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Modelling, Control and operation of grid connected wind energy conversion system

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Abstract: The renewable energy resources (RERs) are a good way to supply the electricity for some remote places that are hard to connect to the power grid and some areas where storms and other catastrophic events cause long-term power outages from power grid. What is more, in order to control the global warming and reduce the pollutant emissions, changing fuel power generation to renewable power generation is significant.

This paper discusses the modelling, control and analysis of grid connected wind energy based power generation system for fulfilling the electricity demands load. Battery energy storage system is employed for the backup source as wind is intermittent and unpredictable in nature. As the variations in wind speed and connected load, the power generation and consumption is continuously changing. To counter these variations a control scheme is developed using grid-side controller, generator-side controller and pitch angle controller. The DC link voltage is maintained in specified limits to maintain the active power balance between supply and consumption. Furthermore, a DC-AC converter and its controller is used to maintain the AC side voltage and frequency in limits for proper synchronism with the grid.

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

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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:

$$E = \frac{1}{2} m v^2 \tag{1}$$

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

$$m = \rho A v t \tag{2}$$

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:

$$P_{av} = \frac{1}{2} \rho A v^3 \tag{3}$$

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.

$$C_p = \frac{P_m}{P_{av}} \tag{4}$$

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

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

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.

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2.1.2. BATTERY ENERGY STORAGE SYSTEM (BESS)

Currently, electro-chemical batteries remain the most common and widely used ESS in HRES due to their wide availability and relative high maturity. Different types of electrical battery systems (e.g. lead-acid, Li-ion, NaS, Ni-Cd, Ni-MH) are available from which plumbing batteries are the obvious choice for the work today due to their low cost, high recyclability and a relatively high level of safety. A series and parallel combinations of batteries of the same rating are used to obtain a larger current and voltage rating. In this study, the mathematical modelling while considering various aspects of the battery are considered from Nickel-Cadmium model as per [51]. As discussed previously, with fast change in output of RERs and in load can cause to battery to suffer from sudden charge and discharge. This reduces the cycle life of battery. Battery life can be improved by reducing sharp charge and discharge along with operating battery in such a limit that it cannot be drained and charged 100%. The SoC limits are considered as 20% $\leq SoC_{Bat} \leq$ 80%. The mathematical modelling is represented by the equations written below and in the

FIGURE .

$$E = E_0 - K\frac{Q}{Q-\int idt} + A\exp(-B\int idt) \tag{3.16}$$

$$V_{batt} = E - RI_{batt} \tag{3.17}$$

Where,

Q = Maximum ampere-hour capacity of battery

K= Polarization constant

E= Voltage at no load

R_{batt} = Battery internal resistance

$\int$ i dt = Charge taken/delivered by battery

E_0= Constant voltage

I_{batt} = Battery current

A= Exponential voltage

B= Exponential capacity

V_{batt} = Battery terminal voltage

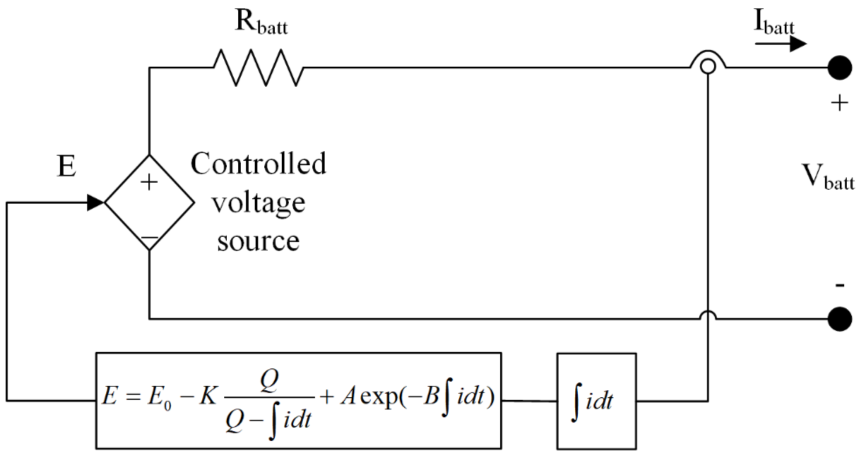

FIGURE 1 Modelling of the BESS

As single battery cannot provide enough power for entire system, a string of batteries are used to produce required power.

III. CONTROL STRATEGY

The PMSG-based VSWT is operated under an MPPT scheme, as long as the conditions on the system and environment permit. Otherwise the WPS comes out from the MPPT scheme, especially during grid disturbances, to balance the power flow with stable and symmetrical three phase current output.

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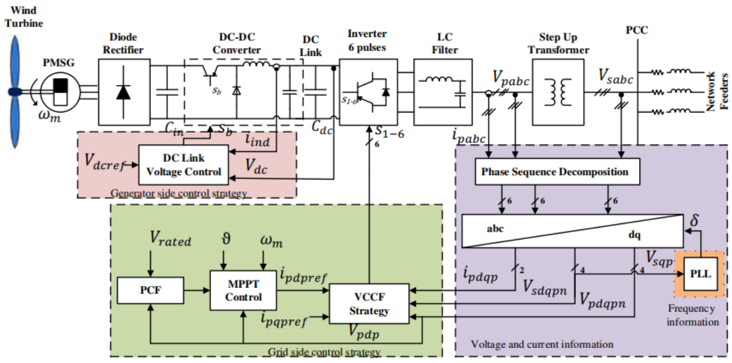

Figure 2 Schematic diagram of PMSG based WPS connected to grid

In this work, separate control are used for generator side and grid side. For the generator side field-oriented control is employed. As far as grid side is concerned, there is voltage-oriented control (VOC) developed. For the generation of control signals, Space vector modulation is utilized. Space vector modulation is performance wise more responsive and have low power losses.

IV. 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).

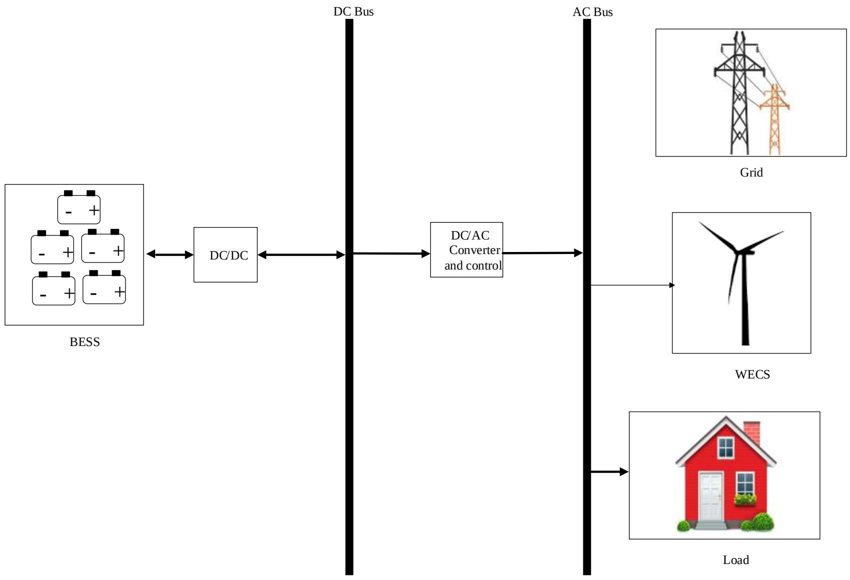

Figure 3 Configuration of the proposed system.

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

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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 4 and 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.

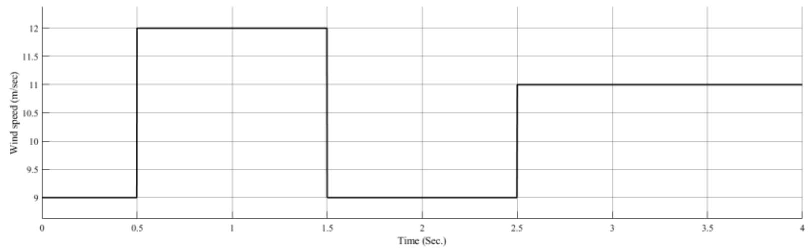

Figure 4 Wind speed pattern for WECS-I

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.

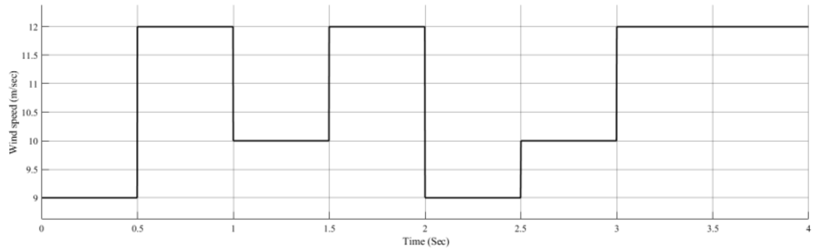

Figure 5. Wind speed pattern for WECS-II

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.

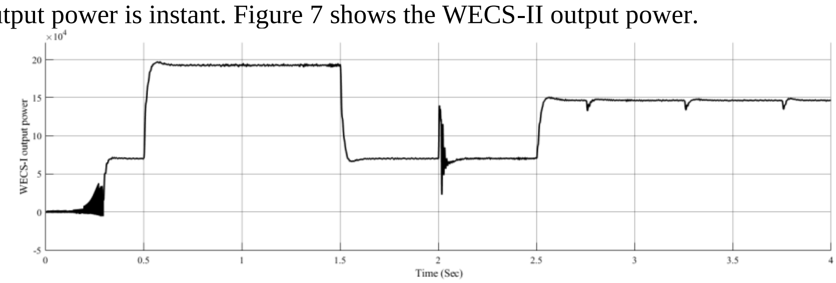

Figure 6 Output power of WECS-I

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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.

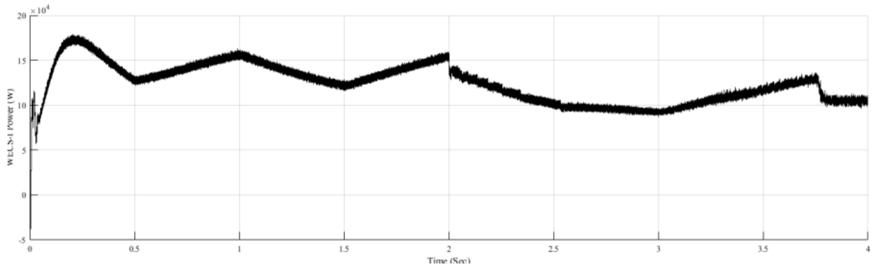

Figure 7 Output power of WECS-II

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.

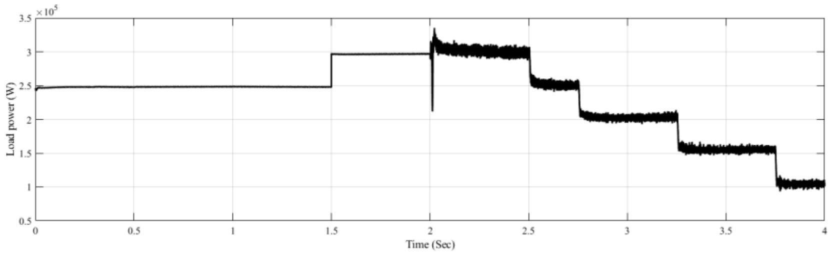

Figure 8 Load active power requirement

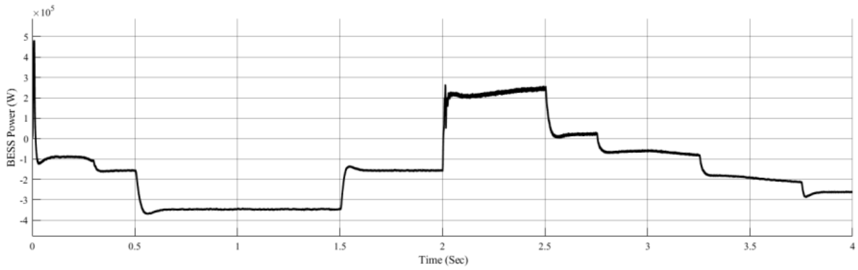

Figure 9 Output power of BESS

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.

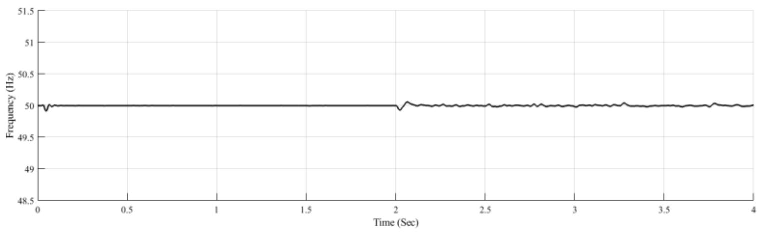

Figure 10 Frequency at PCC

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

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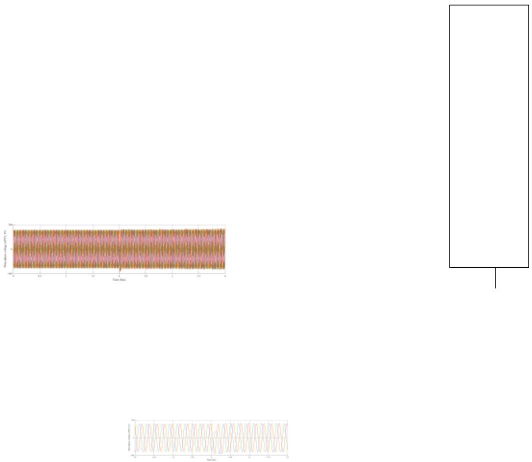

Figure 11 Three phase voltage and its zoomed view

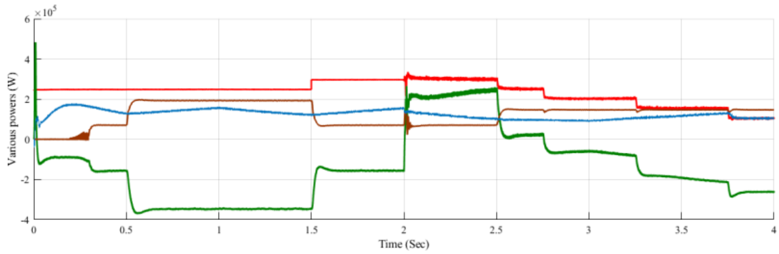

Figure 12 Waveforms of various powers

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.

V. 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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