A Further Modification of Squirrel Cage Single-Phase Induction Motor to Low-Speed Single-Phase Permanent Magnet Generator to Generate Sinusoidal Output Voltage

I. Made Wiwit Kastawan[1(✉)], Rusmana Rusmana[2], Achmad Mudawari[1], and Haris Prasetia[1]

[1] Diploma 3 of Energy Conversion Engineering, Department of Energy Conversion Engineering, Politeknik Negeri Bandung, Bandung, Indonesia
wiwit.kastawan@polban.ac.id

[2] Diploma 4 of Electrical Power Generation Technology, Department of Energy Conversion Engineering, Politeknik Negeri Bandung, Bandung, Indonesia

Abstract. Design of a low-speed single-phase permanent magnet generator obtained from further modification of a squirrel cage single-phase induction motor is proposed. Modification is done for rotor and stator parts of the induction motor. 10 permanent magnets are implanted in the rotor to get a sinusoidal output voltage with magnitude and frequency of 110–115 V and 50 Hz respectively at 600 rpm. Number of stator windings and slots are kept the same, 4 windings and 36 slots, without any modification. However, number of turns is increased to 600 turns per winding. Laboratory tests are conducted to get generator no-load output voltage characteristics.

Keywords: generator · induction motor · low-speed · no-load · permanent magnet · sinusoidal voltage

1 Introduction

In Indonesia, technologies grow rapidly to meet various people's needs. Almost all these technologies are work with electrical energy source. As a result, demand for electrical energy increase constantly. This must be followed by constant increase of electrical power generation.

Indonesia has abundant reserves of renewable energy like wind, solar and hydro. Small rivers with small amount of hydro energy potential can be easily find in remote areas in Indonesia. Unfortunately, this hydro energy potential has not been converted to generate electrical energy to supply houses not yet connected to the existing grid. The main obstacle is requirement of hydro turbine and generator able to work on low speed [1, 2]. In addition, a permanent magnet generator is used instead of an external excitation type generator. The hydro energy potential is converted to rotational mechanical energy of the turbine. Then, low-speed generator converts it further to electrical energy.

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Permanent magnet generator can work on low speed because it has higher number of magnetic poles [3].

There are many kinds of permanent magnet generator. Axial flux permanent magnet (AFPM) generator is an example. Due to its simple construction, AFPM generator has become a popular choice for small scale electrical power generation, such as wind [4–6], pico-hydro, micro-hydro [7–11] or even motorcycle and stationer bike [12] power generation units. Another example is the radial flux permanent magnet generator. This generator can be easily constructed through modification of a squirrel cage single-phase induction motor [13].

Single-phase induction motor can be operated as single-phase induction generator without any modification. Just rotates the rotor at speed higher than synchronous speed [3]. However, capacitor is needed to regulate output voltage of a single-phase induction generator [14]. Thus, modifying a squirrel cage single-phase induction motor to a single-phase permanent magnet generator is preferred due to these following advantages [15]:

- Requires no external dc excitation source, made it very suitable for harnessing energy from small rivers.
- More economical. Squirrel cage single-phase induction motor is widely used. Modifying it to single-phase permanent magnet generator copes with motor disposal problem.

Modification of a squirrel cage single-phase induction motor to a single-phase permanent magnet generator has been done. The generator can run at 750 rpm to produce an output voltage of 110 V. However, waveform of output voltage generated is not sinusoidal. It contains harmonics with total harmonic distortion (THD) number of 15.8% [13]. The voltage drop and efficiency vary from 4.5% to 29.1% and 32.6% to 67.5% respectively when the generator is on-load condition. [13]. Another work shows using of this generator to convert hydro energy potential of a selected small river [15]. The generator is coupled with a low-head hydro turbine. The turbine generator set then installed and tested in the selected small river. Data show that on no-load condition, output voltage generated is about 32 V and 30 V on 260 and 246 rpm rotation speed respectively [15].

In this paper, further modification on a squirrel cage single-phase induction motor is described. Modification steps taken are described in general in the next subsection of this paper. It is expected that the low-speed single-phase permanent magnet generator obtained will generate output voltage close to sinusoidal.

2 Methodology

To modify a squirrel cage single-phase induction motor, two major works are done. First one is modifying the rotor part by placing permanent magnet poles. Second one is modifying the stator part by calculating possible number of windings and turns to be placed in existing stator slots to generate maximum output power. More detail of the modification step is given in points below:

- Initial step taken is disassembling all parts of the squirrel cage single-phase induction motor. It is a 2 HP or approximately 1.5 kW, 1440 rpm, capacitor type single-phase induction motor. Aim of this disassembling step is to get dimensions of rotor and stator of the motor. Once the dimensions of rotor and stator known, the dimensions and number of permanent magnets, turns and windings can be determined. Equation that relates number of permanent magnets and generator speed is [3]:

$$n = \frac{120 \times f}{p} \tag{1}$$

with f (Hz) is output voltage frequency, n (rpm) is rotation speed and p is number of permanent magnet poles. Next, number of turns and windings determine magnitude of output voltage based on two equations below [3]:

$$V_o = E_{rms} - \Delta V \tag{2}$$

$$E_{rms} = 4,44 \times N_t \times N_s \times f \times \varphi_m \tag{3}$$

with E_{rms} (V) is generator output voltage, E_{rms} (V) is induced voltage, ⊗V voltage drop, N_t is number of turns of a stator winding, N_s is number of stator windings and ϕ_m (Wb) is maximum flux of permanent magnet pole.

- First thing to do after disassembling the motor is modifying its rotor. Square holes are made in the rotor. Number of square holes are determined by number of permanent magnet poles, while size of each square hole is determined by permanent magnet dimension. Permanent magnet poles needed is calculated referring to necessary rotation speed to generate ac single-phase output voltage with frequency of 50 Hz.
- Next step is modifying stator. When doing this, the existing stator slots remain the same. Modification is done on number of a stator winding turns, which is calculated based on stator slots size and output voltage generated. Modification is also done on pattern of winding to get adding induced voltages and currents.
- Last step is reassembling the modified rotor and stator to get a single-phase permanent magnet generator. Then, laboratory test is run on no-load condition to get its output voltage characteristic. Waveform of output voltage on no-load condition is captured too.

3 Result and Discussion

3.1 Modification of the Induction Motor

As explained earlier, disassembling the squirrel cage single-phase induction motor is the first step taken. Figure 1 shows separate parts of the disassembled motor.

After doing careful observation, dimension of rotor and schematic or pattern of stator winding are obtained, as shown by Fig. 2 and Fig. 3.

It is found that length of the rotor is 154.3 mm. Thus, we use a permanent magnet with dimensions of 100 × 20 × 10 mm. Taking this dimension, maximum number of permanent magnet poles is found to be 10. Therefore, the single-phase permanent magnet

Fig. 1. Parts of the induction motor

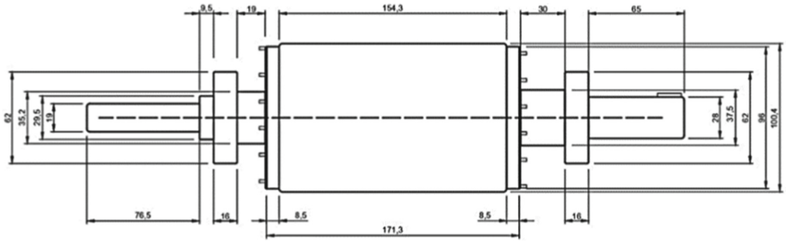

Fig. 2. Rotor dimensions

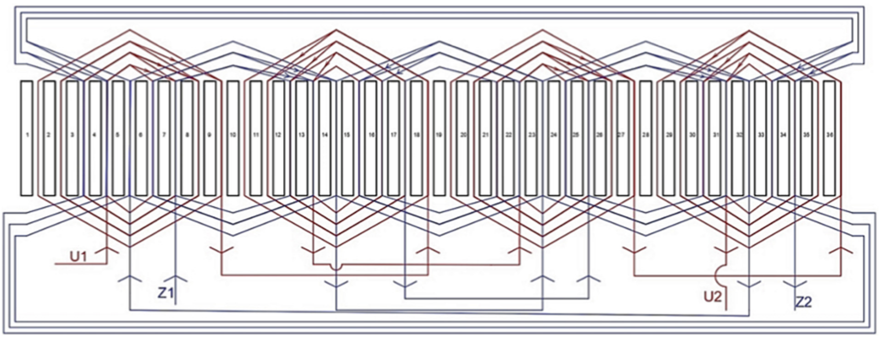

Fig. 3. Schematic of stator windings

generator will rotate at 600 rpm to generate 50 Hz output voltage. It is also found that the motor has 36 slots on stator. Direction or pattern of the winding as well as number of turns per-winding are modified according to these existing slots. Calculation shows

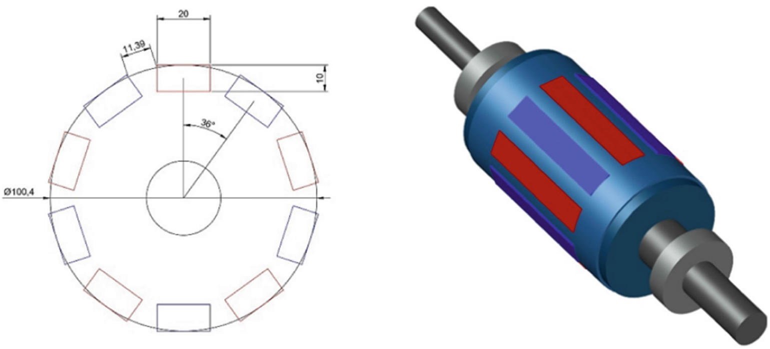

Fig. 4. The modified rotor

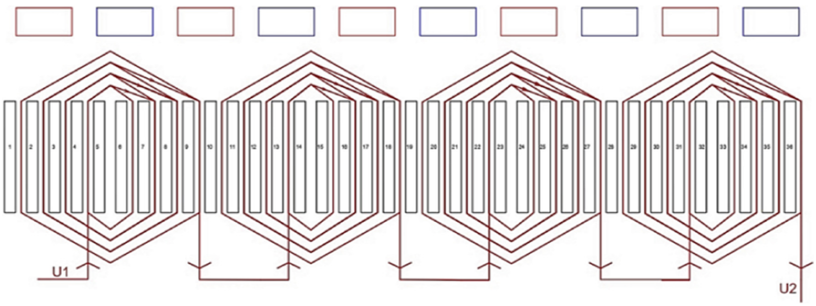

Fig. 5. The modified of schematic of stator windings

that the generator will has 4 windings with 600 turns per-winding. Size of winding conductor/wire is 0.55 mm^2. Expected maximum output voltage and current of the generator are119.23 V and 1.53 A respectively. Figure 4 and Fig. 5 show rotor and stator winding schematic after modification.

3.2 Output Voltage Characteristic of the Generator

After completing the modification, all parts of the motor are reassembled to get a single-phase permanent magnet generator. To get its voltage generation characteristic, no-load laboratory test is run. Generator output voltage is measured for different speed. Also, generator output voltage waveform is captured using a waveform recorder. Table 1 shows generator no-load test data.

Generator output voltage under no-load condition can also be obtained using Eq. (2) and (3). Table 2 shows the calculated output voltage of generator.

Based on data in Table 1 and 2, two graphs showing relation between generator speed and its output voltage are obtained. Figure 6 present these two graphs i.e. output voltage generator based on laboratory test and calculated one. Both graphs show that generator output voltage changes proportionaly to its rotation speed. Generator output voltage according to laboratory test is slightly lower than calculated one. The output

Table 1. Generator no-load test data.

No.	Rotor speed (n in rpm)	Output voltage (V_o in V)
1	61	10.6
2	113	21.4
3	153	26.8
4	206	37.3
5	253	45.5
6	350	62.5
7	463	84.0
8	563	101.0
9	607	111.0

Table 2. Calculated output voltage of the generator.

No.	Rotor speed (n in rpm)	Output voltage (V_o in V)
1	61	12.02
2	113	22.45
3	153	30.40
4	206	40.94
5	253	50.27
6	350	69.55
7	463	92.01
8	563	111.88
9	607	120.62

voltage characteristic of this single-phase permanent generator is similar to single-phase permanent generator developed earlier [13]. It differs in magnitude of output voltage generated. For same speed, magnitude of output voltage of this single-phase permanent magnet generator is higher than single-phase permanent generator developed earlier [13]. It also differs in nominal speed. This single-phase permanent generator works on lower speed, 600 rpm, to produce output voltage of 108.6 V and 50 Hz. Meanwhile, the single-phase permanent generator developed earlier must rotate at higher speed of 750 rpm to produce output voltage of 110 V and 50 Hz [13].

Output voltage waveform of this single-phase permanent magnet generator is shown in Fig. 7. Still, it is not purely sinusoidal, but it is closer. Percentage of total harmonic distortion (THD) of this output voltage is about 10.3%. It is lower than output voltage

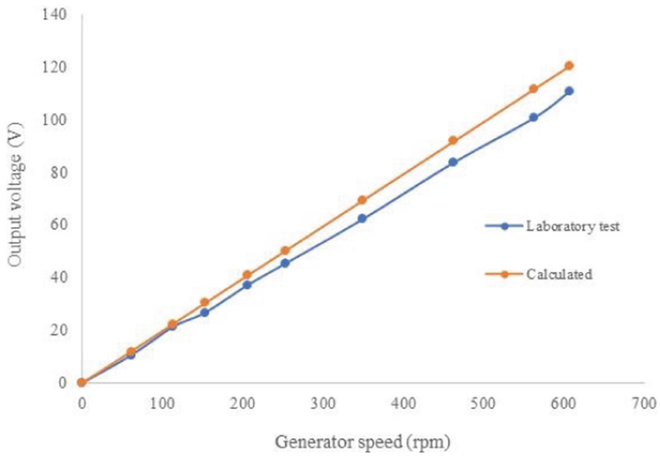

Fig. 6. Graph of generator output voltage characteristic.

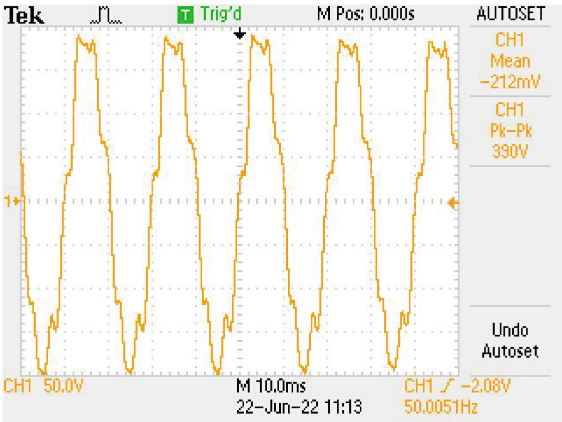

Fig. 7. Generator output voltage waveform.

THD of the single-phase permanent generator developed earlier, that is 15.8% [13]. Non-uniform rotor surface is the reason for the non-sinusoidal output voltage waveform generated. Using permanent magnet pole with flat surface creates non-uniform air gap between rotor and stator. Non-uniform air gap results in inequal magnetic flux received by stator windings.

4 Conclusion

A squirrel cage single-phase induction motor has been modified further. The low-speed single-phase permanent magnet generator obtained has 10 permanent magnet poles and 4 stator windings distributed in 36 slots. Each winding contains 600 turns made of 0.55 mm^2 sized conductor. No-load test data show that on rotor speed of 600 rpm, generator output voltage is 108.6 V and 50 Hz. The generator also able to generate ac single-phase output voltage waveform closer to sinusoidal with 10.3% THD.

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