Performance analysis of maximum power point tracking control system for standalone wind power system in Sittwe, Myanmar

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Abstract. One of the most feasible Renewable Energy resources of the World is wind energy. The performance of the Maximum Power Point Tracking (MPPT) control system for the operation of the Standalone Wind Power generation system is studied in this research. Sittwe, the capital of Rakhine State in Western Coastal Region, is the chosen case study area that enriches the Wind Energy resources in Myanmar with the low electrification rate. The proposed Standalone Wind Power generation system is composed of three-phase, 20kW Permanent Magnet Synchronous Generator (PMSG), DC-DC bidirectional converter, switch mode rectifier, voltage source inverter, and three-phase load. It is modelled and simulated in the MATLAB/Simulink. The simulation period is set to 15 seconds. Under Wind speed variation from 3 m/s to 13 m/s, the investigation is performed with the nexus of the speed, torque, power, DC link input, DC link output, and the parameters of the load side. In the simulation results, the power characteristics show the 20 kW standalone wind power system. It is observed that the output load voltage can be controlled by load side converter to required load voltage. In addition, the simulation results reflect the dynamic performance can be improved with the proposed MPPT control system.

Keywords: Standalone Wind Power, PMSG, MPPT, Sittwe, MATLAB/Simulink
1. Introduction
Nowadays, the global energy demand is increasing with population growth and industrial expansion. There is a rapid increase in energy problems in developing countries. The energy problems faced by many countries are based on the rising petroleum cost and ecological constraints and a lack of technology suitable for the utilization of existing energy resources.

Wind energy is a simple air motion and a special form of kinetic energy in air as it flows. Wind power is the clean and green renewable energy because the wind will blow as long as the sun shines, which produces no carbon dioxide during its operation. Wind energy conversion systems are used to capture the energy available in the wind to convert it into electrical energy. Wind turbine with generator transforms the mechanical power from the wind into the electrical power, while the rectifier converts the AC power into DC power and batteries are connected to the DC link voltage through control. The DC voltage is converted again to AC voltage.

Wind energy conversion systems have three main parts: wind turbine technology, power electronic technology and system control technology. A wind speed that varies in both time and space is one of the most critical characteristics in wind power generation. The output voltage waveforms in multilevel inverters can be generated at low switching frequency with high efficiency and low distortion. The main topologies of multilevel inverters are diode clamped or neutral point clamped multilevel inverter (DCMLI), capacitor clamped or flying capacitor multilevel inverter (FCMLI) and cascaded H-bridge multilevel inverter (CHBMLI). Comparing the devices and components used, the diode clamped inverter requires more number of diodes and the flying capacitor inverter requires more number of capacitors while the cascaded H-bridge inverter requires less number. As the number of levels increases, the multilevel inverter configuration consists of larger number of switching devices and the voltage stress across each device will reduce, which makes this topology suitable for high voltage application where low voltage rating devices can be used. This results in smaller harmonics, but on the other hand it has more components and is more complex to control [1].

Wind energy is plentiful, renewable long life, widely distributed, clean and reduces toxic atmospheric and greenhouse gas emission if it is used to replace fossil fuel derived electricity. As the wind occurs naturally and wind energy is infinitely renewable, the use of wind energy is more economic and more advantages. This study emphasizes on the standalone wind power system for the rural areas in Myanmar.

2. Overview of Wind energy system
One of the available non-conventional energy sources such as wind energy is clean and infinite natural resource. The need for a renewable energy source that will not harm the environment has been increased.

![Wind energy conversion system](image_url)
Wind power has been a fast-growing alternative power source in the world. Wind power is an environmentally attractive form of renewable energy from an overall toxicity and fuel use perspective. Wind is created by the unequal heating of the Earth’s surface by the sun. Among the various types of renewable energy, wind energy is now emerging as one of the most promising of the renewable technologies. The kinetic energy in wind is converted into mechanical power that runs a generator to produce clean electricity by using wind turbines. To capture the maximum energy from the wind, the wind turbine blades are aerodynamically designed and the wind energy conversion system is as shown in Figure 1. The wind turns the blades that spin a shaft connected to a generator which makes electricity. There are two types of wind power systems. They are Standalone Wind power System (Small) and Wind Farm Power System (Large)[2].

3. Simulink model of wind turbine with permanent magnet synchronous generator

The simulation model for wind power generation system as shown in Figure 2 is executed with Matlab/Simulink. The wind power system consists of wind turbine connected to 20 kW load and battery energy storage system. The turbine input is wind speed and the outputs are speed and power. This block implements a variable pitch wind turbine model. The mechanical output power of the turbine is the product of the power coefficient \( C_p \) of the turbine, a function of wind speed, rotational speed, and pitch angle (beta). At zero betas, the maximum value of \( C_p \) reaches.

The generator speed in per unit of the generator base speed is the first input. The base speed is the synchronous speed for a synchronous or asynchronous generator. The base speed is the speed producing nominal voltage at no load condition for a permanent-magnet generator. The second input, the blade pitch angle (beta), is counted in degrees. The wind speed is the third input counted in m/s. The output of the generator is the torque applied to the generator shaft in per unit of the generator ratings. The turbine inertia must be added to the generator inertia. The stiffness of the drive train is infinite and the friction factor and the inertia of the turbine must be combined with those of the generator coupled to the turbine [1].

The output power of the turbine can be calculated from the following equation [7];

\[
P_m = 0.5 \rho A C_p (\lambda, \beta) V_w^3
\]

Where, \( P_m \) = Mechanical output power of the turbine (W), \( C_p \) = Performance coefficient of the turbine, \( \rho \) = air density (kg/m\(^3\)), \( A \) = Turbine Swept Area (m\(^2\)), \( V_w \) = Wind speed (m/sec), \( \lambda \) = Tip speed ratio of the rotor blade tip speed to wind speed, \( \beta \) = Blade pitch angle (deg)

![Figure 2. Simulation model for standalone wind power generation system](image)
4. Simulation model of MPPT control for wind

To provide the required duty cycle to the boost converter, the MPPT controller implements the P&O control technique. Thus, DC link voltage will be optimized and hence maximum power is generated by the generator. The choosing of the best place where quality of air can produce more electricity is essential because wind energy is dependent on weather, topology and environment. The amount of power output from WECS depends on the tracked wind power due to the losses like mechanical friction and generator's efficiency which is low. Thus, a maximum power point tracking control is essential. By using a three-phase diode rectifier, the three-phase AC voltages from the PMSG are rectified. Instead of a three-phase controlled PWM rectifier, the diode bridge rectifier is used in this research because of its lower cost and higher reliability.

![Flow chart of MPPT](image1)

![Configuration of MPPT control system](image2)

This rectified DC voltage serves as an input to the boost converter. To track the MPP and boost the voltage across the load resistor, the components of the boost converter such as the inductor L, the diode D and the switch Q will be controlled. The gating pulse to the IGBT switch is provided by a PWM generator which is a function of duty cycle. The values of inductor and capacitor for switching frequency, and load resistance R are determined by using the Equation (2) and Equation (3) [7].

\[
C = \frac{k}{2R} \quad (2)
\]

\[
L = \frac{(1-k)kR}{2f_s} \quad (3)
\]

k=0.5, R= 8Ω, L_i= 0.2 mH and C = 6.25 µF. Where, L=inductor, C =capacitor, k=duty cycle (0.5), \(f_s\) =switching frequency (5 kHz) and R=Load Resistance

5. Simulation results of standalone wind power system

In this paper, a simple control strategy is proposed to extract maximum power from a PMSG based variable speed wind turbine under fluctuating wind speeds.

For a standalone variable speed wind energy supply system, the control strategy in this research is simulated under different conditions. The results of standalone wind power system (20 kW) are simulated by using MATLAB/SIMULINK of each system component in this paper. In wind power project, the cut in wind speed is 3m/s, the cut out wind speed is 25m/s and the rated wind speed is about cut in speed because of energy storage system. In Figure 5, simulation result is output speed and torque of wind turbine for different wind speed. For all the simulations, the simulation period is set to 15 seconds. When the wind speed is about 12 m/s turbine run 2010 rpm and torque is -100 Nm. The
second five seconds, the turbine run 1900rpm and torque is -80 Nm when wind speed is changed at 10m/s. When wind speed is changed, nearly cut in speed the turbine run 1500rpm and torque are shown in the results.

5.1. Simulation Results of DC Link
This simulation result is shown in Figure 6, DC link input voltage is 220 V and DC link output voltage is 400 V, which is attached energy storage system. Moreover, DC link voltage is maintained at constant value.

![Simulation results of Wind Turbine speed and Torque](image1)

**Figure 5.** Simulation results of Wind Turbine speed and Torque

![Simulation result of DC link input voltage and output voltage](image2)

**Figure 6.** Simulation result of DC link input voltage and output voltage

5.2. Simulation results of voltages and currents of wind generation system
The simulated results of generator output voltage and current according to the wind speed changes are shown in Figure 7. The results show the fluctuated generator output voltage and current when the wind speed vary between the turbine cut-in speed and nearly maximum wind speed. The results in Figure 8 reflect the output load voltage and load current.

![Simulation result of voltage and current](image3)

**Figure 7.** Simulation result of voltage and current

![Simulation result of output load voltage and current](image4)

**Figure 8.** Simulation result of output load voltage and current
5.3. Simulation results of powers without and with control System

Figure 9 shows the active and reactive power without control system and Figure 10 illustrates the simulation result of load power with the control system.

Figure 9. Simulation result of active and reactive power without control system

Figure 10. Simulation Result of load power with the control system

6. Conclusion

The simulation results demonstrate the power characteristics of the standalone wind power system. The proposed system can be controlled and output waveforms are observed at different wind speeds. The simulated results show a good performance under different conditions. Moreover, the analysis methods and resulting output presented in this study are helpful for understanding and application of small scale wind power system in Sittwe, Myanmar.

The conventional wind power system consists of AC/DC generator, rectifier, battery and charger and also includes inverter. In this control system, switching inverter portion is important. In this portion regulated voltage must be obtained from variable input supply. In addition, the proposed system simulated in MATLAB/SIMULINK to obtain current, voltage, active power, reactive power and DC bus voltage. These results from the performance of the control strategy are proved for variation wind speeds.
Appendix A

| T (sec) | Wind Speed (m/s) | Turbine Generator | Load Side |
|---------|------------------|-------------------|-----------|
|         |                  | Speed (rpm) | Torque (Nm) | V | I | Power | V | I | P |
| 1       | 3                | 1600        | -20        | 250 | 15 | 7     | 0.78 | 230 | 28.5 | 19 |
| 2       | 4                | 1625        | -27        | 250 | 20 | 9.5   | 1.35 | 230 | 28.4 | 19.1|
| 3       | 5                | 1675        | -35        | 250 | 26 | 12    | 2.2  | 227 | 28.3 | 19.2|
| 4       | 6                | 1705        | -43.5      | 250 | 32 | 15    | 2.75 | 230 | 28.5 | 19.3|
| 5       | 7                | 1750        | -51        | 250 | 38 | 17.5  | 3.5  | 230 | 28.5 | 19.4|
| 6       | 8                | 1800        | -60        | 250 | 44 | 20    | 4.6  | 230 | 28.5 | 19.5|
| 7       | 9                | 1875        | -70        | 250 | 50 | 20.35 | 5    | 230 | 28   | 19.7|
| 8       | 10               | 1900        | -80        | 250 | 56 | 27    | 5.8  | 230 | 28   | 19.8|
| 9       | 11               | 2000        | -90        | 250 | 65 | 31    | 6.8  | 230 | 28.5 | 19.9|
| 10      | 12               | 2060        | -102       | 250 | 70 | 35    | 7.2  | 230 | 28   | 20  |
| 11      | 13               | 2050        | -104       | 250 | 80 | 39    | 7.3  | 230 | 28   | 20  |
| 12      | 14               | 2250        | -130       | 260 | 90 | 44    | 7.5  | 230 | 28   | 20  |
| 13      | 15               | 2230        | -130       | 260 | 90 | 43    | 7.2  | 230 | 28   | 20  |

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