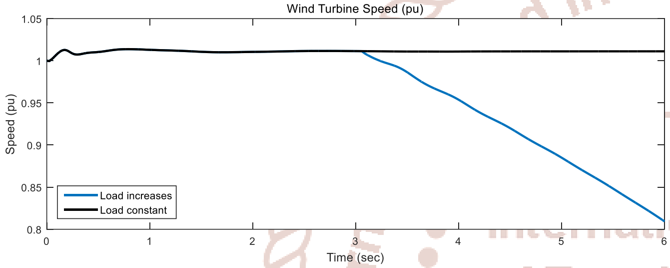

Figure8. WT speed variations with constant and variable load

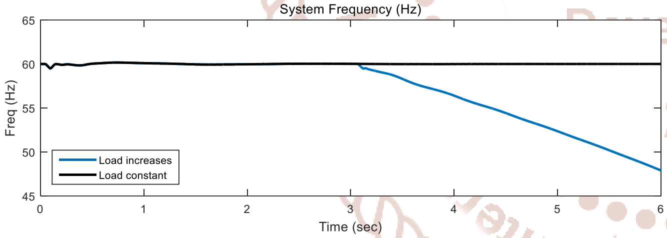

Figure9. Frequency variations with constant and variable load

As the speed of the WT decreases, the frequency get reducing and ultimately, the load current collapse to zero. This can be seen in Figure 10 at time 3 sec. load is increased beyond the capacity of the WT, therefore it will halt ot standstill and current value becomes zero. Figure 11 showing the corresponding three phase load voltage.

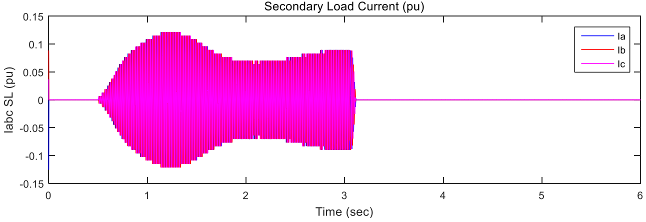

Figure 10 Three phase instantaneous load current in WT only mode.

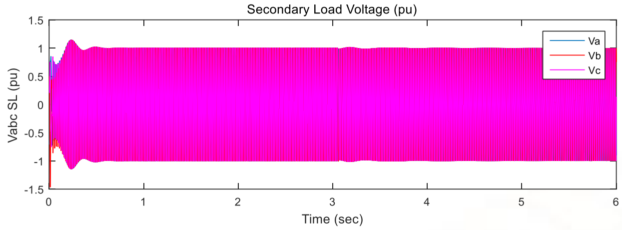

Figure 11 Three phase instantaneous load voltage in WT only mode

B. Wind diesel mode results

In this mode, wind turbine and diesel engine generator are operated simultaneously with dump load and BESS serves as the frequency regulation purpose. In this case also two further cases are considered:

1. With power sharing
2. Without power sharing

In with power sharing mode, dump load and BESS share the active power deficiency and excess with each other according to the control strategy discussed in previous chapter.

In this mode the load is increased from 175 kW to 300 kW and shared by the WT and DG. The consumer load requirement is shown in Figure 12. When load sharing is adopted than there is very less fluctuation in the load power but without load sharing these fluctuations are very high which and be clearly seen in Figure 5.9.

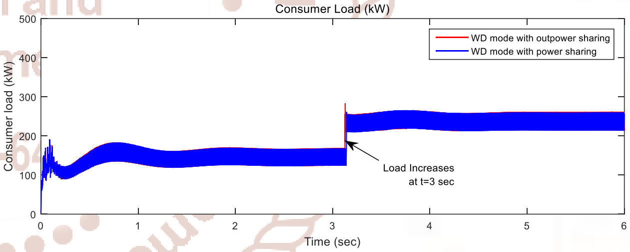

Figure 12 Consumer load requirement (kW)

As there is backup to the WT is available, the WT speed will not decrease to zero as it happened in WT only mode. Figure 13 showing the variations in WT speed with and without power sharing. Without power sharing there is more variations in the WT speed but these variations will not decrease beyond the prescribed limits.

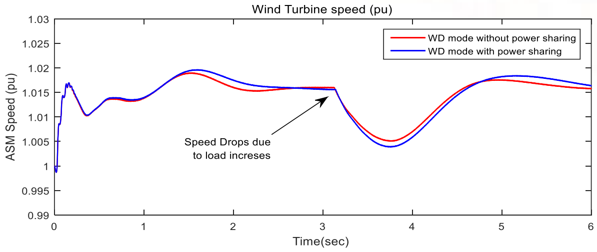

Figure 13 WT speed variations with and without power sharing

As the frequency is associated with the speed of the WT, the corresponding frequency will follow the ASM speed path and can be seen in Figure 14.

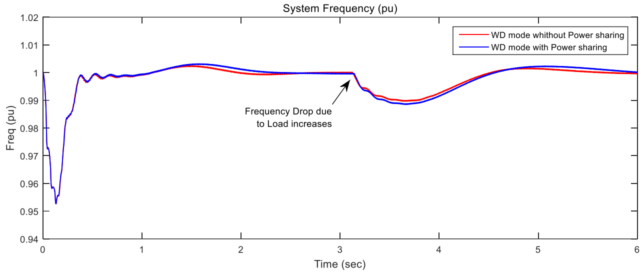

Figure 14 Frequency variations with and without power sharing

The output power of the WT, in this case not become zero as previous case. The extra load is now shared by DG whose output is proportional to the increase in load. Figure 15 shows the variations in the WT output power with and without power sharing.

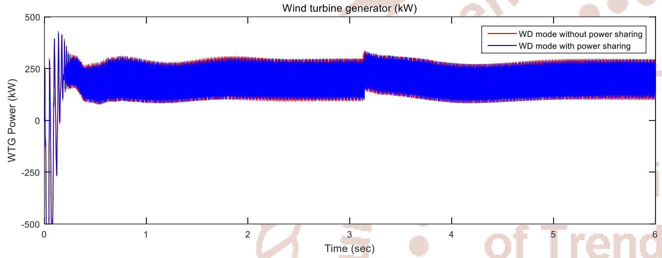

Figure 15 Output power of the WT with change in load

In WD mode, the DG also share the active power which acts as a cushion to WT. Whenever there is change in load suppose load is increased, firstly WT will give its rated power to the load and if there is any deficiency left DG provide that power. In case of WT is sufficient enough to supply load itself then fuel governor of the DG system comes in to action and DG output is reduced to zero by controlling the fuel intake to the diesel engine.

As the load is increased at 3 sec, the DG output is increased up to the level load minus supply by the WT. Figure 16 showing the output power of the DG with both the cases i.e with and without power sharing.

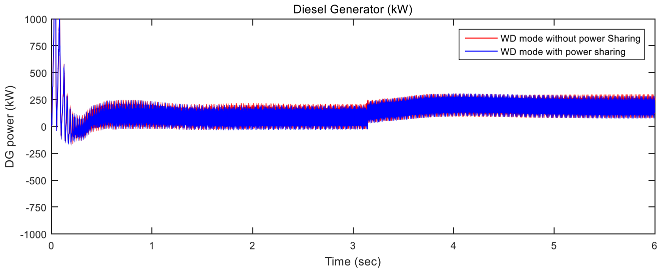

Figure 16 Output power of the DG with change in load

The load is purely reactive in this case also, so the requirement of reactive power by the load is zero. But as the induction generator is also connected to the diesel engine, there is reactive requirement by this induction generator.

Synchronous machine connected to the system acts as synchronous condenser and along with active power generation it can also provide reactive power if overexcited. Figure 17 showing the reactive power waveform.

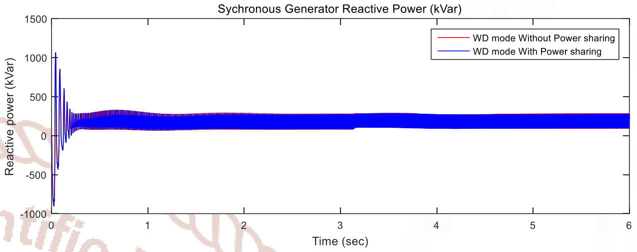

Figure 17 Reactive power provided by synchronous machine

V. CONCLUSIONS

This study focuses on the design of a control for the automatic operation of a hybrid power system. Initially, the main objective of the research was as follows:

- ➢ Develop a control strategy to combine the actuation of three balancing mechanisms (BESS, DG and DL) according to the established dispatch and operational guidelines in order to maintain frequency regulation.
- ➢ The use of multiple balancing mechanisms increased the control task complexity. The main control objective was then divided in two parts:
  1. choosing which balancing mechanism to use,
  2. Provide frequency regulation.

The dispatch guidelines prioritized the use of the BESS as balancing mechanism. However, the operational guidelines require the BESS to operate between operational boundaries. Hence, the balancing mechanism had to be chosen according to the dispatch guidelines and the BESS operational limits. The proposed control strategy is based on a three layer control. In the first control layer, the global controller chooses one balancing mechanism from various mechanisms according to the system's condition. The available balancing mechanisms are a BESS, DG and DL. Once a mechanism is chosen, the global controller outputs the running status of the second layer controllers. In the second layer, four controllers have been designed to provide and improve frequency regulation. The third control layer drives the balancing mechanisms from the operational point to the required set point.

REFERENCES

1. Y. Murata, T. Inaba, H. Takizawa and H. Kobayashi, "A distributed and cooperative load balancing mechanism for large-scale P2P systems," in *Applications and the Internet Workshops, 2006. SAINT Workshops 2006. International Symposium on*, 2006, pp.126-129.
2. R. Al-Khannak and B. Bitzer, "Load balancing for distributed and integrated power systems using grid computing," in *Clean Electrical Power, 2007. ICCEP '07. International Conference on*, 2007, pp. 123-127.
3. M. Vandenbergh, C. Garza and A. Notholt-Vergara, "Overview of Supervisory Control Strategies including a MATLAB® Simulink® Simulation Tool," Fraunhofer Inst. for Wind Energy and Energy Systems Technology, Kassel, Germany, Rep. IEA-PVPS T11-08:2012, 2012.
4. *Voltage characteristics of electricity supplied by public distribution systems*, EN Standard 50160, 1999.
5. W. H. Zhu, Y. Zhu, Z. Davis and B. J. Tatarchuk, "Energy efficiency and capacity retention of Ni–MH batteries for storage applications," *Appl. Energy*, vol. 106, 2013, pp. 307-313.
6. R. Sebastián, "Smooth transition from wind only to wind diesel mode in an autonomous wind diesel system with a battery-based energy storage system," *Renewable Energy*, vol. 33, no.3, 2008, pp. 454-466.
7. R. Sebastián and R. P. Alzola, "Effective active power control of a high penetration wind diesel system with a Ni–Cd battery energy storage," *Renewable Energy*, vol. 35, 2010, pp. 952-965.
8. R. Sebastián, "Reverse power management in a wind diesel system with a battery energy storage," *International Journal of Electrical Power & Energy Systems*, vol. 44, no. 1, 2012, pp. 160-167. 167
9. R. Sebastian and R. Pena-Alzola, "Simulation of a wind diesel system with a Ni-Cd battery energy storage," in *Power Engineering, Energy and Electrical Drives (POWERENG), 2011 International Conference on*, 2011, pp. 1-6.
10. R. Sebastian, "Modelling and simulation of a high penetration wind diesel system with battery energy storage," *International Journal of Electrical Power & Energy Systems*, vol. 33, no.3, 2011, pp. 767-774.
11. B. Sedaghat, A. Jalilvand and R. Noroozian, "Design of a multilevel control strategy for integration of stand-alone wind/diesel system," *International Journal of Electrical Power & Energy Systems*, vol. 35, 2012, pp. 123-137.
12. N. Mendis, K. M. Muttaqi, S. Sayeef and S. Perera, "A control approach for voltage and frequency regulation of a wind-diesel-battery based hybrid remote area power supply system," in *IECON 2010 - 36th Annual Conference on IEEE Industrial Electronics Society*, 2010, pp. 3054-3060.
13. M. Datta, T. Senjyu, A. Yona, T. Funabashi and Chul-Hwan Kim, "A Frequency-Control Approach by Photovoltaic Generator in a PV–Diesel Hybrid Power System," *IEEE Transactions on Energy Conversion*, vol. 26, 2011, pp. 559-571.
14. H. M. Hasanien, S. M. Muyeen and J. Tamura, "Frequency control of isolated network with wind and diesel generators by using fuzzy logic controller," in *2009. ICEMS International Conference on Electrical Machines and Systems*, 2009, pp. 1-6.
15. M. Marzband, A. Sumper, O. Gomis-Bellmunt, P. Pezzini and M. Chindris, "Frequency control of isolated wind and diesel hybrid MicroGrid power system by using fuzzy logic controllers and PID controllers," in *2011 11th International Conference on Electrical Power Quality and Utilisation (EPQU)*, 2011, pp. 1-6. 168
16. S. Sharma and B. Singh, "Fuzzy proportional-integral regulators for stand-alone wind energy conversion system," in *2010 International Conference on Power, Control and Embedded Systems (ICPCES)*, 2010, pp. 1-8.
17. H. S. Ko, T. Niimura, J. Jatskevich, H. C. Kim and K. Y. Lee, "Power quality control of hybrid wind power generation with battery storage using fuzzy-LQR controller," *Power Engineering Society General Meeting, 2004. IEEE*, Vol.2, 2004, pp. 1721-1727
18. H. S. Ko and J. Jatskevich, "Power Quality Control of Wind-Hybrid Power Generation System Using Fuzzy-LQR Controller," *IEEE Transactions on Energy Conversion*, Vol. 22, 2007, pp. 516-527.