Power Electronics Based Voltage and Frequency Controller Feeding Fixed Loads For Application In Stand-Alone Wind Energy Conversion System

Bikram Das[1], Naireeta Deb[2]
1. *Electrical Engineering Department, NIT, Agartala.*

Prabir Ranjan Kasari[1], Abanishwar Chakraborti[1]
2. *Student M.Tech (Power electronics & Drives) Electrical Engineering Department, NIT, Agartala.*

Abstract

It deals with a power electronic controller which controls the voltage and frequency of an isolated asynchronous generator feeding consumer loads. 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. 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. 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 Blockset) Toolboxes. The simulated results are presented to demonstrate the capability of an isolated generating system driven by a wind turbine feeding three phase loads.

Keywords- Isolated asynchronous generator, uncontrolled bridge rectifier, voltage and frequency controller (VFC), switching pulse generator.

I. Introductions

An increasing rate of depletion of conventional sources of energy and growing power demand has diverted attention of scientists towards nonconventional sources of energy such as wind and solar energy. Induction generators have been found to be very suitable for wind energy conversion. These may be operated in grid- connected or self-excited mode [5]. A Standalone wind energy conversion system (WECS) is useful for powering small villages located far from the grid. It is also well known that an externally driven asynchronous machine can sustain self excitation when an appropriate value of capacitor bank known as excitation capacitor is connected across its stator terminals. In case of constant speed application, the Isolated Asynchronous Generator (IAG) operates at practically constant speed. In variable speed operation, IAG needs an interface to convert the variable voltage output of the generator to the fixed voltage at the load terminals. Moreover brushless constructions with squirrel cage rotor, reduced size, absence of DC excitation reduces the maintenance and improves the transient performance. Thus asynchronous generator has emerged as main candidate to supply energy using non-conventional resources like wind and hydro power potential. This specific paper emphasizing on **wind energy conversion-system.**

However even with large number of advantages the main disadvantage of synchronous generator are poor regulation of voltage under varying load condition. This is the main barrier in its effective operation. In this project work an attempt has been made to make a voltage controller with power electronic equipment. The whole controller feeding from a wind turbine whose torque has been calculated and fed into the asynchronous machine. The induction machine stators are further connected to the rectifier-filter-inverter bridge via a delta connected excitation capacitor bank. This allows the controller to produce a constant power to the grid. All simulations are performed in MATLAB using SIMULINK toolbox and power system block set.

2. System Configurations and principle of operation

Fig-1shows the schematic diagram of the proposed system with the imaginary wind turbine, the asynchronous machine, the excitation capacitor, the proposed power electronic controller and the consumer loads. A delta connected [1] excitation capacitor is used to generate the rated voltage at no load. The stator terminals of the IM are connected [4] to the power electronic controller. The controller consists of a three phase diode bridge rectifier connected to an inverter via a filter capacitor of 1mF. 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.

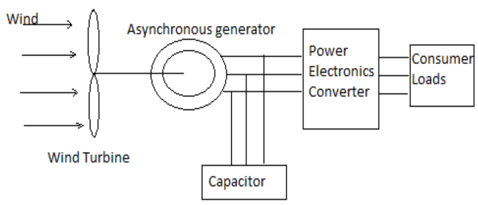

Figure 1. Complete arrangement of the system.

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 [1]. So it controls the magnitude of the voltage under various wind speed condition.

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3. Wind turbine Characteristics

In wind parks, many wind turbines are equipped with fixed frequency induction generators. Thus the power generated is not optimized for all wind speed conditions [5].To operate a wind turbine in its optimum condition [3] at different wind speeds, the wind turbine should be operated at its maximum power coefficient. To operate around its maximum power coefficient, the wind turbine should be operated at a constant tip-speed ratio, which is proportional to ratio of the rotor speed to the wind speed. As the wind speed increases, the rotor speed should follow the variation of the wind speed. In general, the load to the wind turbine is regulated as a cube function of the rotor RPM to operate the wind turbine at the optimum efficiency.

The wind turbine output power is given by,

$$P_m = \frac{1}{2} \rho \pi R^2 V_w^3 C_p \qquad (1)$$

Where

P_m- Mechanical output power of the turbine (W)
C_p- Performance coefficient of the turbine
ρ - Air density (kg/m^3)
R - Turbine rotor radius (m)
V_w - wind speed (m/s)

The tip speed ratio of the turbine blades is given by

$$\lambda = \omega R \qquad (2)$$

Where

ω -rotational speed of the wind turbine. The wind turbine model used here is represented as a family of turbine power-speed curves are shown in fig .2.

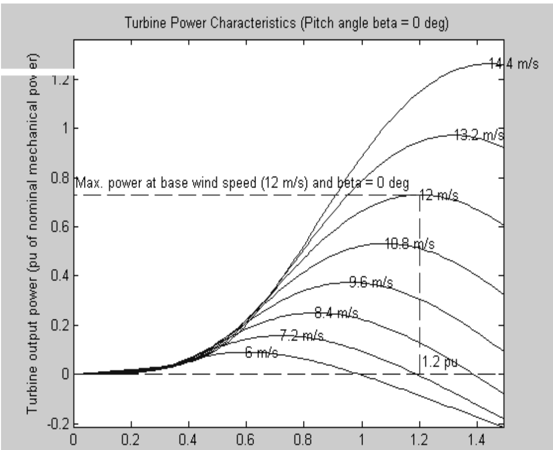

Figure 2. Wind turbine speed versus turbine output power characteristics.

4. Selection of wind turbine and generator parameters

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= 15000kW
- AC voltage =400V
- Frequency =50Hz
- Pole pairs= 2
- Type= squirrel cage induction machine
- Speed =1460 rpm

Parameters:

- Stator
  Resistance (R_s) = 0.2147Ω
  Inductance (L_s) = 0.000991H
- Rotor
  Resistance (R_r) =0.2205Ω
  Inductance (L_r) =0.000991H

Mutual inductance (L_m) =0.06419H
Loses, Inertia (J) = 0.102Kgm^2
Friction = 0.009541 N-m-s

5. Calculations

Parameter of the machine

Slip= $(N_s-N_r)/N_s$
For a 4 pole machine Ns = (120*50)/4=1500rpm
Slip= (1500-1460)/1500 = 2.67%
Leakage reactance, $X_r^* = 2\pi f L_r$=0.311H
Stator current (Is)= $(SXE_r^*)/(\sqrt{(R_r)^2+(SXE_r^*)^2})$
Where
E_r^*= emf induced/phase when the rotor is stand-still
Is=$(0.0267*400)/(\sqrt{3}*\sqrt{(0.2205)^2+(0.0267*0.0311)^2})$
=27.95A
Power (P) = $\sqrt{3} V_s I_s \cos\Phi_1$
=>15000= $\sqrt{3}*400*27.95*\cos\Phi_1$
=> $\cos\Phi_1$= 0.774
=>Φ_1= 39.22
=>$\tan\Phi_1$=0.816

Power/phase P_p =15000/3 =5000W
Desired p.f =0.8 =$\cos\Phi_2$
=>Φ_2=36.86
=>tan Φ_2=0.75
$Q_{cp}=P_p(\tan\Phi1-\tan\Phi2)$ [6]
=5000(0.816-0.75) KVar

=330KVar/phase

Calculations of the value of capacitance (Δ – Connection) [6]

$V_p = V_L = 400V$

$Q_c = V_P I_C$

$I_C = Q_C / V_P = (330*1000)/400 = 825A/phase$

Capacitance /phase

$C_\Delta = I_C / \omega V_P = 825/(2\pi*50*400)F = 6.5mF$

Speed of wind turbine rotor:

R=8/2m= 4m

Speed of wind =8m/s (standard value)

No. of blades= 3

Tip speed ratio for optimum output

$\Lambda_0 = 4\pi/n = 4.188$

$\Rightarrow 4.188 = (R\omega)/\mu_0$

$\Rightarrow \omega = 8.376$ (at standard temp)

Torque calculation [8]

At 25˚C speed of wind = 19m/s

Therefore,

$P_{max} = 1/2\rho(A)V_i^3$

$= 1/2*1.225*(50.265)*19^3$

$= 211170W$

As, $C_{Tmax} = C_{Pmax}/\lambda = 0.593/4.188 = 0.1415$

$T_m = (P_{max}/\mu_0)*R$

$= (211170/12)*4$

$= 70390N$

$T_{Smax} = T_m * C_{Tmax}$

$= (70390*0.1415)$

$= 9960N$

$= 9.96KN$

6. Control Strategy

The induction machine driven by wind turbine is controlled to get fixed output powers under varying wind speed conditions. The stator voltage [4] 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.

However a source inductance of small value (1mH) is placed at the input of the uncontrolled rectifier [7]. 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. But with the source inductance present the four diodes /two legs continue to conduct for some interval known as overlap interval [2].

The use of diode rectifier significantly reduces the cost and is ideal for low /medium voltage application.

The ripple DC voltage is fed through 1mF capacitor and we get stiff DC. This is fed to the inverter input. The switching pulse required for the different devices of the inverter has been shown by using pulse generator. Complete MATLAB simulation circuit for the switching pulse generation is shown in figure 3 below.

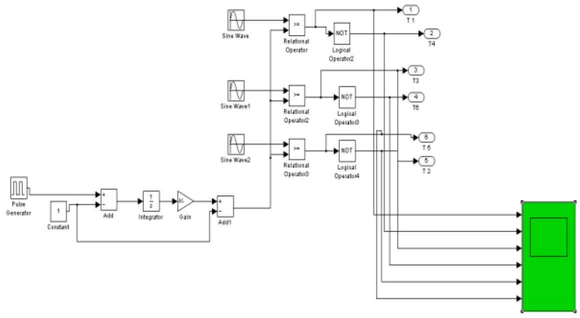

Figure 3. Simulink model for switching pulse generation for 3 phase inverter

7. Simulation results

The schematic diagram shown here in fig. 4 is done in MATLAB using SIMULINK toolboxes for varying wind speed conditions. It consists of the power electronic controller which controls the voltage of an isolated asynchronous generator feeding consumer loads. Resistive, inductive and capacitive loads are connected across the output.

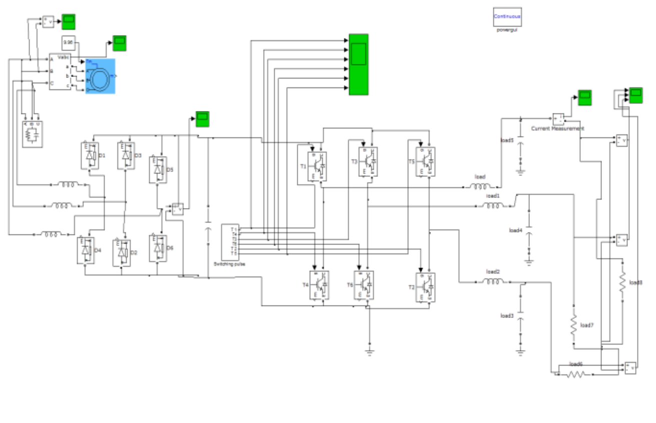

Figure 4. Simulink model for power electronics based voltage and frequency controller feeding fixed loads for application in WECS.

In fig.4 the complete wind turbine is replaced by the actual torque of the turbine which is 9.96KiloNewton as calculated for a standard wind turbine.

The three phase uncontrolled (diode) rectifier configuration can handle reasonably high power and has acceptable input and output harmonic distortion. The configuration also lends itself to easy series and parallel connection for increasing voltage and current rating or improvement in harmonic behavior. The fig. 5 shows the input voltage and fig.6 & fig.7 shows the output voltage waveform of the rectifier without filter element and with filtering element respectively.

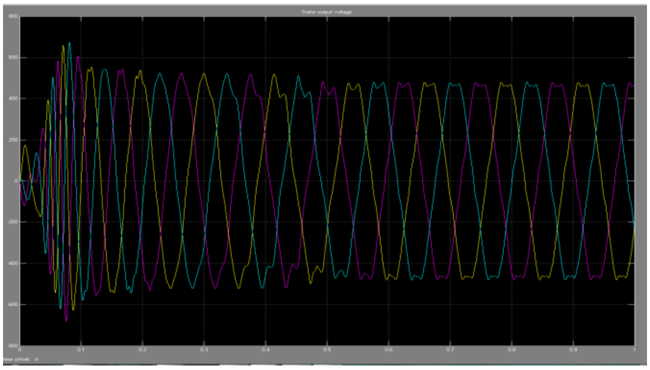

Figure 5. Rectifier input voltage waveform.

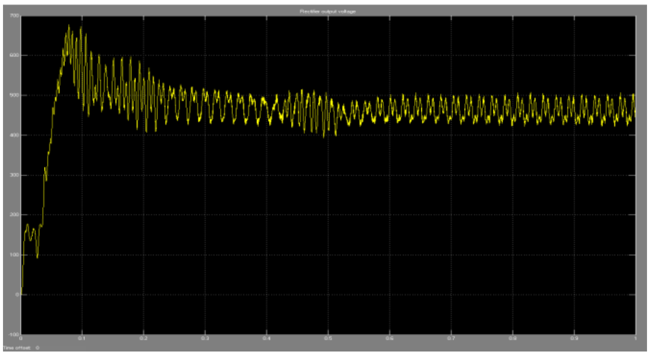

Figure 6. Rectifier output voltage without filter capacitor.

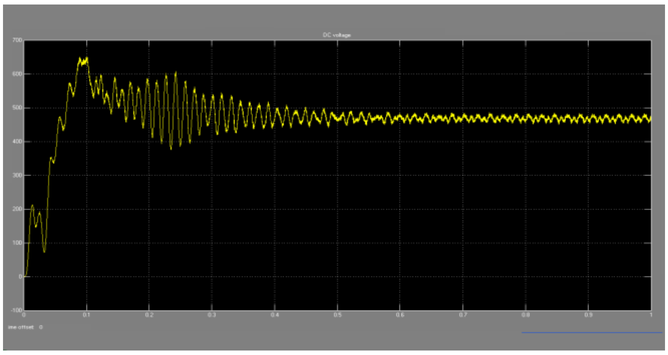

Figure 7. Rectifier output voltage after filtering.

From fig.7 we can see that the dc voltage has a bit of ripple at starting that becomes almost stiff with a ripple of 30volts which is acceptable in this case.

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. and the simulink model was as shown in fig.3.

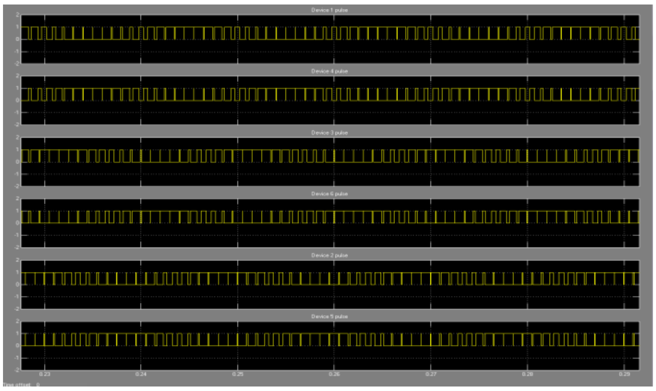

Figure 8. Six switching pulses for six devices of the inverter

The inverter consists of 3 IGBT pairs whose output is controlled by switching pulses. The output current for A-phase and voltage for each phases are as shown in fig.9 and fig.10 respectively.

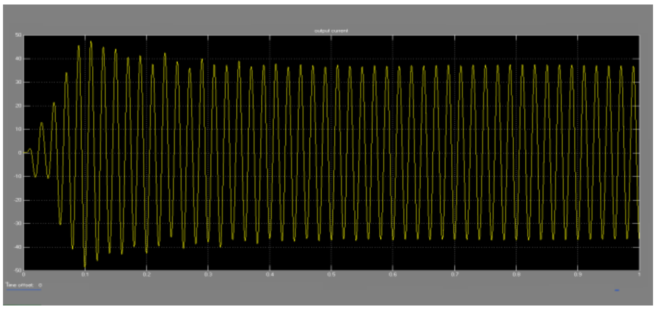

Figure 9. Output current waveform for phase A

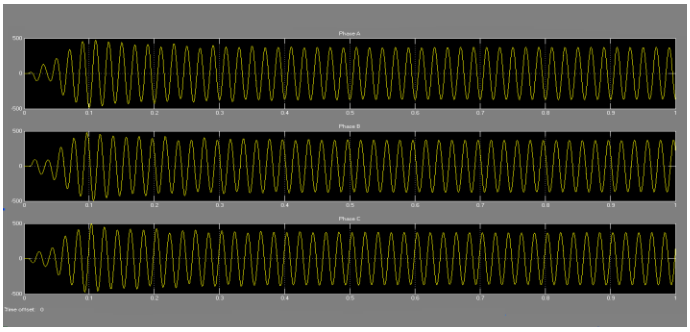

Figure 10. Output voltage waveforms for the 3 phases

8. Observation of the waveforms

Here we have seen the input voltage waveform, rectifier output dc voltage, switching pulse wave forms, controlled ac voltage and current waveforms of the complete system. The result shows that the input voltage is near to 550 volts which is far more than prescribed limit. At the output of the inverter we can see from the simulated results as in fig.10 that the output voltage is approximately 380volts 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.10 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.

9. Conclusions

In this paper controlling the terminal voltage and frequency of an isolated wind turbine generator has been presented. The power electronic controller here produces a new approach towards the controlling of power generated by **IAG** (Isolated asynchronous generator). The proposed bi-directional controller controls the active as well as reactive power thus controlling the voltage and frequency of the system. Use of uncontrolled rectifier has reduced the cost significantly. The simulation results demonstrate the capability of **VFC** (voltage and frequency control) for power quality improvement.

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