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Modelling, Control and Simulation of Wind Based Energy System Connected With Electric System

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Abstract: **Renewable energy resources based power generation has become need of the hour due to the increasing energy demand and increasing cost of fossil fuels. The significance of renewable energy resources is further increased as they provide clean and green option of energy. In this thesis, a grid connected wind energy conversion system is proposed. As the electricity in conventional grid is mainly generated by conventional energy resources, so in order to reduce dependency on conventional energy sources and for increasing the penetration level of renewable energy resources, wind energy conversion system is integrated with grid.**

The main drawback of wind as source of energy is its random and unpredictable nature. As the load is always variable and if generation is also unpredictable, then the problem for active power balance become serious. In order to tackle this problem an energy storage system also incorporated with the system. Because of the high maturity level and easily availability, battery energy storage system is used for this work. For maintaining the active power balance and voltage at the point of common coupling, different controllers are used. For wind energy conversion system, there are two different set of controllers are used. First set is of grid side and generator side controller and other consists of pitch angle controller. For maintain the voltage at the point of common coupling constant, a DC link voltage controller is used for battery energy storage system. This helps in maintaining active power balance I specified range. A DC to AC converter along with its controller is also employed for maintaining the frequency and AC voltage in limits.

The proposed system is modelled and implemented in MATLAB environment. Various cases are simulated based upon the wind speed availability and load requirements. The results shows the efficacy of the proposed system

***IndexTerms*–Distributed generation power system, renewable energy resources, energy storage systems, PV system, grid-connected systems.**

I. INTRODUCTION

The importance and attention of non-conventional sources of power is getting more and more because of number of reasons like, increasing costs of fossil fuels base energy resources, increasing pollution die to the use of fossil fuels and rapid increment in the requirement of energy. Various renewable energy resources emerged in to the role for fulfilling these requirements like solar based power plants, wind energy conversion system, biogas based power generation and many more. Among the different RERs, wind power based electricity generation is leading contender. The wind power industry was flourishing in recent decades and during the economic recession of 2009, there is little effect on wind power industry. The market growth of wind power industry even surpassed the expected growth predicted by the International Energy agency of 12.5% and the actual growth obtained was amazingly 41.5%.

In the year 2009, the total power added from the wind energy conversion system was 38 gigawatt which increased the global wind based power generation capacity to 158 GW. The major share of this increment is mainly due to two countries that are United States of America and China. For each 10 wind turbines 6 are installed in these countries. In Europe also so there is rapid growth in the wind power production. After the year 2008, the wind based power has almost 39%

share of total power generation in Europe. Total of 10.5 gigawatt was added to the Europe total wind power capacity and increased it up to 76.2 gigawatt. This account almost 5% of total power requirement of the region. There is 13 billion euros investment has been made in Europe only and it is expected to grow in the near future also. The new directive of European Union also set ambitious target for increasing the Renewable Energy share for each of its 27 member nations. One Target is to install renewable energy resources to fulfill one fifth of total energy consumption by the year 2020. The wind industry in Europe has provided 192000 jobs in Europe only and it is expected that this will grow in near future at the faster rate.

As far as India is concerned, India is moving towards increasing the share of renewable energy sources to the power mix by 30% by the year 2030. According to Paris agreement, India has pledged to follow the path of cleaner energy for fulfilling its power needs. More efficient Technologies has been adopted for increasing the efficiency and performance of renewable energy Technologies. India has capability to meet the energy demand by renewable energy sources in secure and efficient manner. At the end of year 2019, total installed wind power is 37 gigawatt which is fourth largest in world. The wind power industry in India is right path to achieve its target of 60 Gigawatt by the year 2022. Great improvement has been made in the area of renewable energy sources in recent years. The electrification of rural areas has been doubled and number of peoples living without electricity has been halved since Year 2000. Still now, a major portion of India rural population is living without electricity. For electrification of these areas, wind energy conversion system can play an important role. The major growth of wind power sector in India is mainly due to investment by the private organization. The support provided by the Government of India to the private sector in terms of fiscal support, policy making, and subsidies provided to the consumer are drawing appreciable steps. Target of achieving 60 GW of wind power when announced in Year 2015, the wind industry responded in great and timely manner and added 3.6 gigawatt of new capacity in the year 2016 alone. By the year 2017, another 5.4 gigawatt was added to the installed capacity bringing total capacity up to 31 GW. The make in India initiative launched by the government of India also helped in promoting renewable energy sector. This initiative increased the power consumption of India and helping the power industry to grow. To meet the target of achieving 60 GW, it is required to grow the wind power industry 7.5 gigawatt yearly. Long Term Policies also required to meet the Goals. To remove the obstructions and bottleneck in growth of wind power is very necessary. State as well as central governments are focusing on the policies required for investment in this sector.

II. WIND ENERGY SOURCE

The wind energy source has been used for many centuries. In early years, wind energy (which is in the form of mechanical energy) could be used directly or converted into other forms of energy such as electrical energy. The pumping of water and grain grinding were the most common applications of wind energy. The other possible application of wind energy could be the producing of hydrogen from the electrolysis of water. Hydrogen, which is a clean fuel, can be used for electricity generation employing fuel cells. It can also be used as a fuel for producing heat or running internal combustion engines. Nowadays, the wind energy source is becoming extremely popular for generating electricity. It can be used as a standalone hybrid system for a small community or in a microgrid with other energy sources. Due to the advancement of wind energy technology, the wind energy source is also used as an active power source in a power system utility. However, the basic fundamentals of generating power from a wind energy source are the same irrespective of new technology. Therefore, the following sections explain the wind power production along with different energy conversion systems. Finally, the modeling of wind energy source based on the latest conversion system technology is presented.

2.1.1. Generation of electricity form wind

The kinetic energy of the masses circulating around the surface of earth is wind energy. When wind energy strikes at the blades of WTs, the kinetic energy try to rote the blades of the WTs. In this fashion, the WT coupled with the electric generators also rotates and convert the mechanical energy of the WTs in to the electrical energy. Consequently, the generator yields the EMF or electricity based on its working phenomenon.

Air having mass (*m*) travels to a speed of (*v*), the energy (*E*) can be presented as:

$$E = \frac{1}{2}mv^2 \tag{1}$$

In the duration of time (t), air of mass (m) flow in an area of (A) at speed (v) can be shown:

$$m = \rho A v t \quad (2)$$

Here air density is ρ. From now, energy per unit time, that is the power (P_{av}) in the wind stream available for the rotor can be expressed using (3.1) and (3.2) as:

$$P_{av} = \frac{1}{2}\rho A v^3 \quad (3)$$

From the equation (3.3), the calculated power is theoretical. However, in real conditions the power obtained is (P_m) of a WT be governed type and size of the WT. Consequently, power coefficient (Cp) of the rotor or rotor efficiency determines the actual wind power, which is the ratio of actual power developed by the rotor to the theoretical power available in the wind.

$$C_p = \frac{P_m}{P_{av}} \quad (4)$$

So, the actual power that is P_m) of a WT is given by:

$$P_m = \frac{1}{2}\rho A C_p v^3 \quad (5)$$

The theoretical optimum power which is obtained from Pm is 59%, which was discovered by Betz in 1926, which is why this is also called Betz law. In practical designs, maximum achievable power coefficient is between (40 -50) % for a three bladed horizontal axis wind turbine.

2.1.2. BATTERY ENERGY STORAGE SYSTEM (BESS)

BESS is utilized primarily to assist the HRES to ensure smooth and stable operation in respect of maintaining a constant voltage in the event of a mismatch between generation and consumption of power and therefore, as such the use of BESS is essential for maximum utilization of the available RERs. Batteries of same rating are connected in series and parallel to acquire greater energy capacities and backup [32]. The ampere hour capacity (C_{Ah}) and watt hour capacity (C_{Wh}) of the BESS should be so selected that it can support the load requirement for longer periods in the eventuality of solar irradiance and / or wind speed being low. The $C_{Wh}$of the battery is given by following equation [33]:

$$C_{Wh} = (E_L \times AD) / (\eta_{batt} \times DoD) \quad (6)$$

Where,
E_L = the average daily load energy (kWh/day),
AD= Daily autonomy of the battery,
DoD= Battery depth of discharge,
η_{inv} and $\eta_{Batt,=}$ Inverter and battery efficiency respectively.

Surrette S-260, lead acid batteries, are used in this simulation and their details are given in Table 4. O&M costs of the BESS are considered based on the prevailing labor costs and the market scenario on and around the particular location. Aging of the battery is also considered with the used batteries having salvage value of 15% to 20% of its original value in scrap market. So, replacement cost for a 260 Ah/12V battery, whose installation cost is considered as 350$, is chosen as 300$. The mathematical equations for battery are taken from [34] and implemented in MATLAB/Simulink using a simple controlled voltage source in series with a constant resistance. The mathematical modelling is described by the following equations and schematically shown in Figure 3.5.

$$E = E_0 - K\frac{Q}{Q - \int idt} + A\exp(-B\int idt) \quad (7)$$

$$V_{batt} = E - RI_{batt} \quad (8)$$

Where,
E= Controlled voltage source (V)
E_0= Constant voltage (V)
K= Polarization constant (V/Ah)
Q= Maximum ampere-hour capacity of battery (Ah)
$\int i\,dt$= Charge taken/delivered by battery (Ah)
A= Exponential voltage (V)
B= Exponential capacity (Ah^{-1})
V_{batt}= Battery nominal voltage (V)
R_{batt}= Internal resistance (Ω)
I_{batt}= Battery current (A)

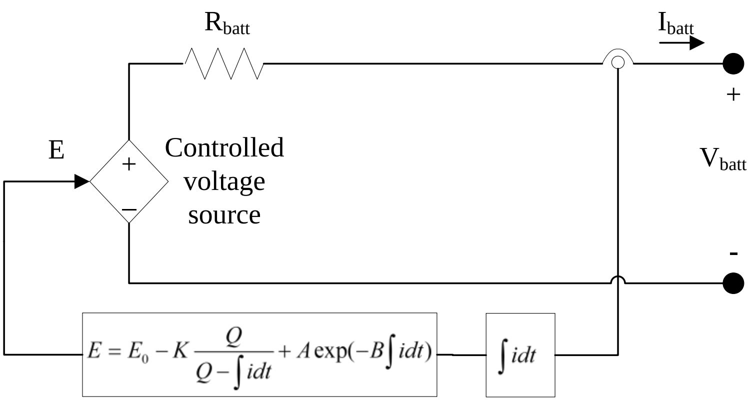

Figure 1: Generic battery model

2.1.3. DC-DC CONVERTER

The buck converter is used as a DC-DC converter, which steps down the input voltage. The buck converter is considered in the experiment for interfacing renewable energy sources to DC link because of the following reasons: (i) is simple and cost effective; (ii) is easily integrated to low voltage DC link; (iii) allows direct connection of battery storage with smaller battery pack to DC link; and (iv) provides better safety by de-energizing the switch at the front end. However, some of the issues in the system due to its presence such as input harmonics and low output voltage are overcome by inserting an LC filter at the output of energy sources or before the converter and step up transformer at the output of AC side LC filter.

Converter Topology

The buck converter topology is shown in Figure 3.6. The output of the buck converter is the average DC value of switching waveform. The LC filter is used to remove high frequency components. The combined action of LC blocks the frequency dependent components and only passes the DC component of the input signal. The wide varying input voltage is stepped down to the output voltage by controlling a gate signal or duty cycle of the power electronic switch, MOSFET.

When the switch (MOSFET) in Figure 3.6 is ON (topological mode I), the diode is reverse biased and the voltage across the inductor is positive as shown in Figure 3.6. The inductor current will rise and energy is stored in inductor (L).

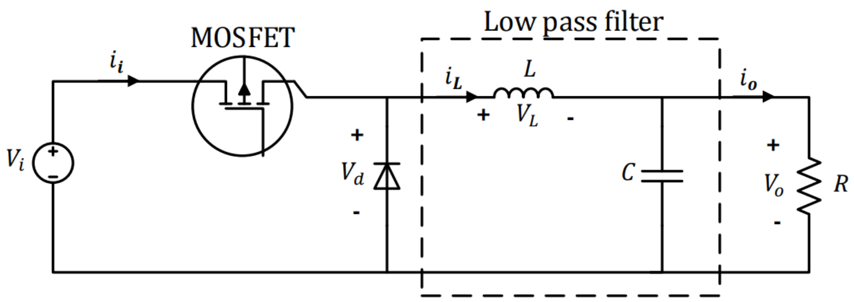

Figure 2: Buck converter topology

In short, during the ON state the DC source is connected to the load resistance (R) and energy is stored in the inductor while in OFF state the source is disconnected from the output circuit, making the inductor the only source providing energy to the output circuit through an output current. When the MOSFET is turned ON and OFF at a certain rate, a pulsed voltage will be generated across the freewheeling diode. This voltage contains a DC component equal to the desired average output voltage plus unwanted harmonics that have to be filtered for smooth operation. The LC form a second order filter of resonant or cutoff frequency as:

$$f_c = \frac{1}{2\pi\sqrt{LC}} \tag{9}$$

The rule of the thumb is to choose cutoff frequency at least one decade below the switching frequency. The bandwidth of the system reduces with the small cutoff frequency; however, it can be increased by increasing the switching frequency, which also reduces the size of the filter inductance and capacitance. However, there are some drawbacks with high switching frequency: (i) high switching losses; (ii) lower efficiency; and (iii) larger size of heat sink. A compromise has to be made when selecting the switching frequency.

LC filter

The inductor current ripple is normally given to the designer, which is typically in the range of (20-40) % of the maximum load. In this thesis, the inductor ripple current is selected at 30 % of the maximum load current. The inductor value (R&) can be calculated from the inductor current ripple equation, which is derived from the fall time of the current and current slope during switch- OFF state:

$$L_i \geq \frac{(V_i - V_0)}{i_{Lripple}} \times \frac{d_c}{f_s} \quad (10)$$

The output capacitor value is determined from the output voltage ripple. The ripple current is shared by the capacitor and the load based on their relative impedances at the harmonic frequencies, assuming all the ripple current is flowing through the capacitor and the load is receiving only the average inductor current. The output voltage ripple across the capacitor is, therefore, the sum of ripple voltages due to the effective series resistance (ESR) and inductance (ESL), and the voltage sag due to the load current that must be supplied by the capacitor while the inductor is discharged.

III. SIMULATION RESULTS

The system under the study consists of a 300-kW WECS which is modelled in MATLAB environment. Main structure parameters are given in Table 1. The sampling frequency of $20e^{-6}$ seconds is used in SVM technique. The inertia constant of the WECS is considered to be less than 1 second for reducing the duration of simulation. In this simulation, thus, in real time scenario the response time is faster than in the simulation (0.42 in this case).

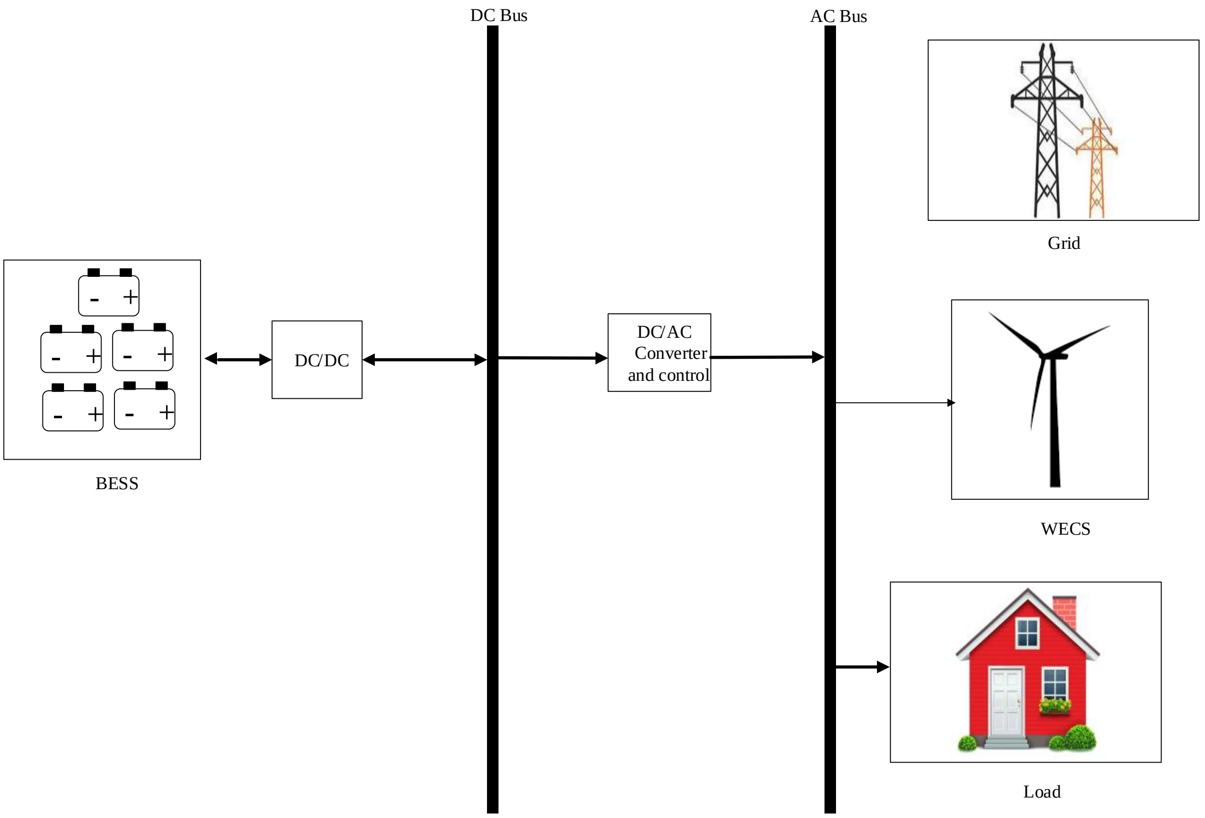

Figure 3 Configuration of the proposed system

When the wind strikes to the blades of the WT, then the kinetic energy of wind is converted in to mechanical energy. So the torque thus generated gradually rotates the generator up to it 50% speed. When the speed reaches to more than 50%, both the controller, generator side control and grid side control come in to action. In this time, there is isolation of grid-side converter from the grid occurs. After the frequency of both generator and grid matches to each other, the converter gets connected to itself to the grid.

Table 1 Characteristics of different components of WECS

Sr. No.	Parameter	Value
1	WT power	300×2 kW
2	Maximum load	450 kW
3	BESS capacity	600 V, 400 Ah
4	LC filter	3 mH, 100 μF
5	Operating frequency	50 Hz
6	Sampling time	$20e^{-6}$ seconds
7	Transformer rating	25 MVA, 50 Hz

In the simulation, the system is driven by a wind turbine model provided by MATLAB/Simulink. The turbine model receives the wind speed and provides an optimized reference speed to the control system.

SIMULATION RESULTS

The WECS system is connected to continuously varying load with maximum load of 450 kW. Initially, the WECS is connected to the grid but isolated itself from grid at 2 seconds. The WECS, itself received continuously varying wind speed patter. Figure 4and 5 show the wind pattern for both the WECS, i.e. WECS-I and WCS-II. The random pattern of wind speed for both systems is in between 9 m/sec. to 12 m/sec. The available power from the WECSs is also variable.

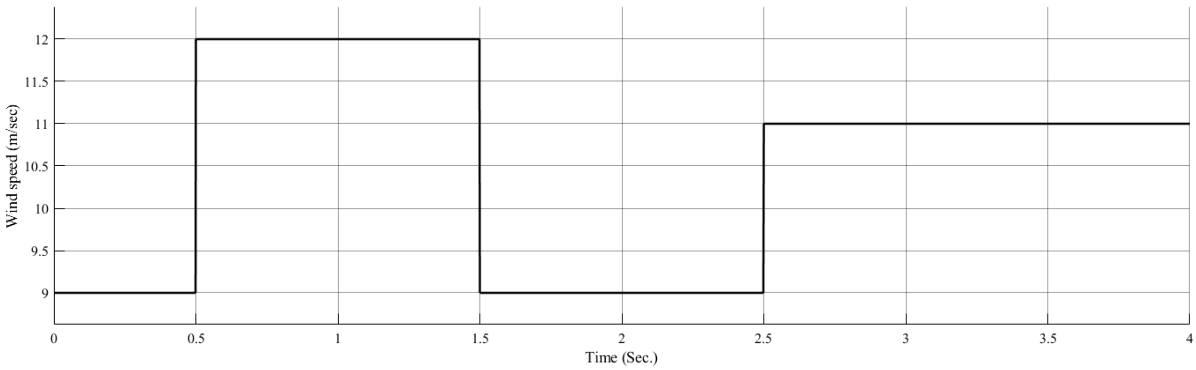

Figure 4 Wind speed pattern for WECS-I

Initially, the wind speed is 9 m/sec, then at time t=0.5 sec, the wind speed increases to 12 m/sec. At time t= 1.5 sec, the wind speed drops to 9 m/sec and again increases to a value of 11 m/sec at time t= 2.5 sec and remains at this value up to t= 4 sec.

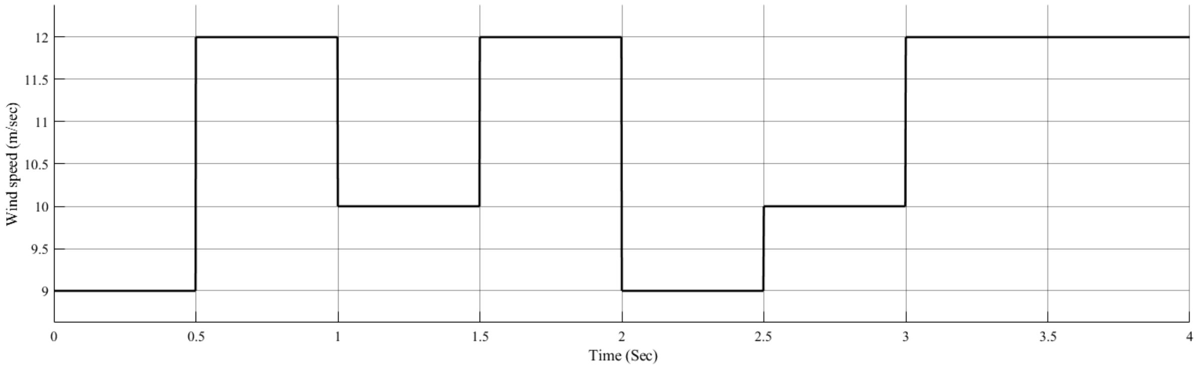

Figure 5. Wind speed pattern for WECS-II

The wind speed for WECS-II, it is initially 9 m/sec and increases to 12 m/sec at t- 0.5 sec. Then there is decrement of 2 m/sec at t= 1 sec and increment of 2 m/sec at t= 1.5 sec. The wind speed reduces to 9 m/sec at t= 2 sec and slightly increases to 10 m/sec at t= 2.5 sec and reaches to 12 m/sec at t= 3 sec and remains there up to 4 sec.

In the WECS-I, the AC power available is converted in to DC using diode rectifier. Then this DC power is controlled using DC-DC converter and through LC filter fed to the point of common coupling (PCC). The available power from the WECS-I is shown in Figure 6.

In WECS-I, the output power is varied accordance to the wind speed availability. But in this case, the grid side controller and generator side controller actively participate in the control of the WECS power and as the wind speed changes, the change in WECS output power is instant. Figure 7 shows the WECS-II output power.

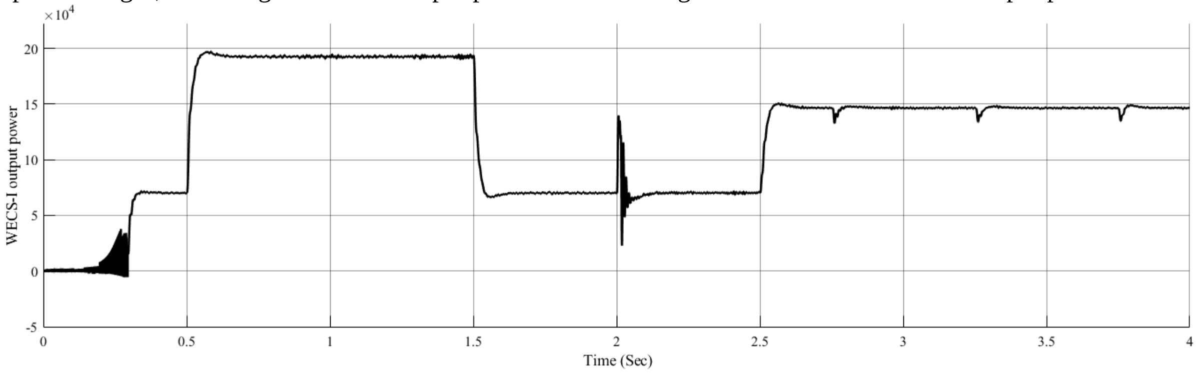

Figure 6 Output power of WECS-I

The power from WECS is according to the availability of the wind speed. As the inertia of this system is more therefore, the instant change in wind speed cannot be seen in the instant power of the WECS. Moreover, when the grid is get isolated from the microgrid, it continuous to provide power to the load after slight disturbance.

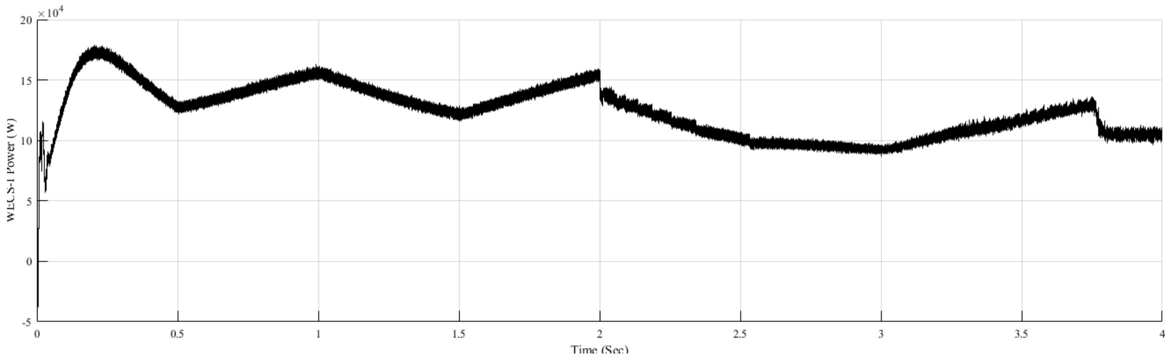

Figure 7 Output power of WECS-II

The grid is active only for time t= 0-2 sec. The waveform for the grid active power is shown in the Figure 5.5. It can be seen clearly that the active power becomes zero when three phase circuit breaker is opened at time t= 2 sec.

As the load is also continuously varying, the power requirement of the connected load is shown in Figure 8. Initially, load is 250 kW and increases up to 300 kW at time t= 1.5 sec. Then step decrements of 50 kW occurs at time intervals of 0.5 seconds as can be seen in Figure 5.5.

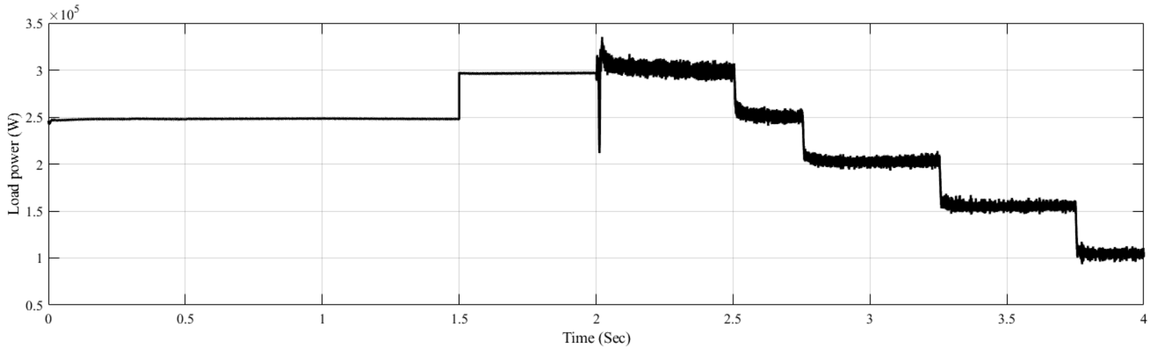

Figure 8 Load active power requirement

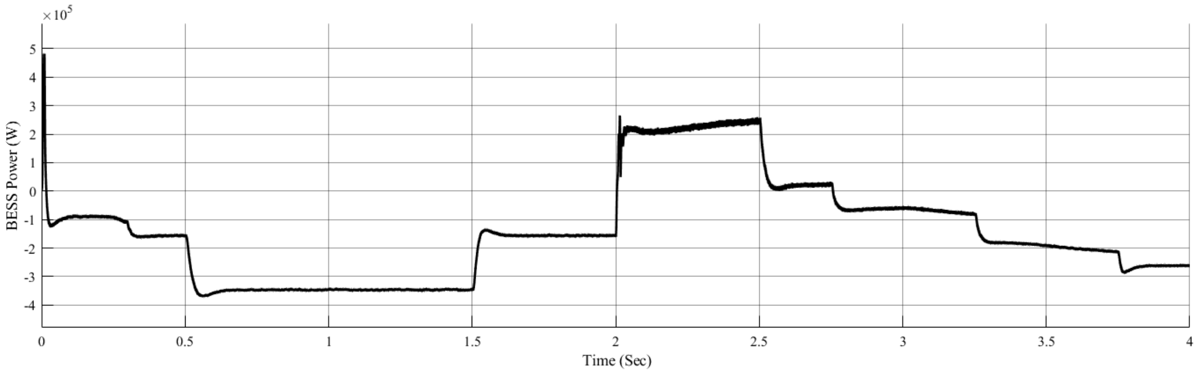

Figure 9 Output power of BESS

The BESS acts as the balancing components where the deficiency and surplus of the power is delivered or absorbed by the BESS. The power waveform of BESS is shown in Figure 9.

The voltage and the frequency at the PCC required to be within limits and the proposed control strategy efficiently maintain these two parameters at the acceptable limits. Figure 10 and Figure 11 presents the waveforms of the frequency and three phase voltages at PCC respectively.

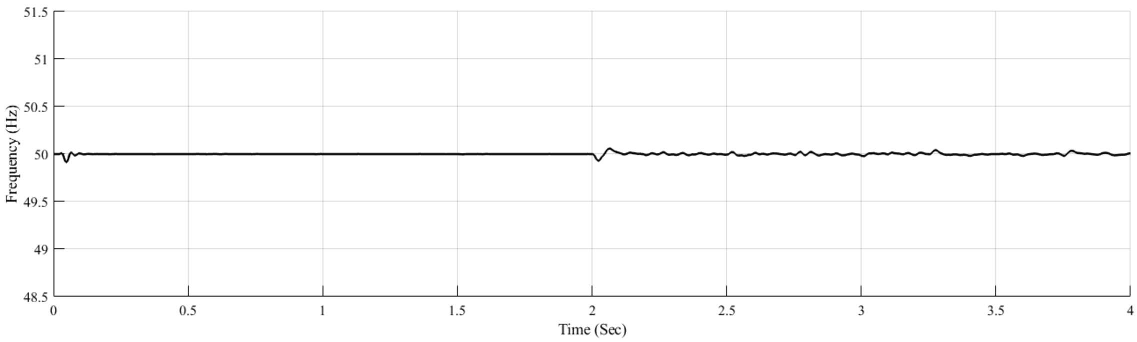

Figure 10 Frequency at PCC

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The zoomed view of the three phase voltage at PCC is also shown in Fig 5.8, where it is evident that at the point when grid is disconnected to the system the voltage at PCC remains in limits and stables itself after couple of cycles

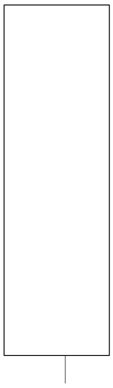

Figure 11 Three phase voltage and its zoomed view

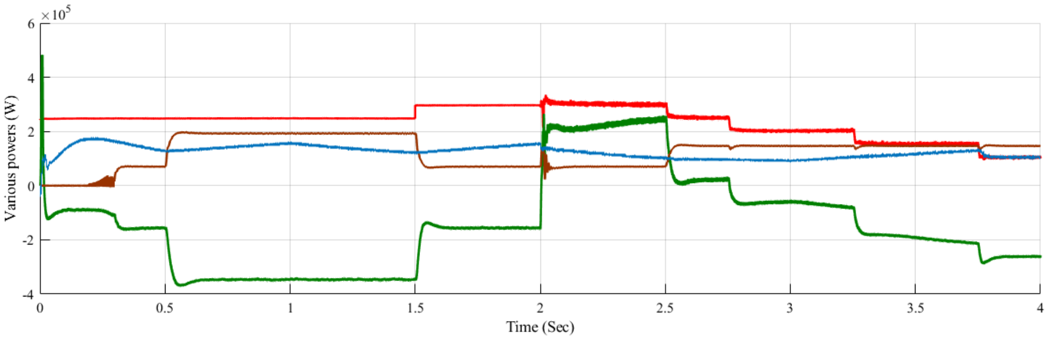

Figure 12 Waveforms of various powers

Furthermore, the comparison of various powers is also carried out and Figure 12 presents the comparative waveforms of various figures. It is evident form this figure that, the proposed control strategy able to provide active power balance and remains in synchronism when changes in load and wind speed are made.

IV. CONCLUSIONS

This paper proposes control scheme for a WECS to control the active power and reactive power. The controller is realized in two separate controllers: grid-side controller and generator side controller. Field orientation control and voltage orientation control are separately utilized for the two different side converters.

The variations in the DC link voltage are reduces with the help of proposed controllers. The DC to DC converters are also utilized to extract maximum power from the wind through MPPT tracker system. The modelling of the proposed system and controller is done in MATLAB/Simulink environment. The results obtained from the simulations validate the efficacy of the control scheme.

The power management control strategies for a direct drive PMSG based VSWT (wind Type IV) in different structures such as hybrid, microgrid and distribution grid network are presented in this thesis. The power management control strategies are varied according to the structure; however, the objectives of regulating DC link voltage, amplitude and the frequency of AC link voltage, and balanced power flow are the same and are maintained irrespective of inherent disturbances (weather fluctuation for renewable sources), varying load demands, and grid side issues, such as balanced and unbalanced voltage sag..

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