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Fuzzy based maximum power point tracking for wind energy conversion system.

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***Abstract*-— Nowadays research focus is towards the variable speed wind power generation instead of fixed speed power generation. With variable speed, there will be 20-30% increase in the energy capture compared to fixed speed operation. For variable speed wind energy conversion system the maximum power point tracking(MPPT) is very important requirement in order to maximize the efficiency. This work deals with the design of maximum power point tracker using step and search algorithm with the Fuzzy logic control. It is a simple control strategy for an optimal extraction of output power from grid connected variable speed wind energy conversion system using permanent magnet synchronous generator. The maximum power from the wind turbine from cut-in to rated wind velocity is extracted by the MPPT by sensing only dc link power. The fuzzy based MPPT step and search algorithm is added to the wind energy conversion system along with the DC-DC and DC-AC converters PWM controllers are simulated using MATLABSIMULINK software.**

***Index Terms*— Rectifier, DC-DC Boost converter, Permanent magnet synchronous Generator, Maximum Power Point Tracking, Wind energy conversion system.**

I. INTRODUCTION:

There has been a tremendous increase in wind power in the present decades. Wind turbines represent an integral part of the electricity network. The WG power production can be mechanically controlled by changing the blade pitch angle [1]. At a given wind speed, the efficiency is drastically affected by the turbine's tip speed ratio (TSR), which is defined as the ratio between the rotor speed of the tip of a blade and the actual wind velocity. There is an optimum TSR at which the maximum energy conversion efficiency is achieved [2]. In [6] and [7], the rotor speed is calculated according to the measured WG output voltage, while the optimal output current is calculated using an approximation of the current versus the rotational-speed optimal characteristic. The error resulting from the comparison of the calculated and the actual current is used to control a dc/dc converter. Variable speed wind energy systems integrated with power electronic interfaces are becoming popular because they can extract maximum power from the wind. A maximum power point tracking (MPPT) algorithm increases the power conversion efficiency by regulating the turbine rotor speed according to actual wind speeds. Therefore, an effective and low implementation cost MPPT algorithm is essential to enhance the efficiency and economics of wind energy conversion systems (WECS). For maximum energy extraction, the speed of the turbine should be varied with wind speed so that the optimum tip speed ratio is maintained constant. To extract the maximum power point, a MPPT algorithm is developed. TSR control directly regulates the turbine speed to keep the TSR at an optimal value by measuring wind speed and turbine speed [5]–[9]. The control strategy is straightforward. In [6], a fuzzy logic controller is used instead of regular proportional integral differential controller to control the optimum rotor speed. Fuzzy logic controller increases the performance of the system. Initially the WECS used is described. It is followed by the presentation of the MPPT step and search algorithm, the pulse width modulation (PWM) inverter and DC-DC converter controllers. Finally the MATLAB-SIMULINK models used as well as the simulation results are discussed.

II. MODELLING OF THE WECS

The wind generator system is formed by a fixed pitch wind turbine, a permanent magnet synchronous generator, a passive rectifier, a dcto-dc boost converter and a current controlled voltage source inverter. It is shown in Figure. 1

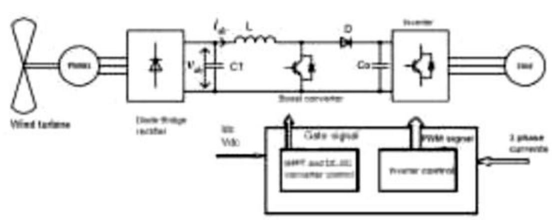

Figure 1: Wind energy conversion system

The blades of a wind turbine extract the energy flow from moving and deliver it via a gear box unit to the rotor of an electric generator. The wind power is estimated by[2]

$$Pwind = 0.5\rho A v^3 \quad (1)$$

Where,
ρ = air density
C_p = power coefficient
λ = tip speed ratio
β = pitch angle

temperature. The power coefficient C_p is usually given as a function of the tip speed ratio and the blade pitch angle β. The pitch angle is the angle between the plane of rotation and the blade cross section chord [3]. The tip speed ratio of a wind turbine is defined as:

$$\lambda = \frac{\mu}{v_1} = \frac{r\omega_r}{v_1} \quad (2)$$

Where μ is the tangential velocity of the blade pitch, ωr the angular velocity of the rotor, r the rotor radius in meters, and v_1 the wind speed. The output power of the wind turbine P_t is calculated as:

$$P_t = 0.5 C_p(\lambda) A v^3 \quad (3)$$

The power extracted from the wind is maximized when the power coefficient Cp is at its maximum. This occurs at a defined value of the tip speed ratio λ. Hence for each wind speed there is an optimum rotor speed where maximum power is extracted from the wind. Therefore if the winds speed is assumed to be constant, the value of Cp depends on the wind turbine rotor speed. Thus, by controlling the rotor speed, the power output of the turbine is controlled.
The electrical system schematic is shown in the figure 1. The wind turbine converts the power of the wind to mechanical power in the rotor shaft. This is then converted to electricity using a permanent magnet synchronous generator (PMSG). The output voltage is rectified using a three-phase diode bridge rectifier. The dc-to-dc converter is used to control the dc voltage Vdc across capacitor C1.The MPPT controller delivers a voltage reference that is compared to the actual value of Vdc, which is fed into a fuzzy logic controller whose output is compared to a triangular waveform to determine when to turn the dc-dc boost converter switch ON or OFF. The voltage source PWM inverter interfaces the wind turbine system with the power grid. It operates so that the amplitude of the output current varies in order to keep constant the dc side voltageV0across the capacitor Co. A separate controller is used to generate the control signals to trigger the IGBT switches in the three phase pulse width modulated inverter. The inverter converts the dc voltage in to ac and then supplies it to the grid. Then the power is supplied to the consumers.

III MAXIMUM POWER POINT TRACKING ALGORITHM.

Due to its monotonic characteristics, wind turbines can be controlled to yield maximum power using search control methods. Before explaining the maximum power tracking controller, it is important to understand the basic physics of the system. The generated mechanical power is given by[3-4],

$$P_{mech} = T_{mech}(t)\omega_r(t) \quad (4)$$

The maximum power searching process by setting an arbitrary dc side voltage reference V_{ref} [6]. The controller then measures both the dc side current and voltage, and calculates the initial electric power $P_o = V_{dc} I_{dc}$. Next, the reference voltage V_{ref} is increased by ΔV_{dc} so that,

$$V_{ref}(k) = V_{ref}(k-1) + \Delta V_{dc} \quad (5)$$

Then the dc power is calculated with $P(k) = V_{dc}(k) I_{dc}(k)$. If P(k) is bigger than P(k-1), the maximum power point has not been reached therefore, the voltage reference needs to be increased by ΔV_{dc} and the dc power needs to be compared. This process will repeat until maximum power is reached. And if P(k) is less than P(k-1), the dc voltage reference is then decreased by ΔV_{dc}. In order to search for maximum power at any wind speed four conditions must be met. They are as follows,

- If $P(k) \geq P(k-1)$ and $V_{dc}(k) \geq V_{dc}(k-1)$, the dc side voltage reference need to be increased by ΔV_{dc}. This condition is met when the turbine operates on the low speed side of the power curve.

❖ If P(k) ≥ P(k-1) and V_{dc}(k) < V_{dc}(k-1), the wind turbine is being operated in the high speed side and the dc reference voltage needs to be decreased by ΔV_{dc}.

❖ When P(k) < P(k-1) and V_{dc}(k) ≥ V_{dc}(k- 1), the decrease the reference voltage by ΔV_{dc}. This condition is met when the turbine is operated in the high speed side of the dome and the power is decreasing.

❖ When P(k) < P(k-1) and V_{dc}(k) < V_{dc}(k- 1), the power is decreasing on the low speed side, therefore the voltage reference is to be increased by ΔV_{dc}. The above algorithm can be explained through the figure shown below. In the Figure 2,

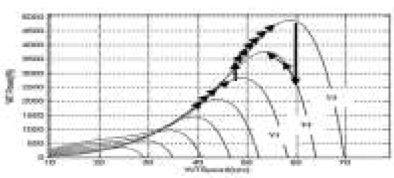

Figure. 2 Maximum power tracking process.

The power-speed plot is shown for three different wind speeds, where v1<v2<v3. The arrows show the trajectory in which the turbine will be operated using the maximum power tracking algorithm explained above. If the wind speed is v1, the controller will search for the maximum power. If the wind changes to v3the turbine is no longer being operated at the maximum power point so the controller will search for the new maximum power point. After reaching the maximum point it will operate the wind turbine at the optimal point until wind changes, thus searching for maximum power at any wind speed. In order to optimize the maximum power search algorithm presented above, a step that combines speed of convergence and accuracy of results was developed. By using this step algorithm search algorithm will converge faster to the maximum point in the power speed curve, where the slope value is equal to zero and it also increase the efficiency. So that the power produced by the wind turbine is increased. The variable step method is to converge the search algorithm faster and also to increase the efficiency. The variable step method is based on the Newton - Raphson method. The value of the root can be calculated as shown,

$$X_{n+1} = X_n - \frac{f(X_n)}{f'(X_n)} \qquad (6)$$

Where is X_n the current known value of X,

$f(x_n)$ represents the value of the function at X_n,

$f'(x_n)$ is the derivative at X_n .

The function $f(x_n)$ can be expressed as,

$$f(x_n) = f(V_{dc}(k))$$

$$= \frac{dP_e}{dV_{dc}}$$

$$= \frac{P(K)-P(K-1)}{V_{dc}(k)-V_{dc}(k-1)}$$

$$= \text{slope}(k) \qquad (7)$$

And the function $f'(x_n)$ can be expressed as,

$$f'(x_n) = f'(V\_dc\ (k))$$

$$= \frac{d^2P_e}{d^2V_{dc}}$$

$$= \frac{Slope(K)-Slope(K-1)}{V_{dc}(k)-V_{dc}(k-1)} \qquad (8)$$

Using (6), (7), and (8), ΔV_{dc} can be express as follows

$$\Delta Vdc = \frac{P(K)-P(K-1)}{Slope(k)-slope(k-1)} \qquad (9)$$

Using this variable step will allow the maximum power tracker to converge faster to the maximum power point and will decrease power oscillations due to large values of ΔV_{dc} when maximum power is achieved. For protection the value of ΔV_{dc} is limited.

IV FUZZY LOGIC CONTROLLER

It is a convenient way to map an input with the output. It solves the problems in the non-linear system. Fuzzy logic is flexible and easy to understand. Paradoxes are avoided by using fuzzy logic controller. Fuzzy logic controller used in the project is mamdani FLC. Here the output is a membership function. The maximum power tracker will generate a reference voltage that will be used to control the dc voltage at the rectifier dc side terminals. The dc-to-

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dc converter uses a simple feedback controller. The dc voltage reference is compared to the actual dc voltage, and the error signal E along with the change in error ΔE is fed to a fuzzy logic controller. The fuzzy logic controller used here is Mamdani FLC since its output is membership function. The MF used here is the triangular membership function. The input is given in the form of linguistic variables. They are negative big (NB), negative small (NS), Zero (ZE), positive big (PB), positive small (PS).

E \ ΔE	NB	NS	ZE	PS	PB
NB	NB	NS	NS	ZE	ZE
NS	NB	NS	NS	ZE	PS
ZE	NS	NS	ZE	PS	PS
PS	NS	ZE	PS	PS	PB
PB	ZE	ZE	PS	PS	PB

Table 1 Rules for the fuzzy logic controller

The output signal is compared with a fixed frequency repetitive triangular waveform to deliver a signal that will turn ON or OFF the switch. The boost converter boost up the voltage which is rectified by the rectifier. The MPPT controller generates the reference signal which is compared with the actual voltage in order to give triggering to the power semiconductor switch in the boost converter. A current control voltage source pulse-width modulation control strategy is used. The controller varies the amplitude of the output current of the inverter in order to keep the dc voltage constant. Two feedback loops are used. The inner loop controls the amplitude of the current and the outer one control the dc side voltage .The reference dc side voltage is subtracted from the actual dc voltage and the error is fed into a look-up table. The look-up table outputs a gain that will then be multiplied by the utility grid ac voltage. This will generate a reference waveform for each phase current with unity power factor. The actual value of the current is then subtracted from the reference and the error is fed into a fuzzy logic controller. The output of the FLC controller is compared with a repetitive triangular waveform to turn the inverter switches ON or OFF. The dc link voltage is maintained constant.

V SIMULATION AND RESULTS

The simulink diagram of the proposed system is shown below. The wind energy conversion system is shown in the figure. The simulink diagram in figure 3 contain two subsystem. The first subsystem contain the generator, rectifier, MPPT controller and the dcdc boost converter. The MATLAB-simulink software is used to design the proposed system

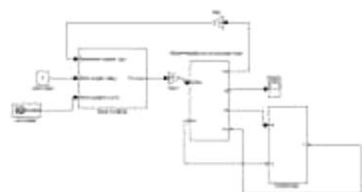

Figure.3. Wind energy conversion Simulink block diagram using MATLAB-SIMULINK software.

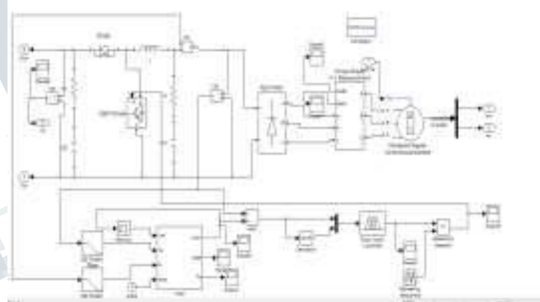

Figure.4. Controller circuit

The subsystem one in figure 4 contain the Permanent magnet synchronous generator which is driven by the wind turbine. The generator is connected to the rectifier which rectifies the ac to dc. Then the dc voltage is given to the dc-dc converter. The MPPT controller generates the reference voltage which is used to make the switch on or off in the boost converter. The output results of the wind energy conversion system with proposed MPPT controller is given below. The work deals with proposed MPPT controller for two wind speed profile 6m/s and 8m/s. This is shown in the figure 5.

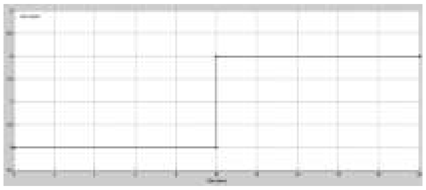

Figure .5. Wind Speed vs Time characteristics

The maximum power point is obtained in the power speed characteristic curve at a point where the differential of power with respect to voltage is zero. The slope at maximum point is shown in the figure 6.

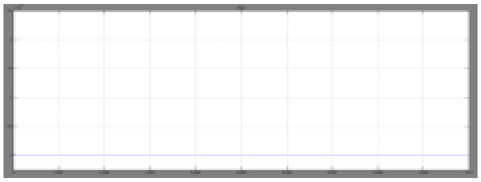

Figure .6 . Slope at the maximum point

The output voltage of the permanent magnet synchronous generator obtained for wind speed 6m/s and 8m/s is shown in the figure 7a,7b

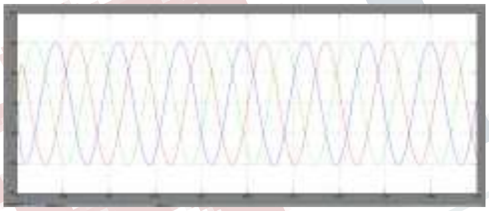

Figure.7a.PMSG phase voltage waveform for wind speed V=6m/s

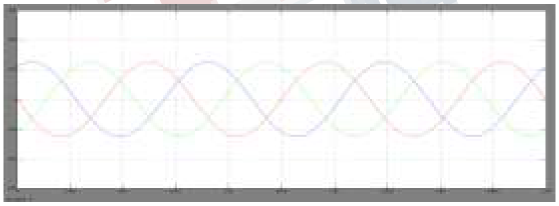

Figure 7b PMSG phase voltage waveform for wind speed V=8m/s

The output current of the permanent magnet synchronous generator obtained for wind speed 6m/s and 8m/s is shown in the figure 8a, 8b

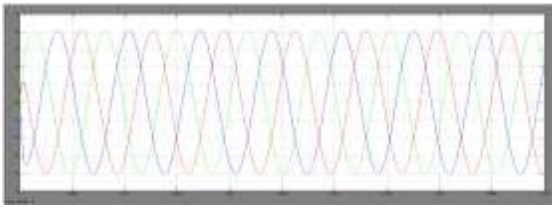

Figure.8a. PMSG phase current waveform for wind speed V=6m/s

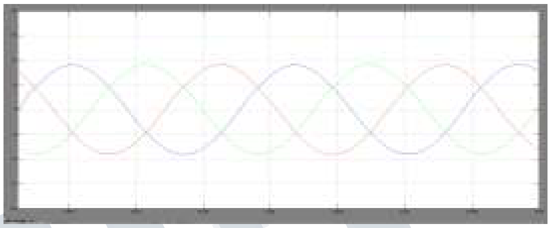

Figure.8b.PMSG phase current waveform for wind speed V=8m/s

The output of the dc link voltage (Vo) is maintained constant for the wind speed 6m/s is shown in the figure9

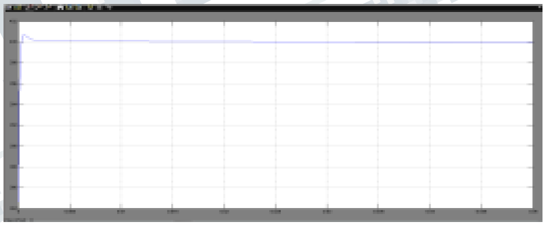

Figure.9.DC link voltage waveform for wind speed V=6m/s and 8m/s.

The output voltage of the inverter for wind speed 6m/s and 8m/s is shown in the figure 10.

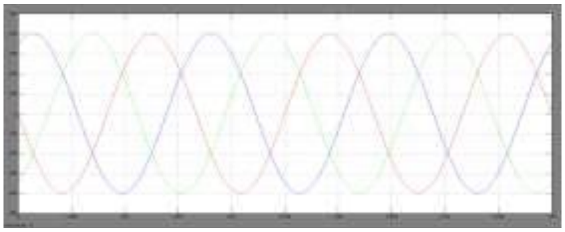

Figure.10. Inverter output voltage waveform for wind speed V=6m/s and 8m/s.

The output current waveform of the inverter for wind speed 6m/s and 8m/s is shown in the figure 11a,11b.

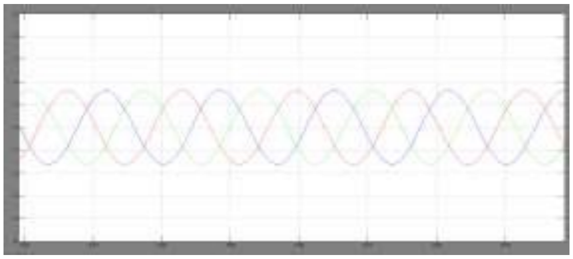

Figure.11a. Inverter output current waveform for wind speed V=6m/s

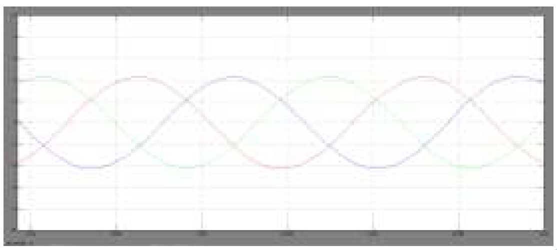

Figure .11b .Inverter output current waveform for wind speed V=8m/s

The simulation output of the MPPT controller is shown below. The maximum power is tracked as shown in the figure 13

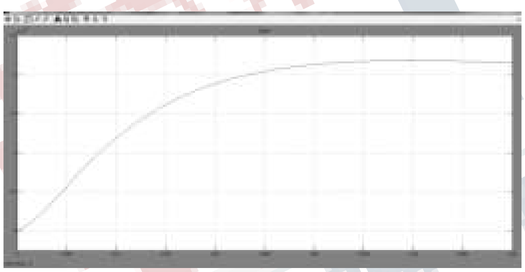

Figure.13. Output power using MPPT

VI CONCLUSION

Renewable energy sources are non pollutant and eco friendly. Wind energy as a renewable energy source plays a major role in producing electrical energy. Nowadays, the most common wind turbine configurations are based on the variable-speed pitch-control and the fixed-speed stall-control concepts. The variable-speed pitch-control concept is the currently preferred option mainly because of its good power control performance, low mechanical stresses and emergency-stop power reduction features. A maximum power point tracker with fuzzy logic controller for a wind energy conversion system as well the dc-dc converter and PWM inverter controllers have been presented and simulated for two wind speed profiles. The proposed wind energy conversion system has been described and each of its components modeled in MATLABSIMULINK. A fuzzy logic controller is used instead of regular proportional integral differential controller to control the optimum rotor speed. Fuzzy logic controller increases the performance of the system. In addition, the knowledge of the wind turbine aerodynamic characteristics is unnecessary in order for the algorithm to work.

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