Fuzzy logic controlled Doubly Fed Induction Generator for Wind Energy Conversion System

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Abstract : The conventional energy resources are being replaced by the renewable energy resources. Among them solar and wind are the two most widely used resources. The energy from these two resources are the basis for domestic usage. The wind energy is harnessed by the wind mills wherein they use doubly fed induction generators. The control method of Doubly fed Induction motor is carried out by the controllers like PI controllers. The maximum power point tracking is done with the help of fuzzy logic controller. The DG system characteristics like the total harmonic distortions, voltage and the current variations and power quality variations at different environmental conditions are observed using MATLAB. The DFIG system is made to use for the smart grid applications as it is more reliable.

IndexTerms - DFIG – Doubly Fed Induction Generator for Wind Energy Conversion System, DBR – Diode Bridge Rectifier

I. INTRODUCTION

The usage of the power electronic devices are increasing due to the wide use of computers in the day to day life. This induces the harmonic components into the grid. The power quality at the grid side gets affected drastically which may lead to additional power loss. The manufacturer of the wind turbine and the power electronic devices certifies them according to the national and international guidelines.

Wind energy is most widely harnessed in the tropical regions. The large wind turbines make use of the doubly-fed induction generators. In the doubly-fed induction generator only a fraction of the system power is handled by the power electronic equipment. The losses can be reduced when compared to the system in which the power electronic equipment handling the total system power. The cost of the system is also minimized due to the usage of smaller converter.

The power quality is a measure of the system in which the characteristics of the voltage and the frequency are defined. The power and the voltage quality of the grid gets affected by the grid interference. It is a difficult process to compensate the voltage fluctuations with a simple compensator. The conventional reactive power compensators are being replaced by the fast controlled power electronic compensators. The maximum power must be extracted from the wind energy for this we are making use of the maximum power point tracking technique. The total harmonic distortion of the Wind energy system can be reduced by the use of soft computing techniques like the fuzzy logic controller.

II.WIND TURBINE MATHEMATICAL MODELLING

The kinetic energy of the wind gets converted into the mechanical energy with the help of a rotating machine. This rotating machine is a wind turbine and the mechanical energy from the wind turbine gets converted into the electrical energy with the help of a wind generator. The rotor shaft of the wind turbine make use of the mechanical torque. The wind power can be calculated as follows

$$P_t= 1/2\rho C_p A V^3 \qquad (2.1)$$

P_t is the rotor mechanical power (W)
V the wind speed (m/s)
$A= \pi R^2$ the rotor surface (m^2)
R is the rotor radius (m)
ρ the air density (kg/m^3)
C_p is the power coefficient.

The rotor aerodynamic power coefficient, C_p, is the function of blade pitch angle (β) and tip speed ratio (λ)

$$\lambda = \text{Tip speed/Wind speed}$$

$$\lambda = \omega_r R/V \qquad (2.2)$$

Sub eqn (2.2) in (2.1) we get

$P_t = 1\backslash 2\ C_p(\lambda)\rho A(R/\lambda)^3\omega^3$ (2.3)

The output torque of the wind turbine T_t is calculated by the following equation

$T_t = 1/2\ \rho C_p A(V/\lambda)$ (2.4)

The optimum tip speed ratio can be obtain by making the variable speed turbine to capture the maximum energy of the wind. The speed of the turbine is directly proportional to the change in the speed.

III.DOUBLY FED INDUCTION GENERATOR

Doubly Fed Induction Generator is a variable speed turbine. In a DFIG system the back-to-back voltage source converter feeds the three phase rotor winding. The mechanical and the electric rotor frequencies are decoupled and the electrical stator and the rotor frequency can be matched, independent of the rotor speed.

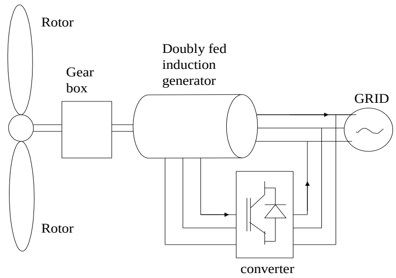

Figure 1: Doubly fed induction generator system

The DFIG can be made to operate at a variety by connecting the stator directly to the AC mains while the rotor is fed from the power electronics converter via the slip rings. A frequency converter can be used between the variable frequency induction generator and the fixed frequency grid. A DC link capacitor is used to link both the stator and rotor side converters which stores the power from the induction generator for the future power generation. The DC-link voltage gets boosted up inorder to get a higher level of line-to-line grid voltage. The machine speed can be controlled at both the stator as well as the rotor side in both the super and sub- synchronous speed ranges. This can be achieved as the slip power flows in both the directions. Motoring mode can be achieved below the synchronous speed. Generating mode can be achieved above the synchronous speed. The machine acts as a synchronous machine when the DFIG is at synchronous speed while the slip power is taken from the supply and the rotor windings are excited. The electric and the mechanical power for the DFIG can be calculated as

$P_r = T_m * \omega_r$ (3.1)

$P_s = T_{em} * \omega_s$ (3.2)

P_r – Power generated at the rotor

P_s – Power generated at the stator

P_m – Mechanical Power

For a loss less generator the mechanical equation is:

$J\frac{d\omega r}{dt} = T_m - T_{em}$ (3.3)

J- Moment of Inertia

In steady-state at fixed speed for a loss less generator

$T_m = T_{em}$

$P_m = P_s + P_r$ (3.4)

and it follows that:

$P_r = P_m - P_s = T_m - \omega_r - T_{em}\omega_s = -sP_s$ (3.5)

$s = (\omega_s - \omega_r)/\ \omega_s$

s – slip of the generator

P_r is positive for negative slip (speed greater than synchronous speed) and it is negative for positive slip (speed lower than synchronous speed).

IV.SYSTEM LAYOUT

A single phase Wind Energy-grid connected system is coupled with a SEPIC converter in a closed loop scheme. The fuzzy logic control scheme is implemented to

- extract maximum power from the wind source
- grid synchronization

- control active and reactive power flow to the grid via PI controller

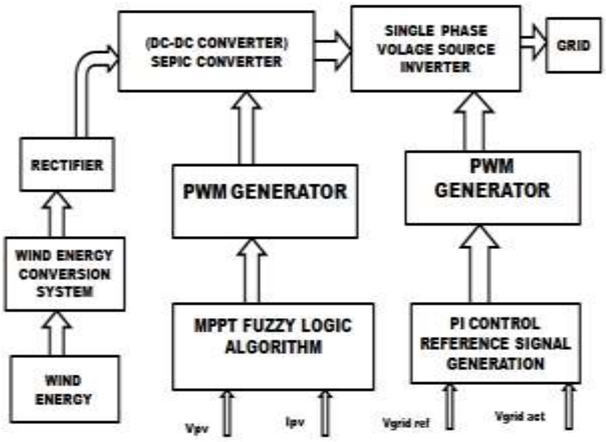

Figure 2: Block Diagram

The DFIG output voltage is fed to the Diode Bridge Rectifier. The uncontrolled Diode Bridge Rectifier converts the AC output voltage to the DC voltage. The voltages must be synchronized. The synchronized voltage is given as an input to the SEPIC converter. The variable DC voltage is converted to a fixed DC voltage with the help of the SEPIC converter. The maximum power can be extracted using MPPT technique. The fuzzy logic algorithm is used to produce the reference pulse. The gate pulse is produced by the pulse width modulator by comparing the reference signal with the carrier signal. The SEPIC converter is fed with this gate pulse. The output from the SEPIC converter, fixed DC output voltage is given to inverter to convert into AC voltage. The single phase three level voltage source inverter can be used for conversion of DC to AC voltage. The VSI, make use of a PI controller, which make use of a closed loop control to minimize the current variations and the power quality problems. The circuit diagram for the system is given as

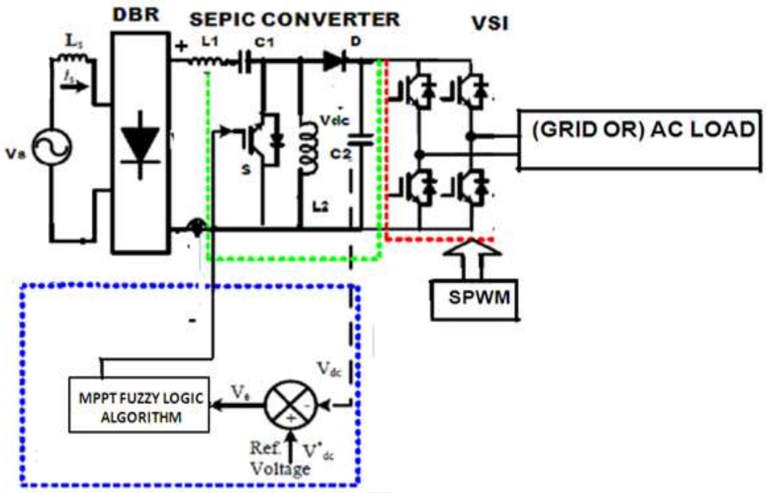

Figure 3: Circuit Diagram for Wind Energy Conversion using Fuzzy logic controller

V.MATLAB MODEL

A MATLAB model was simulated for the understanding of voltage and current variations during different time period. The MATLAB model is given as

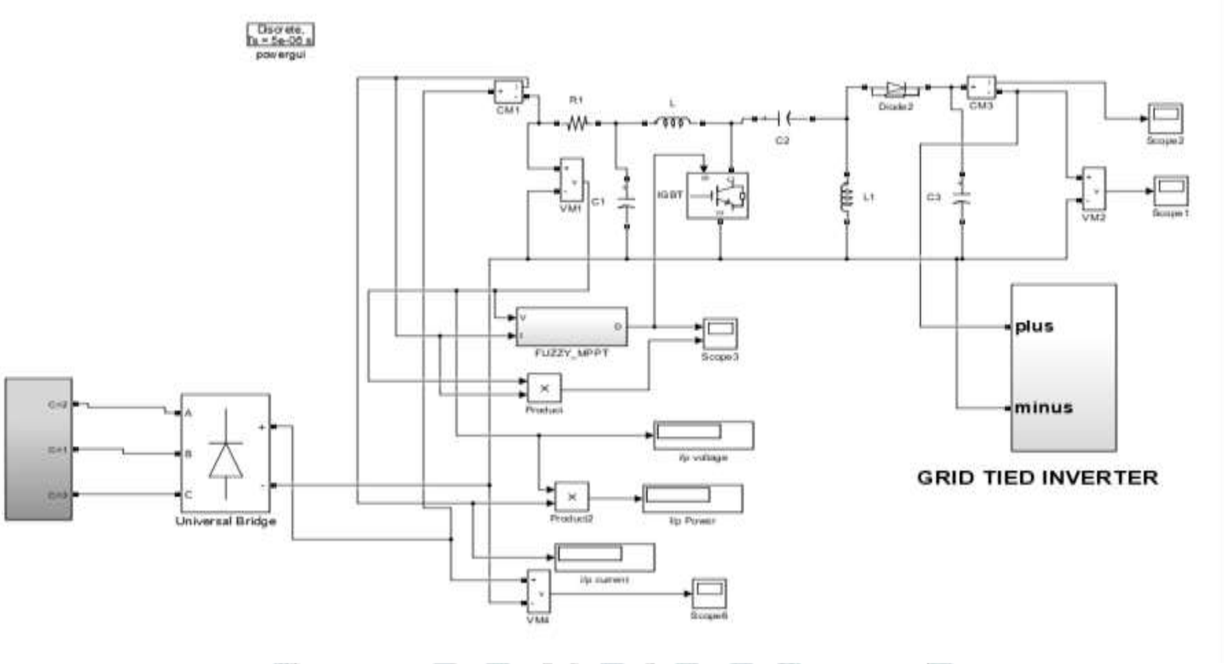

Figure 4 : MATLAB model of Fuzzy logic controlled DFIG wind conversion system

The output of the Diode Bridge Rectifier is given to the SEPIC converter. The MATLAB model for the SEPIC converter is given below.

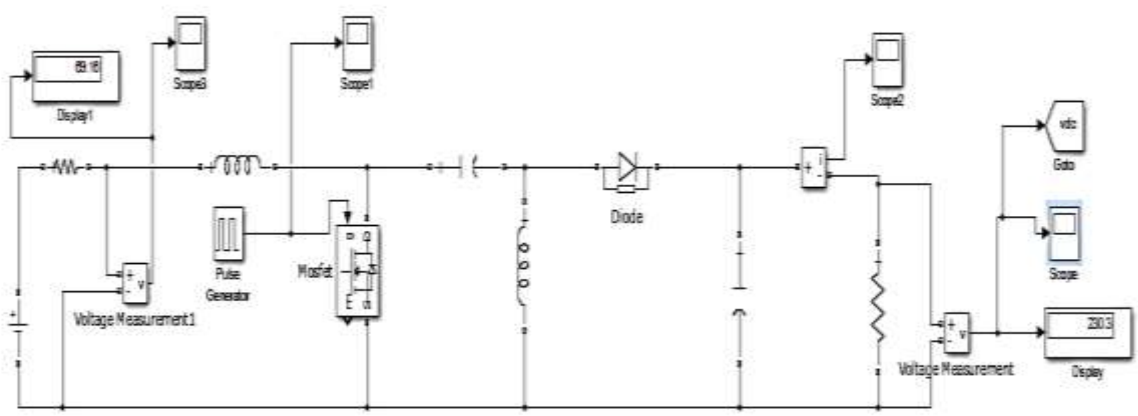

Figure 5: MATLAB model of SEPIC converter

The SEPIC converter is a DC-DC converter in which the given varying DC input can be stepped up or stepped down to a fixed DC input. The input of the SEPIC converter 70V which is a varying DC gets converted to 230V fixed DC. The output from the SEPIC converter is a fixed DC while the input tends to be varying in nature. This can be inferred from the below graph.

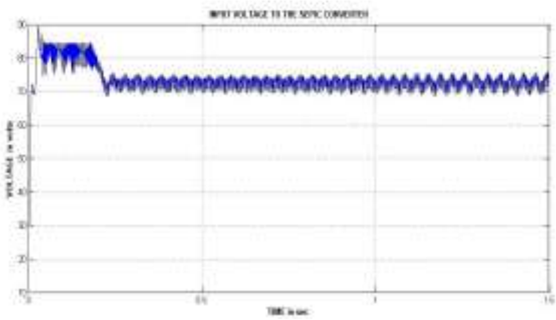

Figure 6: Input DC Voltage to the SEPIC Converter

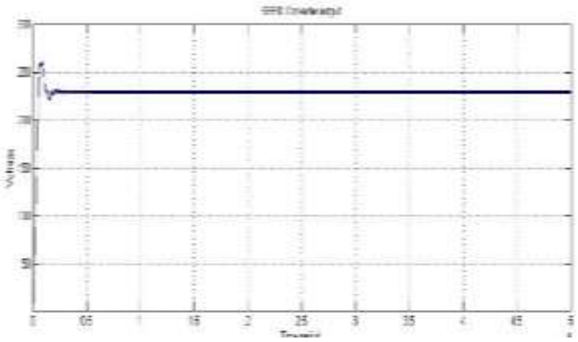

Figure 7: Output DC Voltage of SEPIC Converter

The fuzzy logic controller is implemented for the Maximum Power Point Tracking. The triangular membership function is used in the fuzzy logic controller. A set of rules are defined in the function to generate the reference pulse.

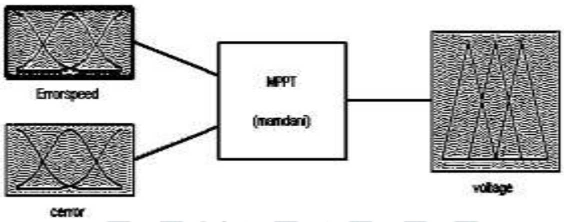

Figure 8: Fuzzy Logic Triangular Membership Function

The reference pulse is generated from the triangular membership function which is given as the gate signal for the SEPIC converter. The below simulation result gives the understanding of the PWM pulse for the SEPIC converter switch.

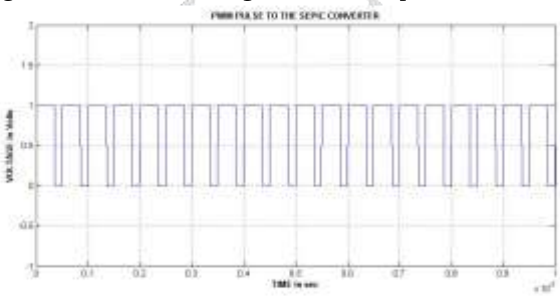

Figure 9: PWM Pulse for SEPIC Converter

The Voltage source inverter is used for converting the fixed DC voltage to a varying AC voltage. VSI is also used for synchronising the output AC voltage with the grid. As it forms a closed loop system, the reference current and the output current is compared and given to the gate of the VSI. The PWM pulse that is given to the VSI is given in the below graph.

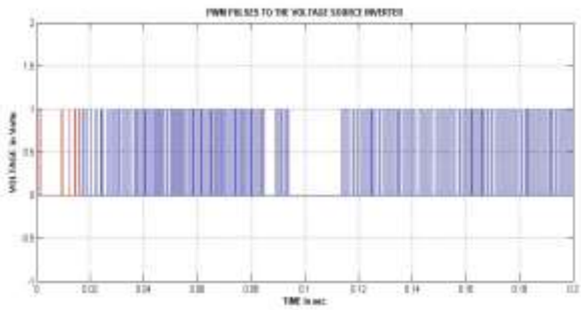

Figure 10: PWM Pulse to the Single Phase Inverter

The final AC output voltage from the single phase Voltage source inverter is given in the below graph.

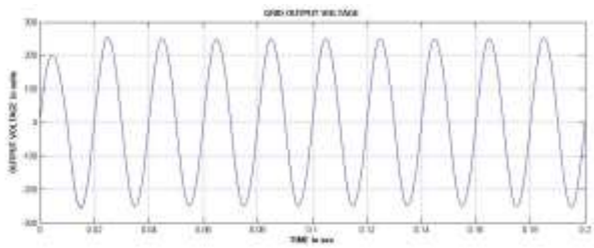

Figure 11: Inverter Output Voltage

The above system is subjected to FFT analysis in which the Total Harmonic Distortion is calculated. The level of THD is reduced to a level of 2.10% or 20 number of cycles. The graph for the THD is given below.

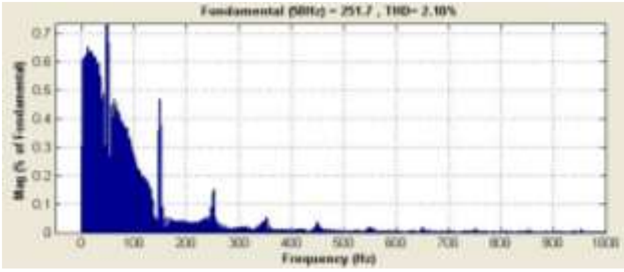

Figure 12: Inverter Voltage THD Waveform Using FFT Analysis

VI.CONCLUSION

The wind energy system is coupled with the DFIG system whose output is rectified and given to the SEPIC converter. The SEPIC converter output is made to be inverted and then it is synchronised to the grid. This proposed system is much more reliable as it gives out perfect sinusoidal wave. The system mathematical modelling is done and the steady state waveforms were extracted. The steady state waveforms got at the grid side shows that the power generated by the DFIG system is fed to the grid at the unity power factor. The THD values are within the IEEE Standards This type of system finds application in smart grid systems.

VII.REFERENCES

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