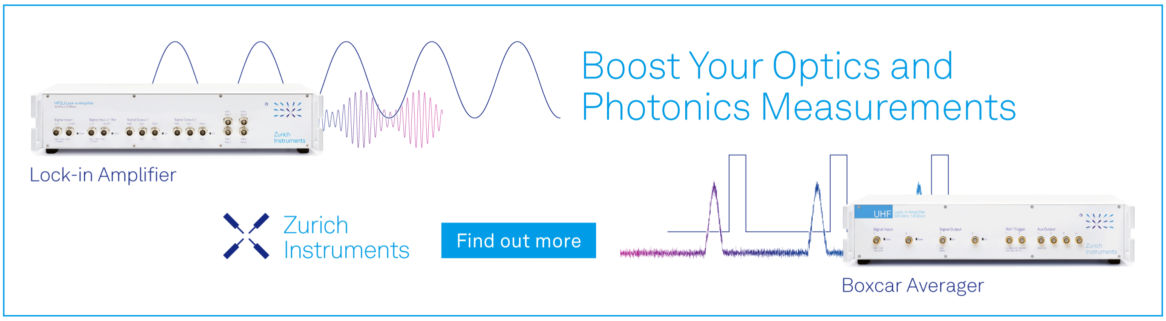
RESEARCH ARTICLE | JUNE 26 2018

Influence of excitation capacitor location to the output of low-power single-phase induction generator FREE

Agus Supardi ✉; Aris Budiman; Dwi Aji Saputro; Anhar Tri Atmanto

AIP Conf. Proc. 1977, 020061 (2018)
https://doi.org/10.1063/1.5042917



Influence of Excitation Capacitor Location to the Output of Low-Power Single-Phase Induction Generator

Agus Supardi[1, a)], Aris Budiman[1], Dwi Aji Saputro[1] and Anhar Tri Atmanto[1]

[1]*Department of Electrical Engineering, Universitas Muhammadiyah Surakarta, Indonesia*
Ahmad Yani ST, P.O. Box 1 Pabelan, Kartasura, Surakarta, Indonesia

[a)]Corresponding author: Agus.Supardi@ums.ac.id

ABSTRACT. Low-power single-phase induction generator is one type of generator that suitable for power generation in rural areas. Single-phase induction generator has two windings, the main winding and auxiliary winding. The main winding usually has a larger cross-sectional area, while the auxiliary winding has a smaller cross-sectional area. In this paper, the effect of excitation capacitors connected to the main or auxiliary winding was investigated. The capacitors were used as an exciter for self-excited induction generator. The induction generator used in this investigation has been built using a machine originally designed as a motor. The specification of this motor is 220 volt, 1 HP, 50 Hz, and 6 poles. It was intended for low-power applications such as in rural electrification. The no-load test results showed that the higher voltage would be generated when the capacitors were connected to the main winding. The no-load voltage changed from 211.4 to 220 volt when the capacitors were connected to the main winding. The voltage of 156.4 to 159.7 volt would be generated when the generator was excited on auxiliary winding. When it was loaded, the voltage and frequency of induction generator decrease linearly.

INTRODUCTION

Many rural areas in developing countries are not connected to the existing grid. A large investment is required to build the transmission and distribution lines in such area. On the other hand, the long-distance lines produce high losses. It is normally considered to be not economical to extend the existing grids in order to connect the rural area. Consequently, local renewable energy sources are being considered as alternatives for supplying electrical energy to rural areas [1,2].

The available resources should be used to produce electrical energy in rural areas. Power generation technologies used in this place should be simple, rugged, inexpensive, and easy to operate. The low-power generator is more suitable for used in rural areas. Single-phase generator is more appropriate to be applied since most of the electrical equipment used by consumers is a single-phase load [3].

One alternative of power generation in rural areas utilizing a single-phase induction generator because it's cheap, simple, rugged, and easy to operate [4]. Many studies have been done on three-phase induction generator [5,6], but there are not so much dedicated to single-phase ones.

In this study, an induction motor has been modified into low-power single-phase induction generator. The single-phase induction generator has two windings, the main winding and auxiliary winding. The main winding usually has a larger cross-sectional area, while the auxiliary winding has a smaller cross-sectional area. In order to generate electricity, the capacitor must be connected to the winding of generator. The capacitors serve as the excitation source for the induction generator. The selection of an excitation capacitor is very important for voltage regulation of a single-phase induction generator. The capacitance must be chosen so that the desired terminal voltage level at the given speed and range of loads is obtained. On the other hand, the existence of two windings on the induction generator becomes a problem related to the determination of locations for installing the capacitors. It is needed to investigate the optimum location of capacitors.

Wang and Ching-Huei [7], Malik and Al-Bahrani [8], Al Jabri and Alolah [9] proposed an analysis to predict the size of capacitors required for self-excitation of an induction generator. It is not advisable to choose the maximum size of capacitors because of the fact that the higher capacitance value will cost more. In addition, there is a possibility that the current flowing in the capacitor might exceed the rated current of the stator.

Human-Dedicated Sustainable Product and Process Design: Materials, Resources, and Energy
AIP Conf. Proc. 1977, 020061-1–020061-6; https://doi.org/10.1063/1.5042917
Published by AIP Publishing. 978-0-7354-1687-1/$30.00

The process of voltage buildup in a dc generator is very much similiar to that of an induction generator. A suitable value of residual magnetism must be present in the rotor. The voltage will not build up in the absence of a proper value of residual magnetism. It is desirable to maintain a high level of residual magnetism, as it does ease the process of machine excitation. In a paper written by [10] is to propose to use a variable speed prime mover for minimum capacitance required for self-excitation. In a paper of [11] proposed a simple and direct approach based on first-order eigenvalue sensitivity method to determine both maximum and minimum value of capacitance required for an isolated self-excited induction generator (SEIG) under different loading conditions. The author [12] proposed technique, which uses nodal analysis instead of loop analysis to obtain just one formula for minimum capacitance required for induction generator operation at different load and speed conditions.

MATERIALS AND METHODS

The induction generator used in this investigation has been built using a machine originally designed as a motor. The specification of this motor is 220 volt, 1 HP, 50 Hz, and 6 poles. It was intended for low-power applications such as in rural electrification. The changing from a motor to a generator has been achieved through stator winding modification. Unlike in motor, the main winding of stator is disconnected to the auxiliary winding. The excitation capacitors can be connected to the main or auxiliary winding while the load is only connected to the main winding.

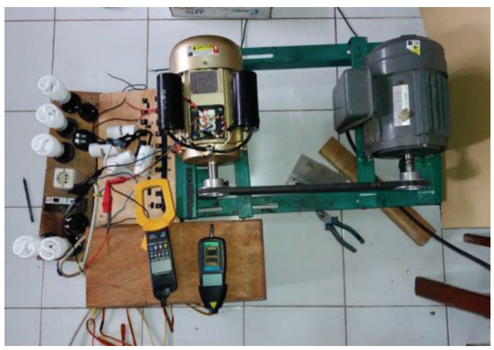


FIGURE 1. The experiment set-up to test the single-phase induction generator

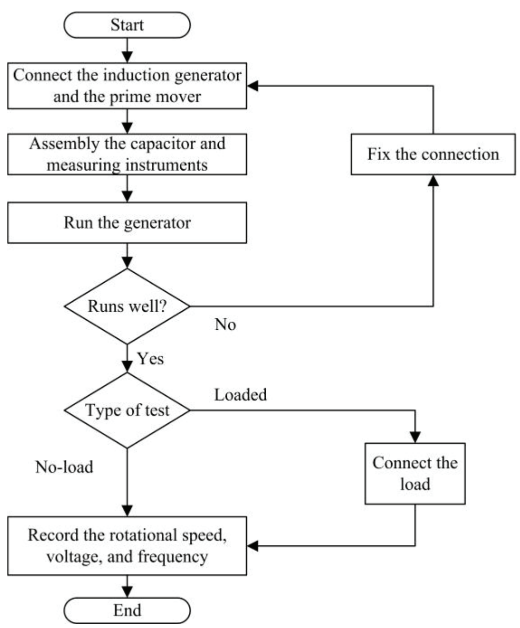


FIGURE 2. The flowchart of laboratory test

A series of laboratory test has been done to obtain the generator characteristics under no-load and loaded condition. The experiment set-up is shown in figure 1. The reactive power of generator has been supplied from capacitors connected in parallel to stator winding. These capacitors were connected to both windings, i.e. the main as well as auxiliary windings. The generator speed was set by using voltage regulator connected to a prime mover. In this research, the experiments to obtain the characteristic of single-phase induction generator for low-power applications have been done by connecting variable loads to the main windings. Generator speed and reactive power from excitation capacitors were regulated. The generated voltage and frequency were measured by using a multimeter. The process of regulations is shown in figure 2. All measurement data resulted from the laboratory test are presented in a chart to get a better representation.

RESULTS AND DISCUSSIONS

No-Load Test of Induction Generator

The induction generator was rotated up to a certain speed by using a prime mover. The excitation capacitors were connected to the stator winding. During the starting-up of a generator, the initial voltage was difficult to get even though the generator had been rotated exceeding its synchronous speed. The pre-charged capacitor was needed. This was done by connecting the capacitors to a voltage source for 1 to 2 second while the rotor was rotated. The size of capacitors was changed from 48 to 80 μF.

The results of voltage measurements in no-load condition are shown in figure 3. It can be seen that the change in the size of capacitors will change the generator voltage. When the capacitors connected to the main winding, the minimum voltage would be generated by using 64 μF and the maximum voltage would be generated by using 72 μF. When the capacitors connected to the auxiliary winding, the minimum and maximum voltage would be generated by using 80 and 48 μF respectively. These results show that the induction generator should be operated with an appropriate capacitor. If it was neglected, the generator voltage can be very low or very high. The very low voltage or the very high voltage can cause the failure or even the damage of electrical equipment connected to it. When connected to the main winding of induction generator, the optimal size of the capacitor is 72 μF as indicated in figure 3. This capacitor was used for the next test.

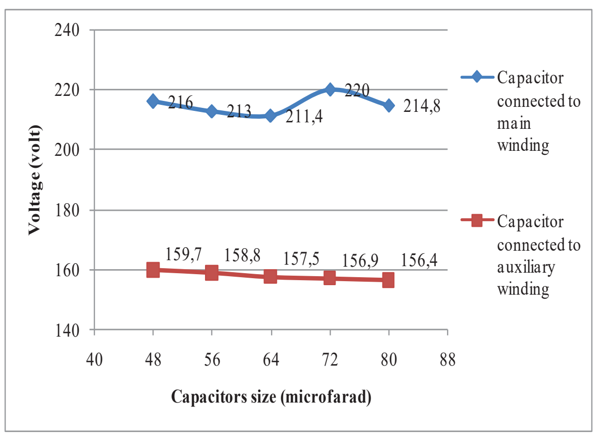


FIGURE 3. The results of experiment on the relationship between capacitors size and generator voltage with constant speed

As indicated in figure 4, the no-load test results at 1000 rpm showed that the excitation on primary winding would generate a voltage of 161.8 volts, while the excitation on auxiliary winding would generate a voltage of 146.2 volts. When the rotational speed was increased to 1150 rpm, the excitation on primary winding would generate a voltage of 264.7 volts while the excitation on auxiliary winding would generate a voltage of 193.3 volts. These results showed that the location of capacitor influence the generator voltage. The excitation capacitor that connected to the main winding will generate a greater voltage than the excitation capacitor that connected to the auxiliary winding.

The results of experiment shown in figure 5 indicate that the rotational speed has an effect on the frequency of induction generator. It can be seen that the frequency relatively linear with the rotational speed. When it rotated at 1000 rpm, the excitation on the primary winding would generate a frequency of 49.4 Hz whereas the excitation on the auxiliary winding would generate a frequency of 49.2 Hz. By increasing it to 1100 rpm, the excitation on the primary winding and auxiliary winding would generate a frequency of 54 Hz. In general, it can be said that the higher the rotational speed, the higher the frequency. For the same speed, the location of capacitor determines the frequency of the generator. When it was connected to the main winding, the generated frequency is higher than when connected to the auxiliary winding.

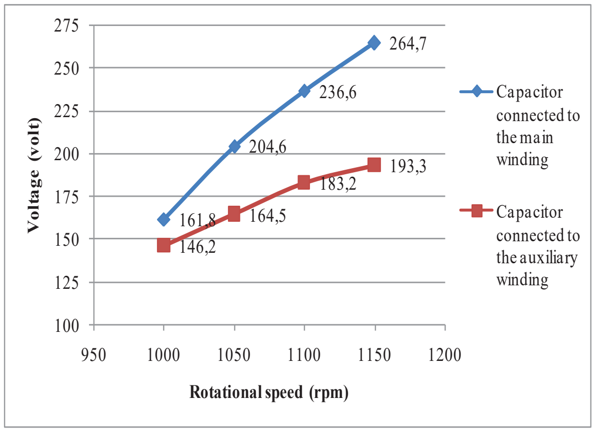


FIGURE 4. The results of experiment on the relationship between generated voltage and rotational speed with constant capacitor

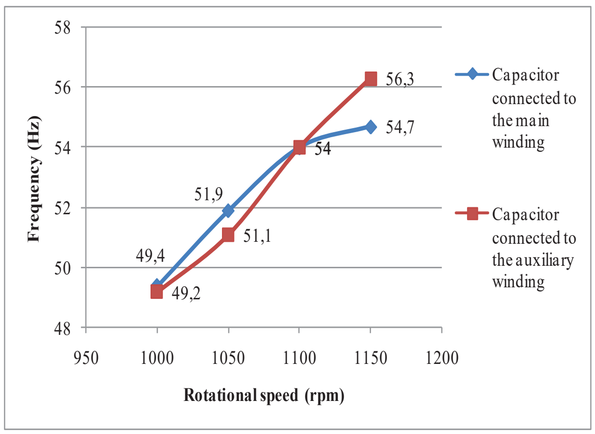


FIGURE 5. The results of experiment on the relationship between generated frequency and rotational speed with constant capacitor

Loaded Test of Induction Generator

As can be seen in figure 6, the test results showed that there is a relationship between generated voltage and load power. When loaded with 24 watt energy saving lamps at 1100 rpm, the excitation on primary winding would generate 217.5 volts whereas the excitation on auxiliary winding only generates 180.1 volts. Load variations of 24 to 120 watt decrease the voltage of induction generator from 217.5 to 163.2 volts. These results showed that the load will cause a voltage drop on induction generator. The greater the load, the smaller the voltage of induction generator. Due to the greater load, the higher current flowing in the windings. The higher current, also made the higher voltage drop. The higher voltage drop cause the voltage of induction generator became smaller. Based on the location of the capacitor, it can be said that the excitation on main winding will produce a higher voltage than the excitation on auxiliary winding. This could be due to the phase angle of the auxiliary winding impedance which was not the same as that of the main winding.

The results of frequency measurement in loaded condition can be seen in figure 7. With unregulated input mechanical power, the generated frequency affected by how the excitation capacitor was connected. When connected to the main winding, the generated frequency is smaller than when connected to the auxiliary winding. The regulated load also influence the frequency of the generator. The higher the load, the lower the frequency. This could be due to the reduction of rotational speed when the load power increased. It can be seen that the load power decrease the frequency linearly.

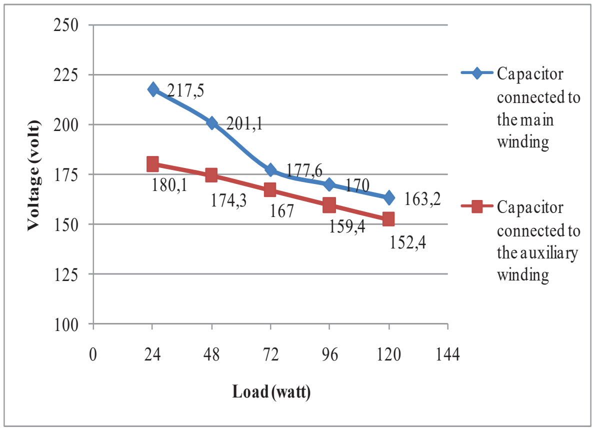


FIGURE 6. The results of experiment on the relationship between generated voltage and load power

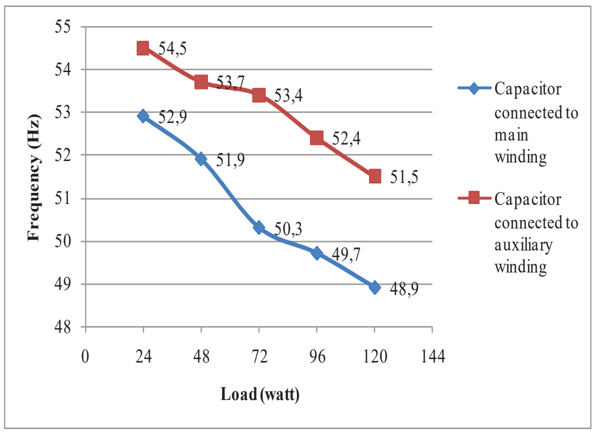


FIGURE 7. The results of experiment on the relationship between generated frequency and load power

CONCLUSIONS

The location of excitation capacitor will have an effect on the voltage of induction generator but it will not have a significant effect on the frequency. The capacitors that connected to the main winding will generate a higher voltage than the capacitor that connected to the auxiliary winding. The load connection decreases the voltage and the frequency of induction generator.

The research is still needed to be continued with machines of more poles in order to lessen the rotational speed of induction generator. By lowering the speed, the induction generator will suitable for pico and micro-hydro power generation system.

ACKNOWLEDGMENT

The authors would like to thank the ‘Direktorat Riset dan Pengabdian Masyarakat (DRPM)’, the ministry of research and technology for higher education, the Government of Indonesia for supporting the research funding.

REFERENCES

1. J. Mutale and C. Mensah-Bonsu, (2009). Electricity supply industry arrangements and policies on rural electrification, *IEEE Power & Energy Society General Meeting*, Calgary, AB, 2009, pp. 1 – 5.
2. G. D. Kamalapur, R. Y. Udaykumar and S. Karajgi, (2008). People's participation in rural electrification a successful case. *1st International Conference on Emerging Trends in Engineering and Technology (ICETET),* Nagpur, Maharashtra, India, 2008, pp. 945 – 949.
3. N. Altawell, (2012). Financing for rural electrification. *IEEE Conference on Computational Intelligence for Financial Engineering & Economics (CIFEr)*, New-York, 2012, pp. 1 – 8.

4. O. D. Mipoung, P. Pillay and L.A.C. Lopes, (2011). Generator selection for rural electrification from renewable energy. *IEEE International Electric Machines & Drives Conference (IEMDC)*, Niagara Falls, ON, 2011, pp. 306 – 311.
5. C. P. Ion and Marinescu C. (2013). Microhydro power plant with three-phase induction generator feeding single-phase consumers. *4th International Conference on Power Engineering, Energy and Electrical Drives (POWERENG)*, Istanbul, 2013, pp. 1211 – 1216.
6. M. H. Haque, (2008). Self-excited single-phase and three-phase induction generators in remote areas. *International Conference on Electrical and Computer Engineering (ICECE)*, Dhaka, 2008, pp. 38 – 42.
7. L. Wang, and L. Ching-Huei, (1997). A novel analysis on the performance of an isolated self-excited induction generator. *IEEE Trans. on EC*, Vol. 12, No. 2, June 1997, pp.109-117.
8. N. H. Malik, and A. H. Al-Bahrani, (1990). Influence of the terminal capacitor on the performance characteristics of a self excited induction generator. *IEE Proc.*, Vol. 137, No. 2, March 1990, pp. 168 – 173.
9. A. K. Al Jabri and A.I. Alolah, (1990). Limits on the performance of the three-phase self-excited induction generators. *IEEE Trans. on EC*, vol. 5, No. 2, June 1990, pp. 350 – 356.
10. T. Ahmed, O. Noro, K. Matzuo, Y. Shindo and M. Nakaoka, (2003). Minimum excitation capacitance requirements for wind turbine coupled stand-alone self-excited induction generator with voltage regulation based on SVC. IEEE Trans., October 2003, pp. 396 – 403,
11. Li Wang and Jian-Yi Su. (1998). Determination of minimum and maximum capacitances of an isolated SEIG using eigenvalue sensitivity approach. *IEEE Powercon*, vol.1, pp. 610 – 614, Aug 1998.
12. A. M. Eltamaly, (2002). New formula to determine the minimum capacitance required for self-excited induction generator. *IEEE CNF*, vol. 1, June 2002, pp. 106 – 110.