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Voltage Stability Analysis of Grid Connected PMSG based Wind Energy Conversion System using Matlab/Simulink

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***Abstract*—To eradicate the environmental pollution and to meet the demand of power generation, the nations are concerned to generate the electrical power through the renewable energy resources. The wind energy is the massive energy resource compared to other mode of renewable energy resources. To integrate the wind energy into the grid often causes stability issues in the grid. The stability issues are normally called as voltage stability. In general the wind is intermittent in nature.Wind speed changes due to turbine speed variations. Primary aim is to maintain the voltage stability in the grid,the DC link voltage in back to back converter should be same as the grid voltage. In order to achieve this, in this proposed work the gate signals passed to the rectifier side as well as inverter side is controlled through the Maximum Power Point Tracking (MPPT) control strategy and Hysteresis current control strategy. By using these control strategies voltage stability is maintained to the power grid.**

Key words—MPPT (Maximum Power Point Tracking), Grid voltage, hysteresis current control, voltage stability

I. INTRODUCTION

As a result of increasing global warming and carbon emissions the nations are concentrated to generate the electricity from renewable energy resources[1].In that the wind energy is the enormous energy resource compare to other form of renewable energy resources like Solar, Geothermal etc.

Currently the 19% of the electricity is generated from the renewable energy resources. In the order of renewable energy technologies the wind energy is the competitive technology and in developed countries with good wind resources. The amount of wind energy and wind farms is increasing quickly; a large amount of wind energy is integrated into the exciting power system.

A huge penetration of wind energy in a power system may cause important problems due to the arbitrary nature of the wind and the characteristics of the wind generators. In large wind farms connected to the electrical network (110 KV – 220 KV) the main electrical constraint to take into account is the voltage instability and power quality problem. This aim of this research is to mitigate the voltage instability problem and improving the power quality in grid side by developing the MPPT and Hysteresis controller.

It made a complete analysis about several rectifier, inverter and matrix converter topologies. While doing comparison one part of analysis showed that matrix converter has several features such as potential size and weight savings. The demerit found in the matrix converter is the large number of switches used, which increases the switching losses and results in increment in the level of harmonics. On the contrary, though the matrix converter has a higher number of semiconductor switches, they are subjects to a lower voltage stress, which decreases the failure rate [2].

This work focuses on the development of DFIG and PMSG. At present, typically three types of WECS for large wind turbines exists. The first one is a fixed speed WECS that operates only in a narrow range around the synchronous speed and is directly connected to the grid. There are many disadvantages of this system like high mechanical and fatigue stress on the system, requirement of large gearbox and no voltage support to the grid. The second one is a variable speed WECS that allows variable speed operation over a large, still restricted range. This type of WECS mainly uses a DFIG. The disadvantage here will be the requirement of gearbox and losses in gearbox are huge. The third one is also a variable seed WECS. It can be equipped with either an SCIG or synchronous generator. The synchronous generator that used is PMSG. With PMSG, gearbox can be eliminated by using large number of poles that allows higher efficiency. As compared to other generators with gearbox, the direct drive PMSG is more expensive but still regarded as a good solution because of its higher efficiency and lower wear and tear [3].

The various converter topology and fundamentals of matrix converter and other converter topologies are analysed. In addition, it clearly states about the various basic essentials about each converter topologies. The drawback in each converter topologies was clearly explained and to overcome the obstacles, classification sketch in the converter topology was useful[4]

Nowadays, DFIG are widely utilized in variable speed wind turbine but the major issue is the requirement of gearbox to match turbine and rotor speed. Another drawback of the gearbox is that it mostly requires a regular maintenance which makes the system unreliable. In case of constant wind speed reliability can be improve by using the PMSG. For the extraction maximum power from the wind energy resource there are various control strategies in case of PMSG based wind energy system control strategies has been developed in which generator side rectifier is controlled to obtain the maximum power from wind energy source. This method consists of one switching device IGBT, which is utilized to control generator torque for the extraction of maximum power [5].

There is insurmountable evidence of the many ways that the burning of fossil fuels pollute the planet, many are stepping up to the worldwide challenge of decreasing dependency upon them. According to the Global Status Report from the renewable energy policy Network for the 21st century (REN21), as of 2009, there were 85 countries with policy goals intended to increase the renewable energy usage and production. The major types of “renewable energy” described in these goals include wind, solar, hydroelectric, geothermal, and biomass [6].

II. PMSG BASED WECS

A. *Characteristics of wind turbine*

The turbine it converts the wind energy into mechanical energy which in turn to generate electricity through generators. The output power of the wind turbine P_t is expressed by using the following equation.

$$P_t = 0.5\, C_p \rho\, A V_{\omega}^{3} \qquad (1)$$

Where, C_p- power coefficient of wind turbine, ρ- air density (The standard air density is 1.2256 kg/m^3), A- swept area (Size of the rotor),V_{ω}-wind speed (proportional to installation height).The performance of the wind turbine is characterized by the non-dimensional curve of coefficient of performance C_P , as a function of tip-speed ratio . The tip-speed ratio (TSR) is given by the expression,

$$\boldsymbol{\lambda} = R\omega_m / V_{\omega} \qquad (2)$$

where R- is the radius of the wind turbine rotor in m, ω-is the angular speed of the rotor pin rad/sec, and V_{ω} -is the velocity of the wind in m/sec.. In general,

$$Pt = Tt\, \omega_m \qquad (3)$$

Combining equations (1), (2), (3), the torque equation is

$$Tt = 0.5 \rho A R \boldsymbol{C_p}(\boldsymbol{\lambda})/\boldsymbol{\lambda} * V_{\omega} \qquad (4)$$

The power extracted from the wind is maximum when the power coefficient Cp is at its maximum. This occurs at a defined value of the tip speed ratio(TSR). Hence, for each wind speed; there is an optimum rotor speed where maximum power is extracted from the wind. Therefore, if the wind speed is assumed to be a constant, the value of $\boldsymbol{C_p}$ depends on the wind turbine rotor speed. Thus by controlling the rotor speed, the power output of the turbine is controlled.

The wind machine has a three operating characteristics, such as start-up wind speed cut-in, rated and cut-out wind speeds. Start-up wind speed is the wind speed that will turn an unloaded rotor.

- Cut-in speed is the minimum wind speed at which the blades will turn and generate usable power. The cut-in speed of most turbines is around 12 Km/h.
- The rated speed is the minimum wind speed at which the wind turbine will generate its designated rated power.
- Cut- out speed is the maximum wind speed the wind turbines cannot operate normally.

The block diagram representation of the variable speed direct drive PMSG is shown in the Figure 2.5.The system consists of the pitch able wind turbine, a PMSG, a passive rectifier, a MPPT controlled dc-to-dc boost converter and an hysteresis band current controlled Voltage Source Converter.

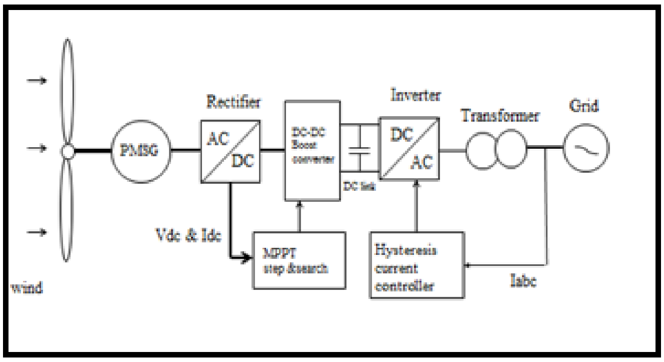

Fig.1 Block diagram of WECS.

The aerodynamic wind turbine in converts the wind power into the mechanical power. That energy is converted into electricity through the PMSG generator. In PMSG are still considerably more expensive and require more advanced rectifiers because they won’t allow for reactive power or voltage control. PMSGs with light weight and low cost are most suitable for applications in WECS. The AC voltage generated from the PMSG based WECS is passed to the rectifier. The rectifier it converts the AC voltage into DC and passed to the boost converter. At low speed, the PMSG generator is incapable to generate the constant high voltage. To improve the voltage level at rectifier side the DC-DC boost converter is used. The MPPT controller is to control the gate signal passed to the rectifier and to obtain the maximum power output from wind. The Voltage Source

Converter (VSC) again converts the DC voltage into AC voltage and integrating into the grid. To control the current in the grid side the adaptive hysteresis band current controller is used. This is maintain the constant current in the for every changing the wind speed.

III. CONTROL STRATEGIES

I. MPPT CONTROL STRATEGY:

(a) Hill Climbing Algorithm

The voltage generated by the PMSG generator (V_{dc}) depends upon the speed of the turbine. So instead of sensing the turbine speed to sense voltage (V_{dc}) and the MPPT controller it tries to control the voltage at constant level for every changing position in the wind speed. The MPPT controller is also used to find out the optimum point at which the generator will generate the maximum power.The maximum power extraction algorithms is classified into three main control methods, namely Tip Speed Ratio (TSR) control, electrical Power signal feedback (PSF) control and Hill-climb search (HCS) control.

In that the Hill Climbing controller algorithm continuously searches for the peak power of the wind turbine. It can overcome some of the common problems normally associated with other two methods. Hence in this research work HCS tracking algorithm method is used. The tracking algorithm, depending upon the location of the operating point and the relation between the changes in power, computes the desired optimum signal in order to drive the system to the point of maximum power. The amount of power output from a wind energy conversion system (WECS) depends upon the accuracy with which the peak power points are consuming the maximum power point tracking (MPPT) controller of the WECS control system irrespective of the type of generator used. The step and search control strategy for tracking maximum power is explained below:

Figure shows the step and search control strategy algorithm to maintain the constant voltage and to set the duty cycle.

- Set the initial duty cycle = 0.5 (D) condition at 15m/s for wind speed .
- Calculate the voltage (V_{new}) & current (I_{new}) value generated by the PMSG generator in WECS. From that values to calculate the power (P_{new}) .
- At stand still condition the WECS it will generates the power (P_{old}).
- Compare P_{old}& $P_{new.;}$ if generating power (pnew) is greater than old power (Pold) the duty cycle has to be incremented.
- And also compare V_{new} & V_{old} values. if V_{new} is greater than V_{old} the duty cycle has to be decrement.
- If duty cycle is decremented means V_{new} is same as that of V_{old} (i.e) Power is also same.

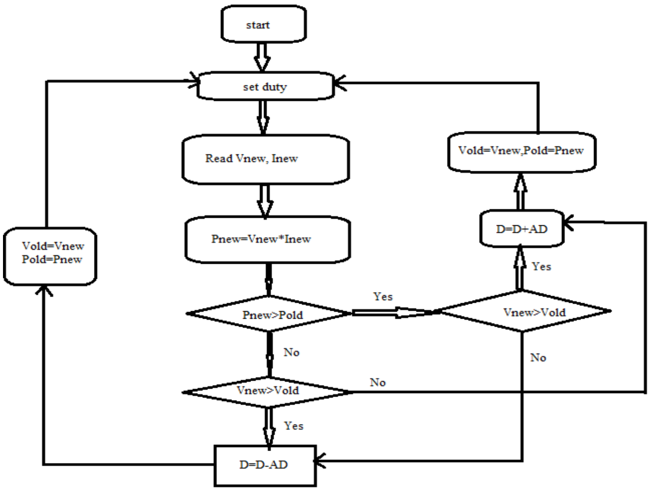

Fig 2. MPPT flowchart control strategy

The wind is always changing the turbine speed; To obtain the maximum power for changing every wind speed the MPPt It depends upon the MPPT controller output, dc – dc boost converter switch operates and maintains a constant Vdc link across the capacitor .MPPT control the output power as well as adjust the electrical torque, the speed of the generator is controlled and then it obtains the best possible speed for driving the power to maximum point.

IV. HYSTERESIS CURRENT CONTROL STRATEGY:

To control the grid current the Hysteresis current controllers are used in Voltage Source Converter (VSC).To obtain variable voltage at constant frequency the hysteresis bandwidth technology is used. In VSC the hysteresis current controller forces the IGBT's to switch only when it is essential to keep on track the position of the current and also it used to regulating the active & reactive power, higher power quality, high immunity to grid perturbations in the grid. Hysteresis control is known to exhibit dynamic responses as it diminishes the error in one sample. This technique is used which adjusts the hysteresis bandwidth as a function of the reference compensator current variation, to optimize the switching frequency varies with respect to the band size, the inverter and grid parameters**.** This control strategy is adjusting the bandwidth based on the measured line current of the grid. The actual current of grid is measured by current transformer is denoted by I and reference current value is I_{ref}. The error signal E(error) can be written as :

$$E_{err} = I - I_{ref}$$

The line current I_a of phase A is to attain the lower hysteresis band at point l means the switch S1 is turned ON. Similarly it attains the upper band at point P means the switch S4 is turned ON. The expressions for adaptive hysteresis bandwidth are derived below.

$$dI_a^+ = 1/L(0.5\,V_{dc} - V_a)$$

$$dI_a^- = -1/L(0.5\,V_{dc} + V_a)$$

Where, L is the inductance, V_a is the grid voltage per phase and V_{dc} be the DC link voltage. from the above equation we obtain

$$\frac{dI_a^+}{dt} * T1 - \frac{d_{Iaref}}{dt} T1 = 2HBa$$

$$\frac{dI_a^-}{dt} * T2 - \frac{d_{Iaref}}{dt} T1 = 2HBa$$

$$T_c = \frac{1}{f_c} = T1 + T2$$

Where, T1 and T2 are the time intervals and f_c is the modulation frequency. To solve the above equations the bandwidth is obtained as:

$$HBa = \frac{0.125V_{dc}}{f_c * L}[1 - \frac{4L^2}{V_{dc}{}^{2}(\frac{Va}{L}+m)^2}]$$

Where, m= $\frac{d_{Iaref}}{dt}$is the slope of command current wave. The profile of HBb and HBc are same as HBa but have phase difference. According to $\frac{d_{Iaref}}{dt}$ and Vdc voltage, the hysteresis bandwidth is distorted to reduce the authority of current distortion on modulated waveform. Thus the switching signals for the Voltage Source Converter (VSC) are generated by the hysteresis band current controller. The hysteresis band current controller technique is used to control the VSC.

V. RESULTS AND DISCUSSION

In this chapter the simulations results of the output performances are discussed. Modeling of PMSG based WECS and its integrating into the grid is simulated. The output waveform explains the voltage stability is maintained to the grid through the constant DC link voltage (Vdc) as grid voltage.

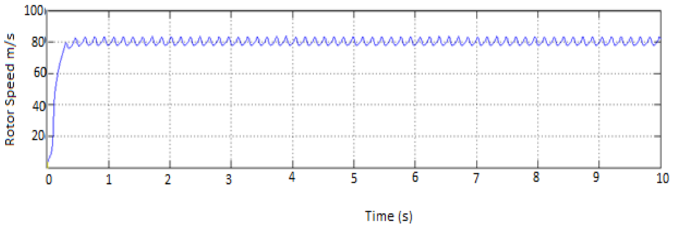

Fig.3 Rotor speed of PMSG at 15m/s.

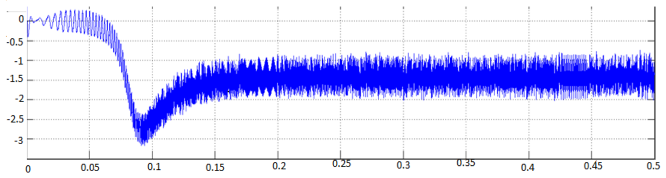

Fig. 4 Electromagnetic torque of PMSG at 15m/s.

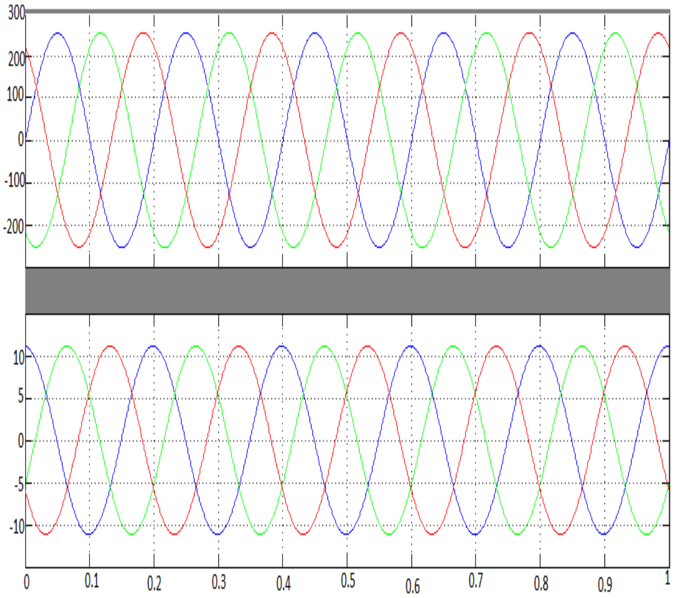

Fig. 5 Generator side voltage and current at 15m/s.

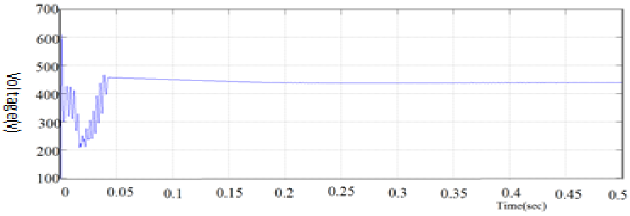

Fig. 6 DC link voltage.

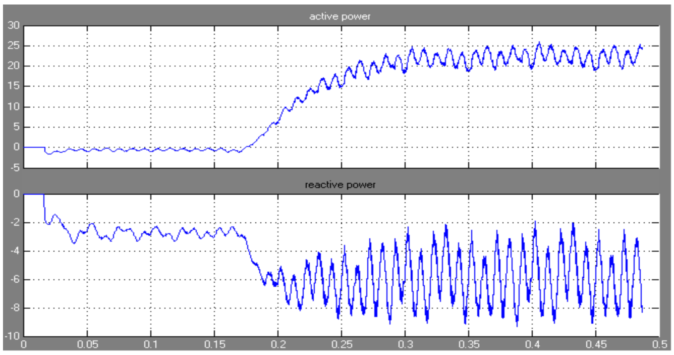

Fig.7 Real & Reactive power from the grid

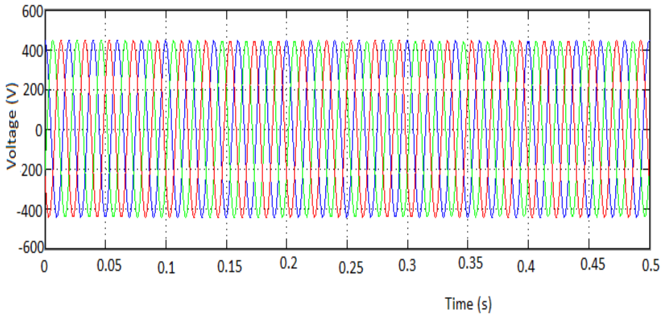

Fig.8 Grid Voltage

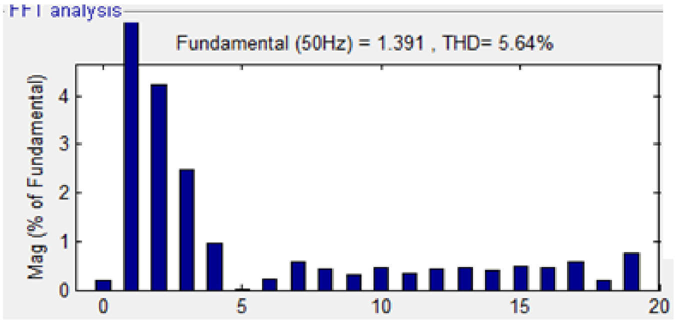

Fig.9 THD

V. CONCLUSION AND FUTURE WORK

This paper describes a simulation model for PMSG based wind turbine integrating into the grid to be used in MATLAB/ Simulink. The proposed model is a solution for impact of voltage stability when the wind energy is integrating into the grid. The proposed model contains the voltage that is maintained at the stable condition.This model clearly shows that the MPPT controller it will manage the rectifier side control and it will extract the maximum energy is obtained from the wind and its uses step and search algorithm in MPPT it will search the maximum power from wind energy system. This proposed system it maintains the DC link voltage constant, Power Quality is also increased by using Hysteresis Current Controller in grid connected mode. In future this proposed work will be implemented along with MOL(Minimum Ohmic loss Controller) towards the rectifier control system in order to increase the overall efficiency of the system.The MPPT and MOL Controller in future can be implemented by means of fuzzy logic and adaptive search control techniques.

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