International Journal of Research in Engineering and Science (IJRES)
ISSN (Online): 2320-9364, ISSN (Print): 2320-9356
www.ijres.org Volume 5 Issue 10 ǁ Oct. 2017 ǁ PP.70-77

Battery Energy Storage and Power Electronics Grid Linked Dependent Voltage and Frequency Controller for WECS

Satyabrata Sahoo[1], Rajesh Kanungo[2]
*[*1]Department of Electrical Engineering, Gandhi Engineering College, Odisha, India*
[2]Department of Electrical Engineering, Gandhi Institute For Technology, Odisha, India

ABSTRACT : *Global environmental problems and climate change due to greenhouse gas emissions from fossil fuels showed the importance of renewable energy resources like hydro energy, geo thermal, ocean, hydrogen energy, bio energy & the most importantly Wind energy. Wind energy is gaining the most interest among a variety of renewable energy resources, but the disadvantage is that the wind generated power is always fluctuating due to its time varying nature and causing stability problem. This weak interconnection of wind generating source in the electrical network affects the power quality and reliability. The localized energy storages shall compensate the fluctuating power and support to strengthen the wind generator in the power system. The model contains an isolated asynchronous generator, wind turbine, PWM power converters and associated controllers, a DC-link capacitor and a battery storage system. SPWM signals have been generated by switching pulse generator for the three phase inverter which provides the function of a harmonic eliminator and load balancer. The complete system is modeled and simulated in MATLAB using the SIMULINK AND PSB (Power System Block set) Toolboxes. The simulated results are presented to demonstrate the capability of an isolated generating system driven by a wind turbine.*
Keywords: *Isolated asynchronous generator, uncontrolled bridge rectifier, VSI, voltage and frequency controller (VFC), SPWM switching pulse generator, Grid and battery energy storage system..*

I. INTRODUCTION

The concern for environment due to the increasing use of fossil fuel and rapid depletion of these resources have led to the development of alternative sources of energy which are renewable and environment friendly. As a renewable source of energy wind power is one of the prominent source of energy. Wind power offers a feasible solution to distributed power generation for isolated communities where utility grids are not available. In such cases, stand-alone wind energy systems (i.e., systems not connected to the utility grid) can be considered as an effective way to provide continuous power to electrical loads [1]. One of the most promising applications of renewable energy generation lies in the development of power supply systems for remote communities that lack an economically feasible means of connecting to the main electrical grid. For isolated settlements located far from a utility grid, one practical approach to self-sufficient power generation involves using a wind turbine with battery storage to create a stand-alone system. Stand-alone wind energy systems often include batteries in order to store surplus power if wind power generated exceeds load demand.Wind electric generator converts kinetic energy available in wind to electrical energy by using rotor, gearbox and generator. The wind turbines installed so far in the country are predominantly of the fixed pitch 'stall' regulated design. However, the trend of recent installations is moving towards better aerodynamic design; use of lighter and larger blades; higher towers; direct drive; and variable speed gearless operation using advanced power electronics. Electronically operated wind turbines do not consume reactive power, which is a favorable factor towards maintaining a good power factor in the typically weak local grid networks. Different types of generators are being used with wind turbines. Small wind turbines are equipped with DC generators of up to a few kilowatts in capacity [2]. Modern wind turbine systems use three phase AC generators.

The common types of AC generator that are possible candidates in modern wind turbine systems are as follows:

- Squirrel-Cage rotor Induction Generator (SCIG),
- Wound-Rotor Induction Generator (WRIG),
- Doubly-Fed Induction Generator (DFIG),
- Synchronous Generator (With external field excitation),
- Permanent Magnet Synchronous Generator (PMSG).

II. SYSTEM CONFIGURATIONS AND OPERATING PRINCIPLE

The controller consists of a three phase diode bridge rectifier connected to an inverter via a filter capacitor of 1mF & also to battery storage system. The inverter consists of three legs each containing one pair of IGBTs. With the use of diode rectifier to generate DC voltage we can aim to cut down its cost. However the pulse width modulated switch of the inverter gives a precise switching [3]. The schematic diagram of the proposed system with the imaginary wind turbine, the asynchronous machine, the excitation capacitor, the proposed power electronic controller with battery energy storage and the grid is as shown in fig.1. With this configuration an attempt has been made to simulate the control algorithm of the wind power generator scheme. The proposed controller has bi-directional power flow capability of reactive and active powers. So it controls the magnitude of the voltage under various wind speed condition

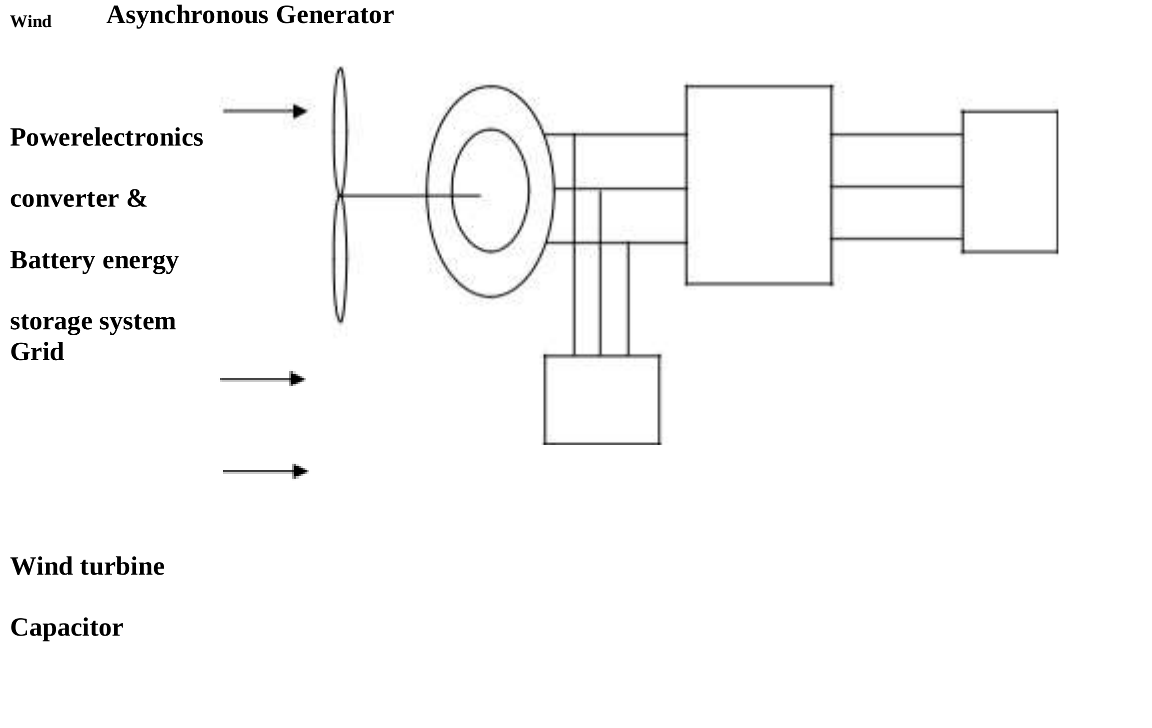

Figure 1. Block diagram of the complete system.

III. WIND ENERGY CONVERSION SYSTEM

Wind energy conversion system is summarized in three aspects

Wind turbine generator.

Power electronics converters & Battery storage system. Grid connectivity.

Wind turbine generators: Main features of various types of generators and their suitability in wind power generation are discussed below: [4]

Dc generator: Conventional dc generators are not favored due to their high cost, weight and maintenance problem due to commutator. However, permanent magnet (brushless and commutator less). DC machines are considered in small ratings (below 100kW) isolated systems.

Synchronous generator: They produce high quality output and are universally used for power generation in conventional plant. However they have very rigid requirement of maintaining constant shaft speed and any deviation from synchronous value immediately reflects in the generator frequency. Also precise rotor speed control is required for synchronization. Requirement of DC current to excite rotor field which needs sliding carbon brush on the slip rings also posses limitation on its use. Machine ratings are limited to tens of kilowatts. Main advantage is that it generates active as well as reactive power.

Induction generator: Primary advantage of induction machine is the rugged, brushless construction, no need of separate DC field power. Compared to DC & synchronous machine they have low capital cost, low maintenance and better transient performance. Machine is available from very low to several megawatt ratings. Induction machine require AC excitation which is mainly reactive. The induction generators are self excited by shunt capacitors

Based on the generator drive two systems have been developed for WECS [4]

Fixed speed drive system: In this scheme constant speed is maintained at the shaft of generator by pitch control. A synchronous or induction generator is used to generate electrical energy. Induction generator is gaining more acceptability due to its ability to absorb small variations in shaft speed.

Variable speed drive system: In this scheme rotor speed is allowed to vary optimally with the wind speed to capture maximum power. As a result it can capture about one third more power per year as compared to fixed speed drive system. Modern variable speed drive scheme make use of power electronics converter for voltage and frequency control. The variable voltage and frequency output available from a generator (synchronous or induction) is first rectified to DC and then converted to fixed frequency & AC voltage using inverter. The harmonics are filtered out to get grid quality output before connecting to the grid. Apart from higher energy yield, use of power electronics offers remotely adjustable & controllable quality of power.

IV. SPECIFICATION OF WIND TURBINE AND GENERATOR

For this project work a 15KW wind energy conversion system with the following specifications is used;
Turbine specifications: Number of blades - 3, Rotating shaft: Horizontal, Stress way of Blades :Resistance, Rotor-blade-diameter:8.0m,Startup-wind-speed:3.0m/s,Rated-wind speed: 8.0m/s, Rated-output-power: 10000W, Maximum output =15000W, Pole Height: 14m, Generator weight: 150kg, Pole diameter: 360mm.
Generator Specifications: Three phase power = 15000W, AC voltage =400V, Frequency =50H, Pole pairs= 2, Type= squirrel cage induction machine Speed =1460 rpm.

Calculations

Speed of wind turbine rotor:
R=8/2m= 4m
Speed of wind =12m/s (standard value)
No. of blades= 3
Tip speed ratio for optimum output
$\lambda = 4\pi/n = 4.188$

$\Rightarrow 4.188 = (R\omega)/\mu 0$
$\Rightarrow \omega = 8.376$ (at standard temp)
Torque calculation [8]
At 25˚C speed of wind = 19m/s
Therefore,
$P_{max} = 1/2\rho(A)Vi^3$
$=1/2*1.225*(50.265)*193$
$=211170W$
As, $CT_{max} = CP_{max}/\lambda = 0.593/4.188 = 0.1415$
$T_m = (P_{max}/\mu_0)*R$
$=70390N$
$TS_{max} = T_m * CT_{max}$
$=9.96KN.$

V. WIND TURBINE CHARACTERISTICS

Mechanical output power of the turbine is given by the equation [5];
ρ - Air density (kg/m3)
$\lambda = \omega R$
ω= rotational speed of the wind turbine.

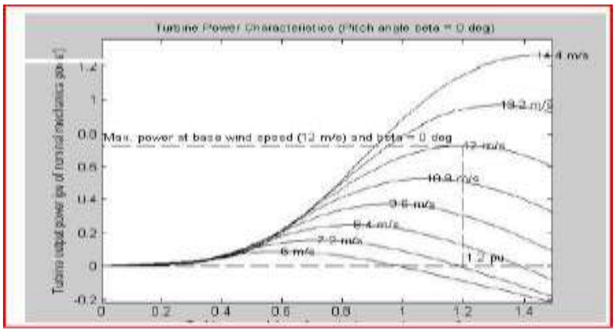

Figure 2. Torque and power characteristics

VI. POWER ELECTRONICS CONVERTER & BATTERY ENERGY STORAGE SYSTEM

Power electronics converter

The circuit has bi-directional power flow capability in order to control active and reactive power thus controlling the voltage and frequency of the system. Figure 3 shows the power electronics converter model [10].

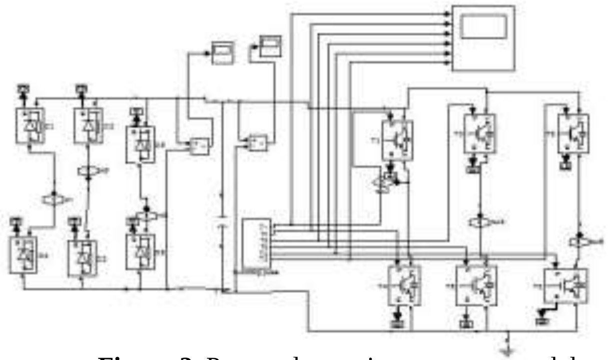

Figure 3. Power electronics converter model

The terminal voltage, value of excitation capacitor, speed and generated power of the generator are considered constant under all operating conditions. Proposed controller consists of a 3 leg uncontrolled bridge rectifier, which acts as a low cost voltage regulator and the output of the rectifier is passed through the filter capacitor and is fed to a 3-phase PWM inverter & also to the battery energy storage system. SPWM signals have been generated by switching pulse generator for the three phase inverter which provides the function of a harmonic eliminator. All simulations are performed in MATLAB using SIMULINK toolbox and power system block set.

Battery energy storage system

The proposed voltage and frequency controller is connected to battery at its link [7]. In fig.4, [9] thevenin's equivalent circuit of the battery based model is shown at the DC link of the controller. The terminal voltage of the battery (V_b) is obtained as follows

$$V_b > (\sqrt{(2/3)}\, V_1) \qquad (2)$$

Where, V_1 is the line to line rms voltage of the generator.

Since the battery is an energy storage unit, its energy is represented in kWh when a capacitor is used to model the battery unit, the capacitance can be determined from

$$C_b = kWh*3600*10^3/0.5(V_{ocmax}^2 - V_{ocmin}^2) \qquad (3)$$

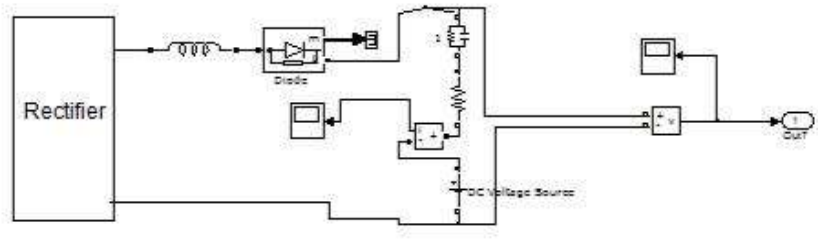

Figure 4. Thevenin Equivalent model of the Battery energy storage system

In the thevenin's equivalent model of the battery where R_s is the equivalent resistance (external + internal) of a parallel/series combination of a battery, which is usually a small value [7].

The parallel circuit of R_b and C_b is used to describe the stored energy and voltage during charging and discharging. R_b in parallel with $C_{b\ represents}$ self discharging of a battery, self discharging current of a battery is small, the resistance R_b is large. Variation of the voltage is between 440V-470V.

Calculation of battery parameters:

Here the battery is considered of having 3kW for 8 Hrs and with the variation in the voltage of order of 470-440V.

R_b = 10k , $V_{oc\ max}$ =470V, $V_{oc\ min}$ =440V

$C_b = 3*8*3600*10^3/0.5(470^2-440^2) = 6329.67$ F.

Grid Connection

Small wind energy systems can be connected to the electricity distribution system and are called grid-connected systems. A grid-connected wind turbine can reduce your consumption of utility-supplied electricity for lighting, appliances, and electric heat. If the turbine cannot deliver the amount of energy you need, the utility makes up the difference. When the wind system produces more electricity than the household requires, the excess is sent or sold to the utility.

The output of the AC-DC-AC converter is fed to a 3 phase step-up transformer (440 V/11kV) which is then connected to 3 phase pi-section network of 10km for transmission. In this paper squirrel-cage induction generator taken is of capacity 15kW. We have taken battery having capacity of 3kW for 8Hrs and rest of the power is supplied to the grid.

CONTROL STRATEGY

The induction machine driven by wind turbine is controlled to get fixed output powers under varying wind speed conditions. The stator voltage is fed to the power electronics converter. The stator is however connected in parallel to delta connected capacitor bank. The value of capacitor bank is calculated so as to generate power at no-load. These are called excitation capacitor [6].

However a source inductance of small value (1mH) is placed at the input of the uncontrolled rectifier. This will thus act as source inductance of the uncontrolled rectifier. The presence of source inductance thus has significant effect on the performance of the converter. With the source inductance present the output voltage of a converter does not remain constant for a given firing angle. Instead it drops with load current. When there would have been no source inductance the diode pair stops conducting [6]. But with the source inductance present the four diodes /two legs continue to conduct for some interval known as overlap interval. The use of diode rectifier significantly reduces the cost.

VII. SIMULATION MODEL AND RESULTS

The schematic diagram shown in fig.5 is built in MATLAB using SIMULINK toolboxes. The circuit consists of a 3 leg uncontrolled rectifier fed with asynchronous generator output followed by 3 phase PWM inverter which is supplying power to the grid, extra power is then given to battery energy storage system , the converter controls the voltage and frequency of generator output.

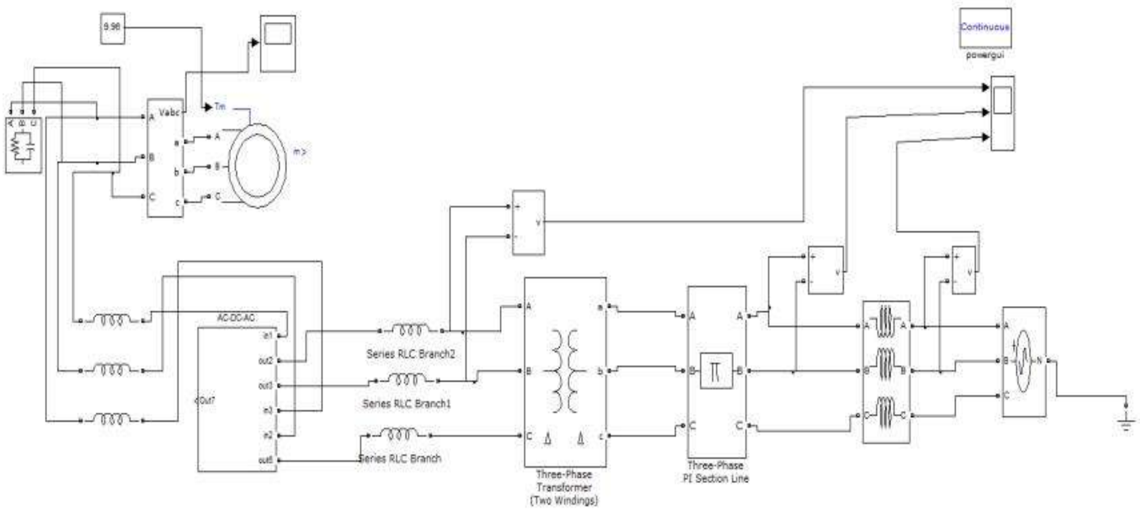

Figure 5. Complete system model developed in MATLAB.

The 3 phase stator output voltage waveform is shown in fig.6 below.The rectifier output voltage shown in fig.7 shows that the required output voltage can be reached with this model.

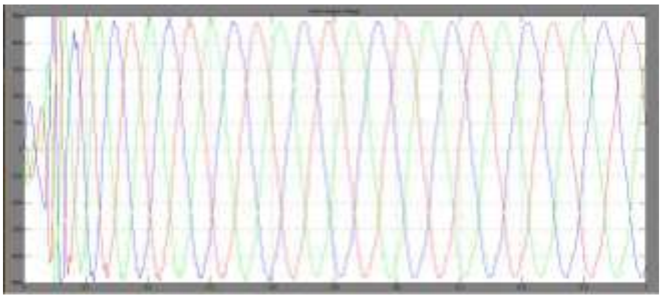

Figure 6. Three phase stator voltage

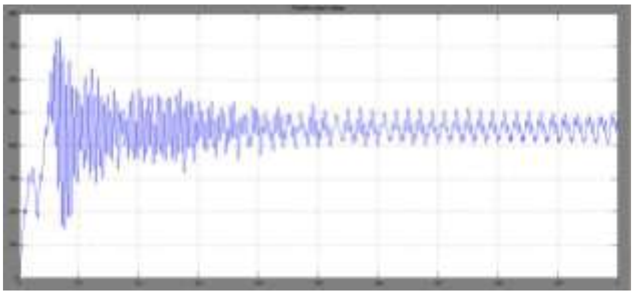

Figure 7. Rectifier output voltage.

The output PWM signals obtained from the pulse generator is fed to the control terminal of the IGBTs so that the devices are turned on at the desired instant to get suitable output from the inverter. The six switching pulses obtained for six devices of the inverter are as shown in figure 8.Fig. 9 and fig. 10 shows the output voltage and current of battery.

Figure 8. Six PWM switching pulse.

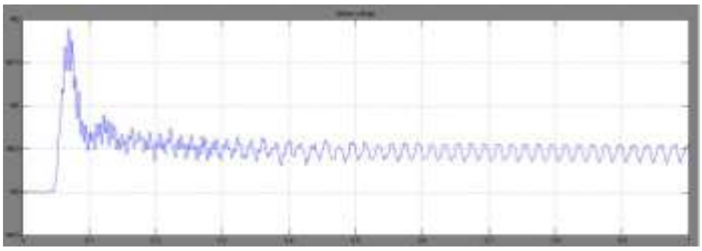

Figure 9. Battery voltage

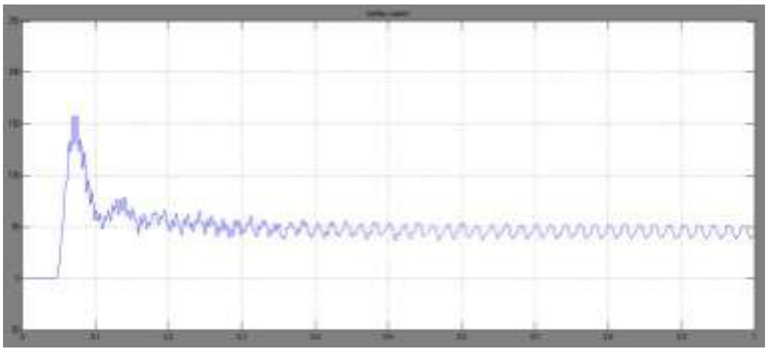

Figure 10.Battery current

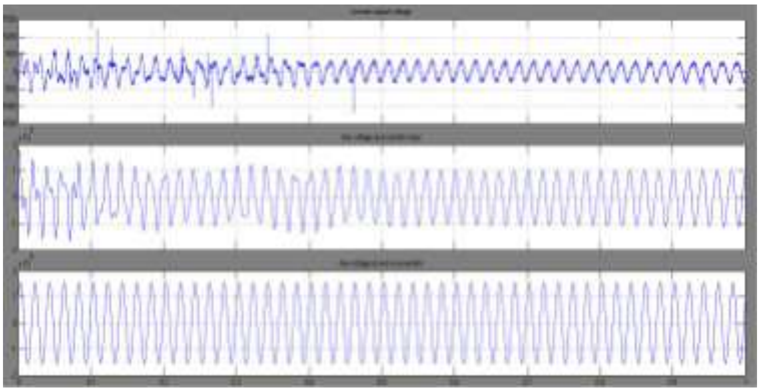

Figure 11. Output voltage of the inverter, input and output voltage to the pie section.

OBSERVATION OF THE WAVEFORMS

The result shows that the input voltage is near to 530 volts which is far more than prescribed limit. At the output of the inverter we can see from the simulated results as in fig.11 that the output voltage is approximately 390volts that is very much close to 400volts which was the rated output. The time duration of each cycle seems to be 0.1second. Thus the frequency becomes 10Hz (f=1/T). It is far below than the prescribed limit. Also from the simulated results of the voltage as in fig.11 we can see that the time duration for each cycle is nearly 0.02 sec. Thus the frequency becomes 50Hz. So this controller controls the reactive power in order to control the frequency.Fig.11 shows that the desired output voltage of the inverter is 400V AC. And the same after transmitting through the power transformer and then through the pie section is suitable for connecting the same power to the grid.

VIII. CONCLUSION

In this paper we have developed constant power supply from a wind power plant (using squirrel-cage induction generator) to the grid using power electronics converter. We have also developed a battery energy storage system to store the extra power. This system is suitable for storing the energy using the Battery Energy Storage system (BES) for which we have used a thevenin equivalent of the battery model. The system is also suitably connected to the grid for feeding the generated power from the wind turbine/wind power generating system.

REFERENCES

[1] Bhim Singh and Gaurav Kumar Kasal, "Solid-State Voltage and Frequency Controller for a stand alone wind power generating system," IEEE Trans. Power Electronics, vol. 23, no.3, pp.1170–1177, 2008.
[2] Bhim Singh and Gaurav Kumar Kasal, "Voltage and Frequency Controller for a 3-Phase 4-Wire Autonomous Wind Energy Conversion System" accepted for publication in IEEE Trans. on Energy.
[3] Voltage and Frequency Control of Isolated Asynchronous Generator with Reduced Switch Integrated Voltage Source Converter in Isolated Wind Power Generation (Sharma & B. Singh, Electrical Engineering Dept. IIT, Delhi). K. Elissa, "Title of paper if known," unpublished.
[4] "Non- Conventional energy Resources" B H KHAN, Tata McGraw-Hill Publication.

[5] K.Premalatha, Daliya. V.V and S. Vasantharathna, Member IEEE,"Voltage and frequency control of independent wind power generating system".

[6] Bikram Das, Naireeta Deb, Prabir Ranjan Kasari & Abanishwar Chakraborti,"Power Electronics Based Voltage and Frequency Controller Feeding Fixed Loads For Application In Stand-Alone Wind Energy Conversion System" International Journal of Engineering Research & Technology (IJERT),Vol. 1 Issue 3, May – 2012,ISSN: 2278-0181.PP. 1-5.

[7] Bhim Singh and Gaurav Kumar Kasal "Battery Energy Storage System Based Controller for a Wind Turbine Driven Isolated Asynchronous Generator"JPE Vol. 8 no. 1, 2008 ,pp 81-90.

[8] Electrical Machines-S.K Sen..

[9] MATLAB 2009a.

[10] Sofia Lalouni and Djamila Rekioua, "Control of Photovoltaic Water Pumping System With Battery Storage", International Journal of Electrical Engineering & Technology (IJEET), Volume 4, Issue 1, 2013, pp. 190 - 199, ISSN Print : 0976-6545, ISSN Online: 0976-6553.

[11] A K Pradhan, S K Kar and M K Mohanty, "Reduction of Mismatch and Shading Loss by use of Distributed Power Electronics in Grid Connected Photovoltaic Systems" International Journal of Electrical Engineering & Technology (IJEET), Volume 3, Issue 3, 2012, pp. 137 - 145, ISSN Print : 0976-6545, ISSN Online: 0976-6553.