

Wind turbine simulator using wind speed dataset on microgrid system

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Abstract. Currently the wind power plant simulation system has been developed by various methods as an effort to optimize energy derived from wind power. This paper proposes a wind power simulator using wind speed datasets to produce electrical energy. The wind turbine simulator consists of a generator driven by an induction motor where the speed of the induction motor is controlled using a variable speed drive. To generate electrical energy based on the dataset used a PC that is connected to a variable speed drive through modbus communication assisted by a computer programming language as the user interface. Furthermore, the output from the wind power simulator is connected to the grid tie inverter to be integrated in the microgrid system. The performance test results of the simulator show that the characteristics of the wind power simulator are in accordance with the characteristics of the actual wind power plant and the power generated by the wind power simulator is 50.6 watts, equivalent to wind speeds of 5.1 m/s.

1. Introduction

Due to the economical and technological developments, demand for energy is increasing significantly. The global economy grow 3,3% per year over the past 30 years and energy demand increased 3,6% [1]. The increasing incidence of distributed, needs to improve the power system reliability and clean power support are providing development of a new power system perception commonly referred as a microgrid system [2].

Microgrids have attracted significant attention in recent years because providing significant advantages for electricity consumers and power grid operators. Microgrid deployments are trusted to improve power quality, reduce emissions, reduce network congestion and power losses, increase energy efficiency and potentially improve system economics [3]. A microgrid consist load, renewable energy (RE) sources are integrated one another as a single controllable load connected to main grid. So far, microgrids have been mostly established as test-bed platforms in some developed countries such as Japan, Canada, USA [2].

Wind turbine system technology is still the most promising renewable energy technology. It started in the 1980s with a few tens of kW power production per unit [4]. Recently, there has been a growing interest in the use of wind energy as enviromental concerns are on the rise. In spit of this growth, more technology advances are needed to make wind energy competitive with many other energy supply methods. Simulation and modeling can be used to study the performance of wind turbine systems [5].



A lot of modeling and simulation on wind turbine has been done. In past few years, there have been a few studies on wind turbine simulator. Author of [6-8] presented a wind turbine simulator using induction motor (IM) and IGBT inverter-controlled. The wind simulator was programmed in C language by application of a wind turbine model, and use PI controller. Reference [9] presented wind turbine simulator use electromagnetic (EM) torque equation of a dc machine. The armature and the field circuits were controlled so that the dc machine generated the static characteristics of a constant pitch wind turbine. In [10] explained wind turbine simulator use permanent magnet synchronous machine (PMSM). In [11], a more general approach of wind turbine simulator was presented by the application of a dc motor. A dc machine, although is ideal from the standpoint of control is in general, bulky, and expensive compare with ac machine and it needs frequent maintenance due to its commutators and brushes. In our research project, made a wind turbine simulator in ac bus microgrid system with using induction motor (IM) that generates energy according wind profile used and integrated with other Distributed Energy Resources (DER) in one grid. This wind turbine simulator can add power generating other unit to make better grid and reduce losses in transmission line so that it can see its characteristic directly.

2. Method

2.1. Microgrid

The concept of microgrid was first introduced in the technical literature in [12] as solution for a the reliable integration of DERs (Distributed Energy Resources), including Energy Storage Systems (ESS) and controllable loads. Three microgrid types can be identified: AC, DC and hybrid. In AC microgrid bus, all DER dan load connected to a common AC bus. DC generating units as well as energy storage will be connected to the AC bus via DC-to-AC inverters are used for supplying AC loads. In DC microgrid, however, the common bus is DC, DC generating units as well as energy storage will be connected to the AC bus via DC-to-AC inverters, then rectifiers use AC-to-DC rectifiers are used for supplying DC loads [3]. Fig.1 show a AC microgrid concept where there are types of DC sources and that connected with grid PLN.

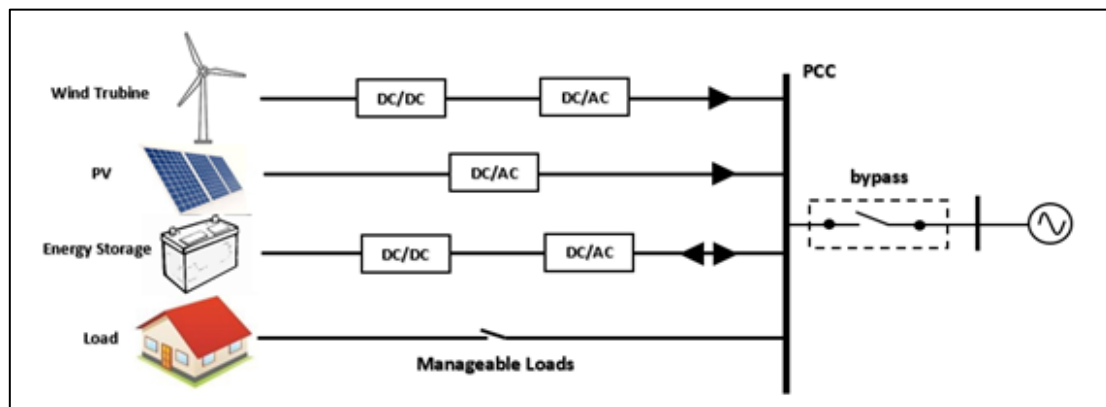


Figure 1. Microgrid system.

Various types of dc source are unlumined PV, wind turbine simulator, microhydro simulator and Energy Storage Systems (ESS). Where each sources generate power at ac bus microgrid system to supply load that connected utility grid, so the consumption power of utility grid at load can reduce in accordance with increasing power of wind turbine simulator.

2.2. Wind turbine simulator

In reality, wind turbine system consist a wind turbine that coupled with generator where wind turbine will move along with the wind speeds that hit it. In this research, not use the real wind turbine but use simulator wind turbine. A wind turbine simulator consist of induction motor (IM) which drives a DC generator and is driven by variable speed drive inverter with realtime wind profile.

In Figure 2 explains a wind turbine simulator system. The microgrid emulator wind turbine system does not use real wind turbine generation but a simulator that uses an induction motor as a wind turbine which will drive the turbine so the generator DC can generate electricity as shown in figure 3. The core of this system is monitoring energy consumption in the microgrid system wind turbine simulator. So this tool is designed by using several supporting sensors to monitor the condition of energy wind turbine simulator at microgrid system. In Figure 3 the speed of the induction motor is regulated using an Altivar 312 inverter (ac drive) by regulating using the frequency. So that match the real wind, so it uses a wind speed dataset in an area from taking wind speed directly. the value of wind speed is obtained from the wind speed dataset. From the dataset, then converted into rotation speed of induction motor (RPM) so that the wind produced is in accordance with the reality of the actual wind speed. In controlled the rotation speed of the induction motor, the wind profile is set using a PC which is assisted by a serial communication using rs485.

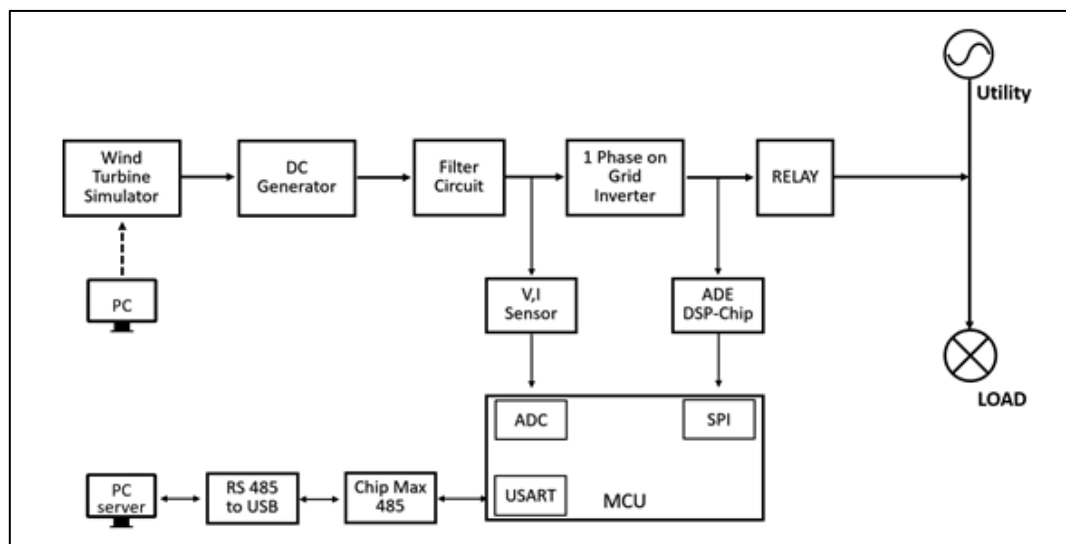


Figure 2. A wind turbine simulator system.

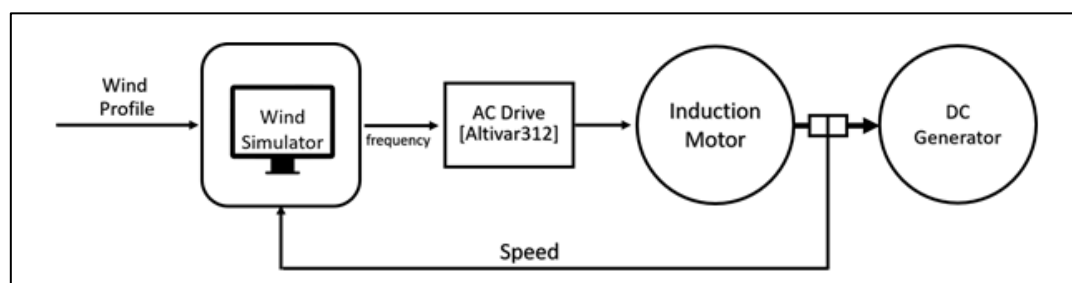


Figure 3. A wind turbine simulator.

2.3. Induction motor modeling

There are many things to consider when modeling wind turbine system. The first thing to consider is how much power is needed, then wind speed, after that no less important is how many blades to use, and many other technical things. The first thing to consider in the design of a wind turbine is the TSR (Tip Speed Ratio) or the comparison of the speed at tip wind turbine and the wind speed obtained by the wind turbine. Calculating TSR (λ) can use the following equation:

$$\lambda = \frac{\omega R_{rotor}}{v} \quad (1)$$

Where ω is the rotation of the wind turbine in units (Rad / s), R rotor is the Radius of the wind turbine rotor in meters (m) [13]. Wind speed affects the amount of torque output and power quality. The torque of a wind turbine can be calculated using the equation as follows:

$$\text{Torque} = \frac{V^2 R^3}{\lambda^2} \quad (2)$$

TSR(Tip Speed Ratio) affects the rotation speed of the wind turbine (RPM). The relationship of TSR (Tip Speed Ratio) with speed is written as follows:

$$\lambda = \frac{2\pi}{60v} \times \text{RPM} \times r \quad (3)$$

Where λ is the tip speed of the blade / TSR (Tip Speed Ratio), v is the wind speed per second in unit (m / s), RPM is the generator rotation speed (RPM) and r is the radius of the blades in meters (m). In Figure 4 shows the power characteristic curve for the speed of a 120 Watt dc generator used in a wind turbine simulator. This curve is obtained by testing a wind turbine simulator generator with each increase in rotation speed motor with respect to the power generated.

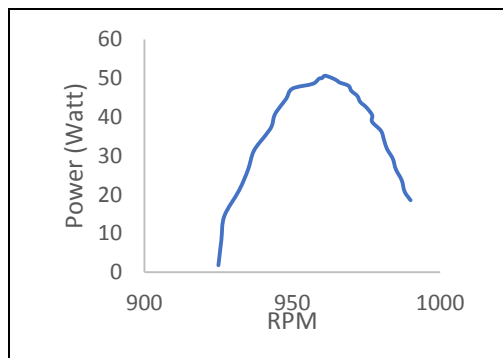


Figure 4. Characteristic of a wind turbine simulator

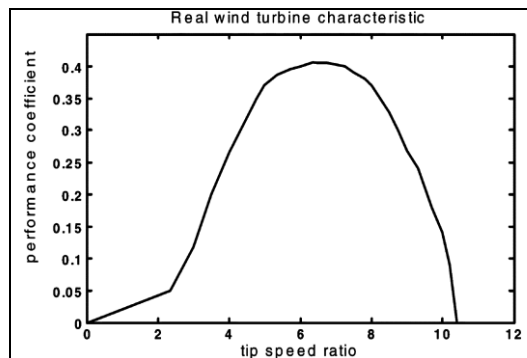


Figure 5. Characteristic of real wind turbine

In reality, the characteristics of wind turbines are represented in the form of power coefficients (C_p) and Tip Speed Ratio (TSR) as shown in figure 4 for the same wind turbine in Figure 5 Power coefficient curves (C_p) and Tip Speed Ratio (TSR) are usually used in industry to describe the characteristics of wind turbines. Tip Speed Ration (TSR) is calculated using the formula:

$$\lambda = \frac{2\pi}{60v} \times \text{rpm} \times r \quad (4)$$

Where λ is the tip speed of the blade / TSR (Tip Speed Ratio), v is the wind speed in units (m / s), rpm is the generator rotation speed (rpm), and r is the radius of the blades in meters (m). Output power of wind turbine is calculated using the formula [6]:

$$P_m = 10,28 \times C_p \times V^3 \quad (5)$$

In a wind turbine simulator, the characteristics of the wind turbine power speed are physically carried out by an induction motor. The wind speed needed for the simulator is supplied from the wind speed dataset which can be obtained from measured wind data from a location or can be set in the form of an induction motor rotational speed.

3. Experimental results and discussion

The wind turbine simulator described has been implemented and tested. The value of wind speed is obtained from the wind speed dataset. From the dataset, then converted into rotation speed of induction motor (RPM) so that the wind produced is in accordance with the reality of the actual wind speed. Calculation of wind turbine system modeling is designed in accordance with the generator and motor used. After obtaining the angular velocity value, it can calculate rotation speed of motor value. From the rotation speed motor value can be used to calculate the frequency value, because controlled speed motor on inverter altivar 312 uses a frequency which in turn changes the frequency value to set the rotation speed of the motor. This test is carried out as a whole from the start of generation to load. The following series of integration tests:

From Figure 7 it can be seen if wind speed is higher, the rotation speed of the generator is also higher. In this research the theoretical rotation speed of the generator measured has an average percentage error of 3.05%. The biggest error occurred at a wind speed of 4.3 m / s with an error of 4.43%.

In Figure 8, the output of the generator power is measured by the output voltage and the output current of the generator. From the current and voltage readings, it can calculate the value of the generator output power. Generator output power written as follows:

$$P = V \cdot I \quad (6)$$

Where P is the power generated in watts (W), V is output voltage of generator in volts (V), and I is output current of generator in amperes (A).

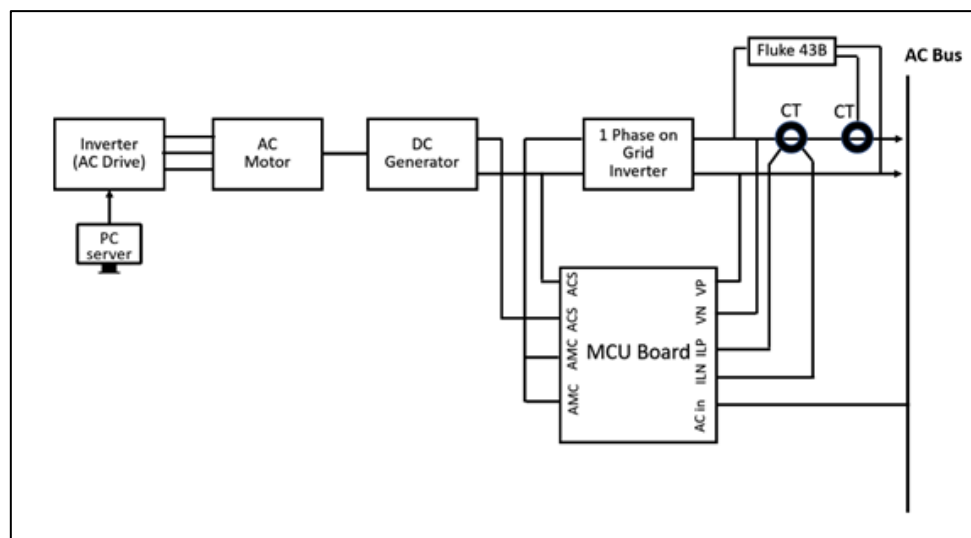


Figure 6. Integration testing.

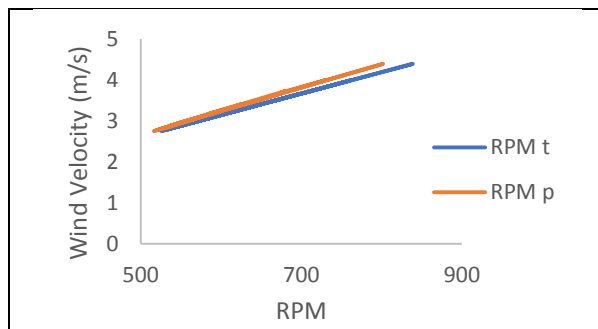


Figure 7. Rotation speed of generator.

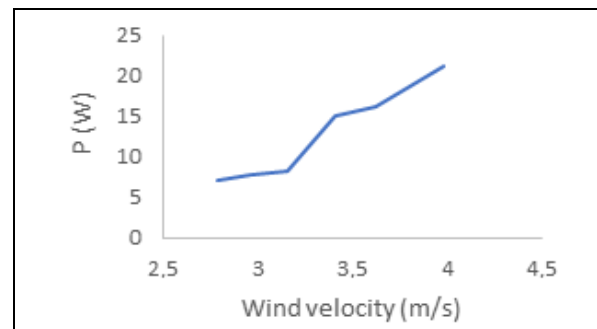


Figure 8. Output power of generator.

The output power of generator produced is relatively small, due to the relatively small wind speed. If the wind speed is higher, output power of generator is also higher. At the output of the inverter is sensing using ADE7953 so that the measurement of voltage, current, pf and power generated. From the reading of current, voltage, and pf, it can calculate the value of the output power of the inverter which will be compared with the measured power on oled.

$$P_o(t) = V_{rms} \times I_{rms} \times pf \quad (7)$$

Where V_{rms} is the power produced by the inverter in volts, I_{rms} is the current generated by the inverter in amperes.

Figure 9 shows that if the wind speed is higher, the power generated by the inverter is also higher. In this research the output voltage generated by the inverter is relatively constant because there is a tracking voltage on the inverter (MPPT). But if the wind speed is higher, output current of inverter is also higher. So that if the wind speed is higher, the output power of the inverter is also higher.

From Figure 10, it can be seen that if the wind speed is higher, the power released by the wind turbine simulator is also higher, but conversely the power on the PLN decreases with a constant load power. So that in this research, the wind turbine simulator on microgrids can reduce the current and power of utility grid that required to load. Which means the wind turbine simulator can the load by reducing power consumption at utility grid.

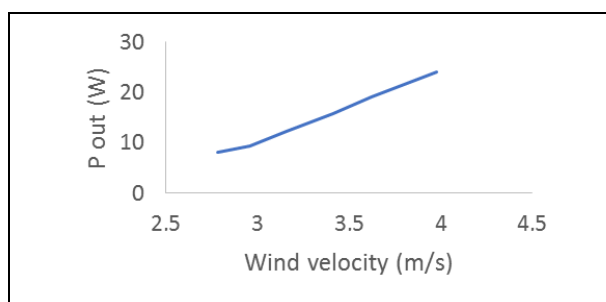


Figure 9. Output power of inverter.

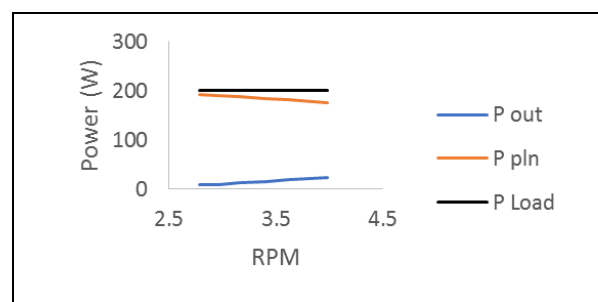


Figure 10. Output power of wind turbine, PLN and load.

The inverter output readings are compared to the theoretical power reading values so that when compared it will get an error value of %, the error value % obtained is <5%. At the utility grid output, the value of the inverter output power is calculated which will be compared with the measured power in the measuring instrument. In this test using incandescent lamps with 200 Watt power. From Figure 11 is the reading of utility grid's output current harmonic.

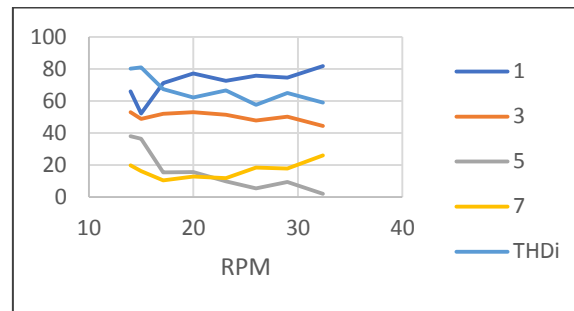


Figure 11. Output current harmonics of inverter.

Output current harmonic of inverter shows that it still has a fairly large current harmonization (THDi) of 64% with the highest current harmonization (THDi) of 71.2% at the time of RPM 522. The THDi value continues to decrease when the RPM is increased by the current harmonization (THDi) value amounted to 49.9% at the time of the generator rotation speed (RPM) 72.

4. Conclusions

From the results of experiments on the proposed system, it is obtained that using a wind turbine simulator can produce the same characteristic curves as the actual P-TSR characteristic curves. The wind power simulator produces power according to the real wind speed dataset with a power value 50.6 Watt at a rotation speed of motor 961 rpm, so that the power generated by the wind turbine simulator can supply the load or the grid. The power generated by the wind turbine simulator is relatively small because the wind speed is also relatively small. If the wind speed produced is higher, the rotation speed of the generator is also higher so that the output voltage of generator produced is higher and the current is relatively constant. While the output current of the inverter output is getting higher and the power produced by the inverter is getting higher. But on the power generated by utility grid is getting smaller. And the output current of the inverter used has a fairly high current harmonization (THDi) with the largest current harmonization (THDi) of 71.2% at the time of RPM 522. The current harmonization (THDi) value continues to decrease when the generator rotation speed (RPM) is raised with a TDHi value of 49.9% at the time RPM 728.

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