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## The Modeling and Simulation of Wind Energy Based Power System using MATLAB

Suman Nath

*Department of Electrical Engineering Bengal Engineering & Science University, Shibpur, India,*  
suman.therebel@gmail.com

Somnath Rana

*Department of Electrical Engineering Bengal Engineering & Science University, Shibpur, India,*  
somnath.besu.ee@gmail.com

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# The Modeling and Simulation of Wind Energy Based Power System using MATLAB

Suman Nath, Somnath Rana

Department of Electrical Engineering, Bengal Engineering & Science University, Shibpur  
E-mail : suman.theRebel@gmail.com, somnath.besu.ee@gmail.com

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**Abstract** - Modeling and simulation of a grid connected wind-driven electricity generation system or WECS (an acronym for Wind Energy Conversion System) has been done. Our aim is to design and test a power system of 14.9 KVA capacity, operating at 440V, 20m/s base wind speed, induction generator based-wind energy system via. MATLAB simulation. The different components of a wind energy system namely the wind turbine, generator, controller system, rectifier-inverter, battery, load and other equipments including transformers, grid etc. were decided as per the scope of this project following which the design steps and modeling of the system in MATLAB simulation environment - SIMULINK was undertaken.

**Keywords**- MATLAB, SimPower System, SIMULINK, WECS

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## I. INTRODUCTION

One of the most significant developments of the late 20<sup>th</sup> century was the re-emergence of the wind as a potential source of energy generation. An emerging awareness of the finiteness of earth's fossil fuel reserves as well as of the adverse effects of burning those fuels for energy had caused many people to look for alternatives. The growing concern about the emissions from fossil fuel generation and increased government support has helped flourish wind power installation in India and abroad. Provision of incentives instituted by the Ministry of New & Renewable Energy (MNRE) has made wind electricity competitive in India. In India present installed capacity is 14158.00MW till 31st March 2011. The need of energy generation, the potential and the technological capacity were the reasons to foster the emergence of wind energy.

Wind is air in motion and this energy is actually derived from solar energy. About 2% of the total solar flux that reaches the earth's surface is transformed into wind energy due to uneven heating of atmosphere. This kinetic energy of wind is used to gain the rotational motion of the wind turbine which is coupled with an electrical generator to supply power over a region acting as stand alone or supplying power to a grid. In an actual WECS, the issues to be considered are as follows:

**Table-I**

<b>Power Generation</b>	Generators
	Power Electronic Converters
<b>Storage</b>	Batteries
	Rectifiers
	Inverters
<b>Interconnection &amp; Distribution</b>	Power Cables
	Switch Gear
	Circuit Breakers
	Transformers
<b>Control</b>	Sensors
	Controller
	Yaw or Pitch Motors
	Solenoids
<b>Lightning Protection</b>	Grounding
	Lightning Rods
	Safe paths
<b>End Loads</b>	Lighting, Heating and Motors
<b>Site Monitoring</b>	Data Measurement & Recording
	Data Analysis

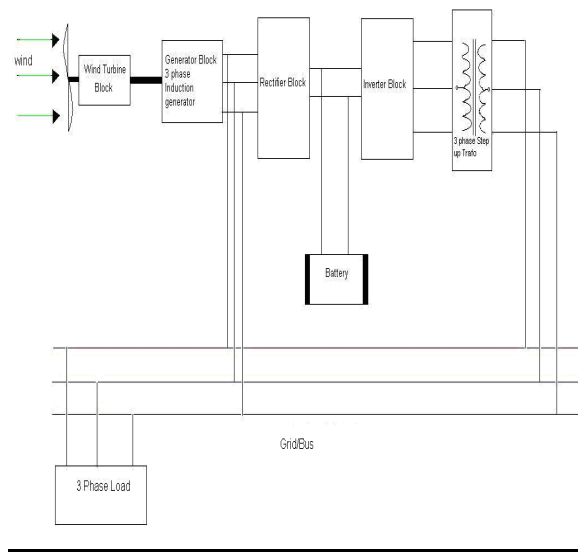
Of these only the most basic and essential parts of a WECS were included in the present work.

Now, WECS can be used in two different ways:

- A) Isolated standalone system
- B) Grid connected system.

Isolated standalone systems are employed to cater the needs of small townships or small scale industries located at far off places/ remote areas. Such systems are set up with a restricted objective to avoid transmission costs over long distances. Whereas, emphasis on grid connected systems is increasing with the integration of renewable energy systems into the grid, which leads to increased energy efficiency, robustness of the system, voltage support, diversification of energy sources, reduced transmission and distribution losses and reliability of the system. As wind is one of the most promising distributed generation sources and their penetration level to the grid is also on the rise, this mode of generation is thus our centre of focus.

**II. A BLOCK DIAGRAM FOR THE OVERALL WIND ENERGY CONVERSION SCHEME**



Block diagram for the overall WECS scheme

The work was initiated by first and foremost modeling a DC generator setup for the wind turbine. On satisfactory simulation and testing, which helped us in familiarizing with MATLAB tools and techniques, we decided on introducing an Asynchronous Machine as wind turbine generator.

The first Induction Generator modeled worked well for its motoring operation but on transition to generation mode, there were severe oscillations, disturbances and computational problems owing to the mathematical framework of the model.

**III. THE MODELING ASPECTS OF WIND ENERGY BASED POWER SYSTEM IN MATLAB - SIMULINK**

GENERATOR MODEL

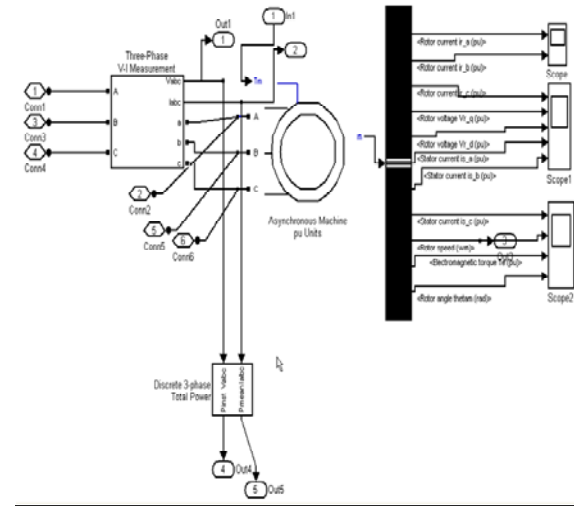


Figure 2 : Generator Model

The Asynchronous Machine block used here is a built-in model of MATLAB 7.0.4 present in the Simpower Systems of Simulink Library. It operates in either generator or motor mode. The mode of operation is dictated by the sign of the mechanical torque: If  $T_m$  is positive, the machine acts as a motor. If  $T_m$  is negative, the machine acts as a generator. The electrical part of the machine is represented by a fourth-order state-space model and the mechanical part by a second-order system. All electrical variables and parameters are referred to the stator. This is indicated by the prime signs in the machine equations given below. All stator and rotor quantities are in the arbitrary two-axis reference frame (dq frame).

**3.1.1. INPUTS AND OUTPUTS**

**$T_m$**

The Simulink input of the block is the mechanical torque at the machine's shaft. When the input is a positive Simulink signal, the asynchronous machine behaves as a motor. When the input is a negative signal, the asynchronous machine behaves as a generator. The

input signal is in p.u. as we have used the p.u. mask here i.e., Asynchronous Machine p.u. Units.

M

The Simulink output of the block is a vector containing 21 signals. We have de-multiplexed these signals by using the Bus Selector block provided in the Simulink library. Depending on the type of mask we use, the units are in SI, or in p.u. In our project we have used it in p.u mask.

**3.1.2. GENERATOR SPECIFICATIONS:**

<u>ITEMS</u>	<u>SPECIFICATIONS</u>
TYPE OF GENERATOR	SQUIRREL CAGE IND.
KVA RATING	14.9 KVA
RATED VOLTAGE	440 V
RATED SPEED	1000 sync R.P.M
RATED POWER	11 KW @ 0.86 p.f.
NO. OF POLES	6
GENERATOR INERTIA	25 kg-m <sup>2</sup>
RATED TORQUE	105 N-m
STATOR RESISTANCE	1.41 ohm i.e., 0.1085 p.u
STATOR REACTANCE	2.3 ohm i.e., 0.502 p.u
ROTOR RESISTANCE	135 ohm i.e., 0.2124 p.u referred to stator
ROTOR REACTANCE	2.3 ohm i.e., 0.502 p.u
MAGNETISING REACTANCE	98.4 ohm i.e., 7.573 p.u
WINDING CONNECTION	DELTA

ACTIVE POWER generated by the machine= LOAD ACTIVE POWER + BUS ACTIVE POWER (as the excess generation by the machine is fed into the bus).

REACTIVE POWER CONSUMPTION BY THE LOAD + MAGNETISING CURRENT (VAR) OF THE GENERATOR = REACTIVE POWER DELIVERED BY THE BUS

A **three phase V-I Measurement** block has been placed at the output terminals of the generator to compute the line voltages and line currents coming out from the generator, which can also be viewed in the scope.

Another measurement block present in the SimPower System of the Simulink Library by the name of **Discrete 3-phase Power** has also been used. This measurement block takes the generator line voltages and

currents as its inputs and enables us in computing the instantaneous power and mean power produced by the generator at its output.

**3.2 WIND TURBINE MODEL**

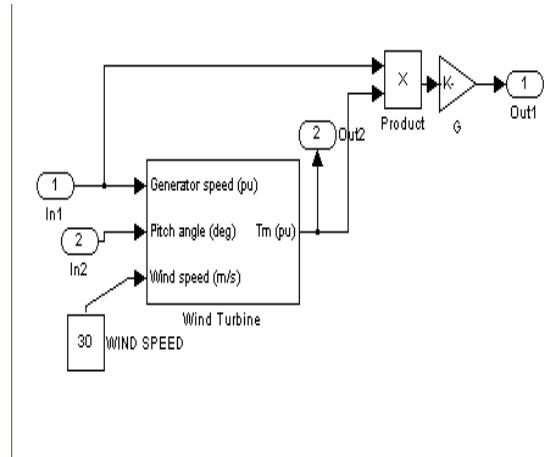


Fig. 3 : A variable pitch wind turbine model.

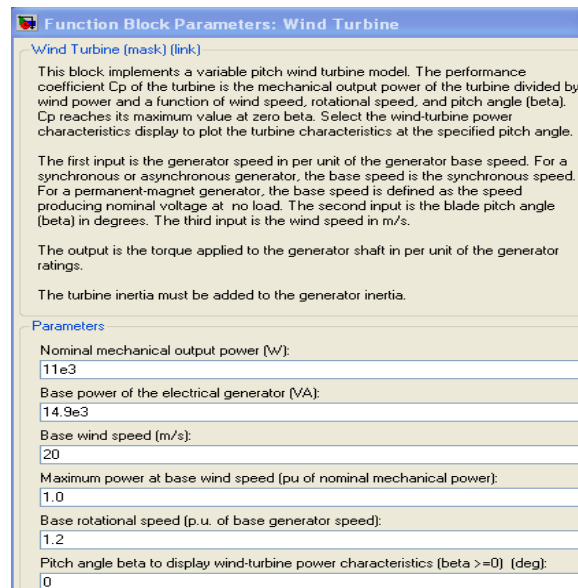


Fig. 4.

The first input is the generator speed in per unit of the base generator speed i.e., we feedback the rotor p.u speed to the wind turbine model. The second input is the blade pitch angle (beta) in degrees. It is a controlled input fed through a pitch controller scheme implemented using a PI controller. The PI controller will track the error signal as long as the generator output power is not equal to the reference power (which controls the generation). The third input is the wind speed m/s.

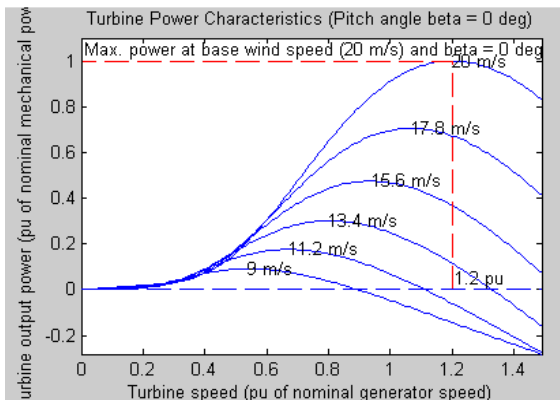


Fig. 5

The performance coefficient  $C_p$  of the turbine is the mechanical output power of the turbine divided by wind power and a function of wind speed, rotational speed, and pitch angle ( $\beta$ ).  $C_p$  reaches its maximum value at zero  $\beta$ . The output is the torque applied to the generator shaft in per unit of the generator rating.

### 3.3 INFINITE BUS/GRID MODEL

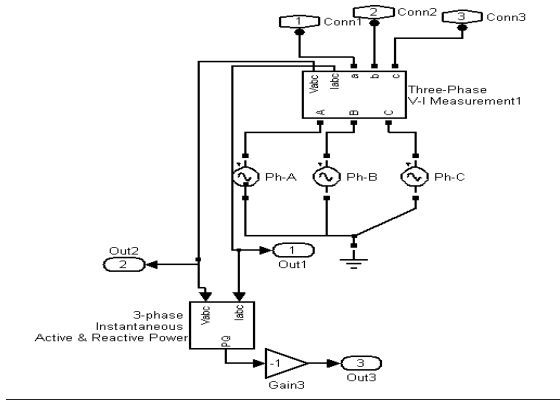


Fig. 6

We have prepared the model of the grid/infinite bus using three balanced AC voltage sources connected in star and shifted in phase by 120 degrees. The phase to phase voltage of the bus is taken as 440 volts so that the phase to neutral is  $440/1.732$ . The frequency is set at 50 Hz and so it acts as an infinite bus. It has a three phase V-I Measurement block in series which gives us the phase to neutral voltages and currents entering the bus. These currents and voltages are then fed to a 3-phase instantaneous Active & Reactive Power block which gives us the Bus Active power and Reactive power flowing in the bus. The generator output terminals are connected to connect to the grid.

### 3.4 LOAD MODEL

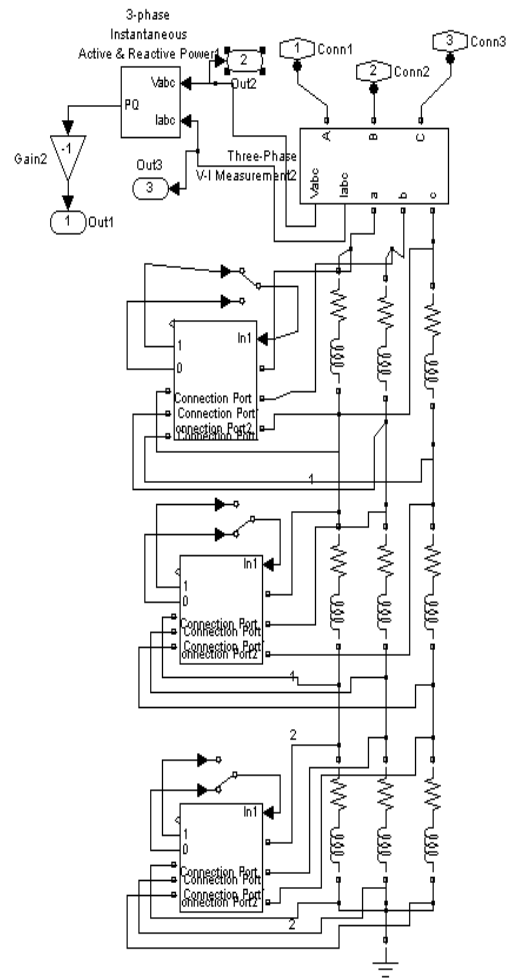


Fig. 7

The figure above shows the three phase load block. We implemented this block using series R-L branches where we have the freedom to feed the values of resistance R and inductance L and vary the load. We have prepared 3 such sets and connected them in series in each phase.

### 3.5. LOAD MANAGEMENT

In physical/real systems there is always some fluctuation in the load on the system. We have made a sincere attempt here to implement this feature in our system using a combination of IDEAL SWITCH and MANUAL SWITCH. Using this feature we can have load fluctuation in the system even in the running condition. However, Care has been taken to ensure that even after increasing/decreasing load, it remains

balanced. This is because our project involves study of balanced currents.

We have placed the switches to perform load fluctuations on the system in the running condition in such a manner so that even after cutting the load, it remains balanced. When the manual switch is at 0, the load is in the system. When the manual switch is at 1, that part of the load gets shorted in all the 3 phases. A power computation block has been used which gives us the load power i.e., 3-phase instantaneous active and reactive power.

### 3.6. OVERALL SYSTEM LAYOUT

The following figure describes our final system with all the components present:

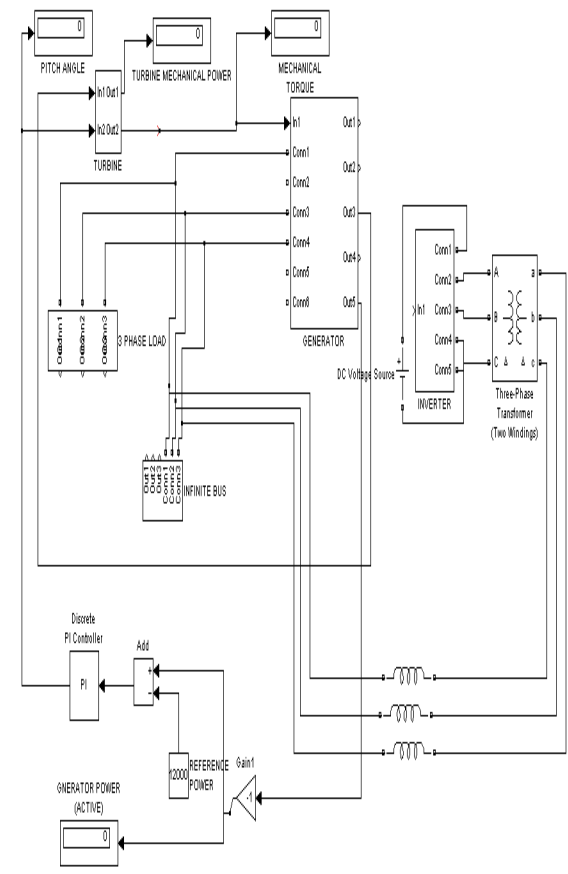


Fig. 8

1. Load block
2. Turbine block
3. Generator block
4. Infinite bus/grid block
5. Inverter blocks
6. Step up Transformer
7. PI. Controller block

### 3.7. RECTIFIER MODEL

The Rectifier model has been realized using a 3-phase Universal Bridge Simulink block. The scheme of modeling is- The Universal Bridge block implements a universal three-phase power converter that consists of up to six power switches connected in a bridge configuration. Thyristors have been chosen as the power switches and a 3 arm converter configuration is adopted using the universal bridge block properties. The gating signals for all six SCRs i.e. Thyristors have been modeled using the logic as mentioned below:

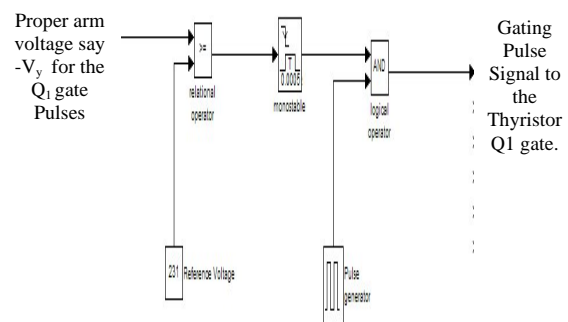


Fig. 9

It is important to mention that the triggering of Thyristors is based on the Cosine Wave Triggering Technique. The control voltage was set at 115 V corresponding to 60 degree firing angle.

### 3.8. MODELING OF THE BATTERY MODEL

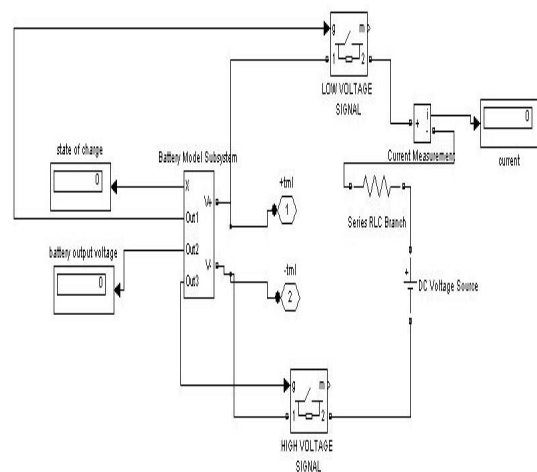


Fig. 10

### 3.9. INVERTER

Presently, our main purpose of using the inverters here is to convert the dc power from the battery into 3 phase ac power. This power is used to meet the load demands under emergency conditions when there is either a shortage of generation or that of the wind. Since the voltage level of this ac power is around 10 V so we have also used a step-up transformer to boost up this voltage before connecting it to the grid. The inverter that we have used here is an IGBT-DIODE based inverter connected in the bridge configuration.

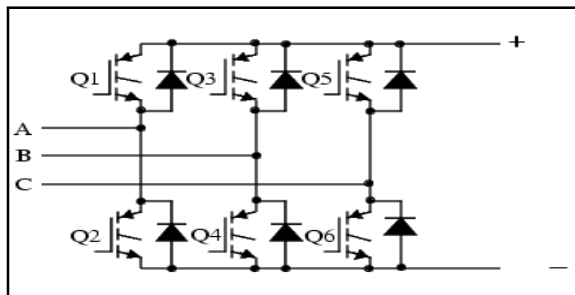


Fig. 11.

To implement this bridge inverter, we have used the Universal Bridge model present in the Simpower Systems of the Simulink Library in Matlab 7.0.4.

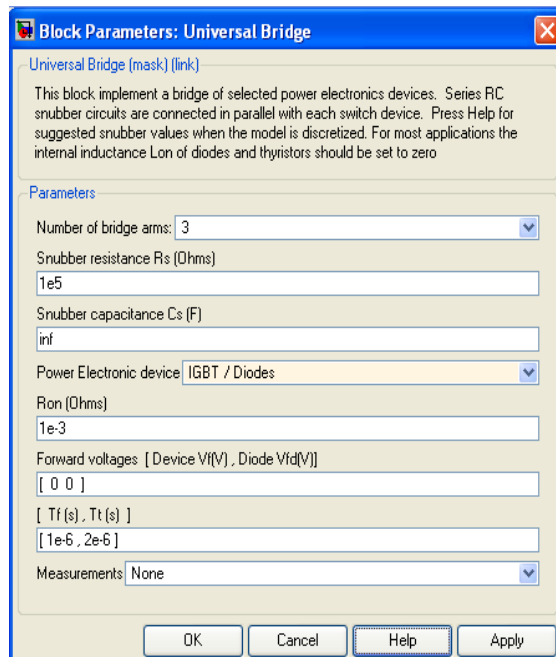


Fig. 12

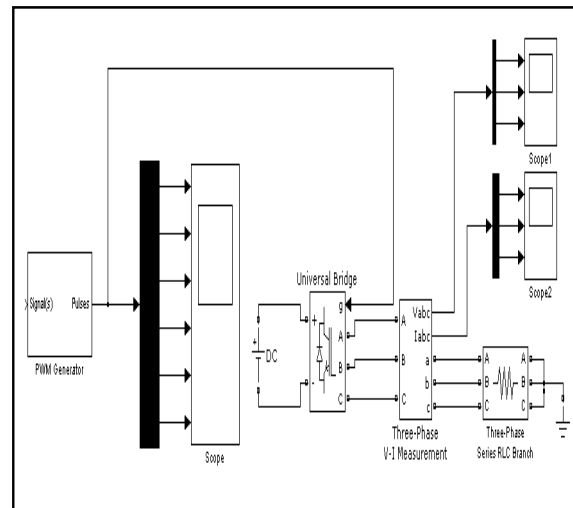


Fig. 13

One of the most promising means of controlling the inverter output voltage is to incorporate time ratio control within the inverter using a suitable modulation scheme i.e., by suitably controlling the ON-OFF time of the switches we control the output voltage. These inverters are called Pulse width modulated inverters.

#### 3.9.1. SPWM TECHNIQUE

The gate pulse requirement of the inverter bridge is taken care of using a PWM Generator

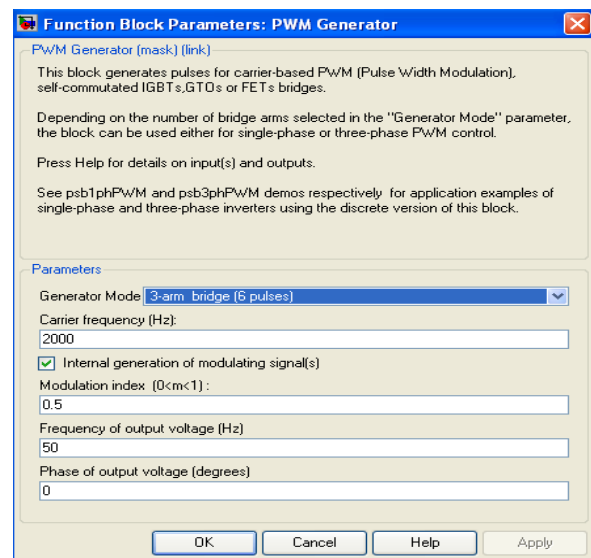


Fig. 14

As the modulating signal is generated internally, it means the reference modulating signal is a three phase sinusoidal wave.



#### IV. INVERTER OUTPUT VOLTAGE AND CURRENT

Substantial amount of harmonic content is introduced in the output voltage, particularly at low values of the output voltage.

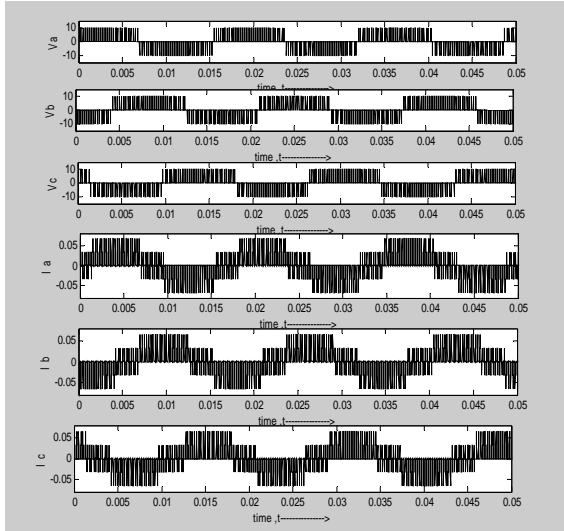


Fig. 15 : Before connecting to Grid

As can be seen, the inverter output voltages are two stepped square wave. The triplen harmonics can be considered to be absent and will be zero. The inverter output current wave is four stepped square wave and it also contains several harmonics.

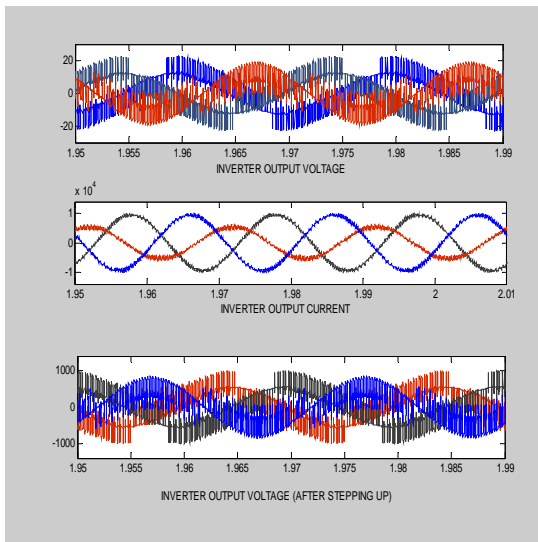


Fig. 16 : After connecting to Grid through a step-up transformer.

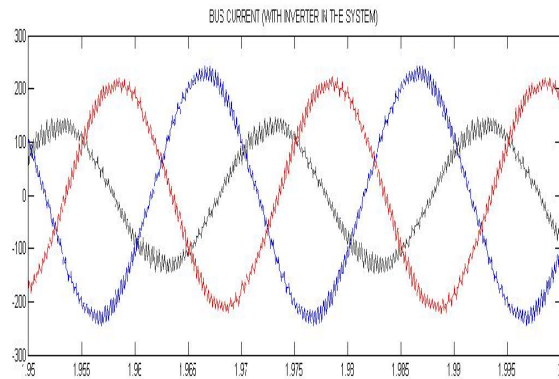


Fig. 17

But the high frequency components have still not been completely eliminated. As a result, the inverter output current has some high frequency components which goes into the grid and get reflected in the grid current. Its effects can clearly be seen in the bus current waveform above. This results in a poor quality of power being obtained from the bus. Moreover, there are Wide fluctuations in the bus power as well. So, this is the problem that needs to be dealt with as far as the working of the inverter is concerned. Infact attempts are being made to improve the quality of power obtained from the inverter and are a hot topic of research nowadays in the power and control sector.

#### V. CONCLUSION

We faced a number of problems while modeling the generator and the other components in our system in the Simulink window of the MATLAB. It was a learning process for us. So, we felt the need to discuss those issues and sum up our critical observations:

1. Phase sequence of the supply is important. It should be kept such that the stator magnetic field rotates in the same direction as the turbine. Otherwise, the generator will not rotate and no torque will be produced.
2. As per the convention, if the mechanical torque from the turbine is positive, the machine works as a Motor otherwise as a Generator.
3. Computation of bus power, load power and the generator output power is very important. It reveals whether the model is working properly, as expected or not.
4. It must also be noted that, if the load is purely resistive, then phase current (= line current) will be in phase with the phase voltages. But the phase voltages itself lag the line voltages by 30 degrees i.e., the phase/line currents will lag the line voltages



by 30 degrees. Hence if we try to compute the power consumption by the load using line currents and line voltages as the inputs, we found that even for a resistive load, there was significant reactive power consumption. Hence we should feed the phase values of current & voltages into the power computation blocks to get the correct result.

5. When the machine settles at an operating point, there will be a perfect balance of power, both active and reactive, between the generator, bus and the load.

## VI. FUTURE WORK

1. The battery model, we have made here, is working properly in isolated condition. But when it is connected in the whole system it was given some computational error. This can possibly be attributed to the fact that it is completely a mathematical model built by implementing this mathematical equation
2. Since the battery could not be connected in the ultimate model, so there is also the scope to connect it making use of the firing angle control scheme described in the Rectifier-battery section. That would enable us to control the firing angle to be used in the rectifier by sensing the charging current.
3. It must be noted that, although the frequency of the inverter output voltage is kept at 50 Hz (same as the grid), but that alone does not ensure that the zero crossings of the reference sinusoidal signals used in SPWM are same as the zero crossings of the sine waves of the grid. So there may be a chance of a mismatch between the two voltages which would later on create problems in synchronizing them. To avoid this problem, what we can do is to take the sine waves from the grid and use it for SPWM. This is exactly what is done in real/physical systems nowadays and can be implemented in future in this system.
4. We have connected chokes (inductive coils) in series with the step up transformer and the grid. These chokes bypass the high frequency components coming from the inverter. Even though they largely reduce the ripples but it could not be completely eliminated and the inverter output shows signs of still carrying them with it. This results in a poor quality of power being obtained from the inverter. Moreover, there are Wide fluctuations in the bus power as well. So, this is the problem that needs to be dealt with as far as the working of the inverter is concerned.
5. Though the inverter has been connected to the system and is almost working satisfactorily but

there is still a lot of scope in properly synchronizing the inverter output voltages with the grid and locking them in phase with each other. That would not only improve the stability of the system but also go a long way improving the quality of the bus power as well.

6. We have not incorporated Reactive Power Compensation Scheme in our Project. There is enough scope to work on it in future, whereby Compensation capacitor can be used under two different schemes: i)NO-LOAD COMPENSATION : It refers to the condition when the capacitor, or rather capacitor bank, fully compensates the reactive power absorption of the Induction Generator under no-load condition, and ii)FULL-LOAD COMPENSATION : It refers to the condition when the capacitor fully compensates the reactive power absorption of the generator under full-load condition.
7. For a grid connected transmission/distribution network, it must comply with certain GRID CODES i.e., fault ride through capability, reactive power range, voltage control, frequency range and frequency control etc. So, this aspect of our system can also be looked into in the future.
8. During network fault, there is a risk that the induction generator will lose stability during the fault. So the TRANSIENT INSTABILITY aspect of a power system, which has not been analyzed here, can also be studied in the future.

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