International Journal of Technical Innovation in Modern Engineering & Science (IJTIMES)
Impact Factor: 5.22 (SJIF-2017), e-ISSN: 2455-2585
Volume 5, Issue 03, March-2019

PERFORMANCE COMPARISON OF STAND ALONE PERMANENT MAGNET SYNCHRONOUS GENERATOR AND SQUIRREL CAGE INDUCTION GENERATOR BASED WIND ENERGY CONVERSION SYSTEMS

Y. Mastanamma[1], Dr. D. Subbarayudu [2]

[1] *Research Scholar at Rayalaseema University, Kurnool, Andhra Pradesh and HOD- EEE/Associate Professor at Methodist College of Engineering and Technology, Abids, Hyderabad,Telangana*
[2] *Research Supervisor at Rayalaseema University, Kurnool, Andhra Pradesh, India*

Abstract — ***Off-Grid small wind turbines provide a very attractive renewable energy source for remote communities and small businesses. Due to its high reliability and efficiency, gearless-drive permanent magnet synchronous generator might currently be the most common wind turbine in such application. However, wind turbines using geared- squirrel cage induction generator are still widely accepted due to robustness, simplicity, light weight and low cost. This work develops variable-speed Wind Energy Conversion Systems (WECS) using squirrel cage induction generator and permanent magnet synchronous generator. Both generators are connected to the load through a rectifier and an inverter. The performances of both generators are examined under comparable power ratings and similar control techniques. In this paper, a comparison between the two generators is presented for generator's voltage and current harmonic distortion.Simulations have been performed using Matlab/Simulink under varying wind speed conditions.***

INTRODUCTION:

Energy serves as the backbone for any progress. Major energy demand is currently dependent on conventional sources. Some major issues are associated with dependency on conventional energy resources. Looking at present consumption rate, existing fossil fuel reserves are going to get exhausted within few decades. Moreover, carbon emission adds up to environmental issues. Therefore, the conventional sources are being replaced by renewable sources to meet the ever-increasing energy demand. Of the available alternatives, wind energy has emerged as one of the most established technologies. Nevertheless, the output of wind energy conversion system (WECS) is dependent on wind flow, which by nature is erratic and unpredictable. So far the development of the control scheme and ensuring a reliable WECS has been a major area of focus.
The topology composed of three-phase diode bridge rectifie and pulse-width-modulated voltage-source inverter (PWM-VSI) is identified as a simple and low-cost configuration, offering satisfactory performance for a low-power off-grid WECS.A small-scale standalone wind energy conversion system featuring SCIG, VSI scheme is proposed. The feasibility of the proposed WECS and performance of the system under variable wind conditions are analyzed and demonstrated through simulation.

2. COMPARISON OF SCIG-WECS versus PMSG-WECS:

The success of the wind topology depends on the appropriate choice on the technology and its implications in the energy conversion, considering and understanding the standing of the renewable energy being highly intermittent. The choice on the generator is critical as the operational limits of the turbine are addressed through high power density capability of the modern generators.
Due to presence of permanent magnets in PMSG, it is not necessary to supply magnetizing current to the stator for a constant air-gap flux. Therefore, the stator current is only responsible for producing the torque component and hence PMSG, when compared to SCIG, will operate at a higher PF, leading to higher efficiency. SCIG, in contrast, needs to be connected to an external VAR source, in order to establish the magnetic field across the air gap. This results in a low power factor and efficiency. In general, induction generators are less efficient than synchronous generators with comparable ratings [2].
PMSG -based WECS offers an advantage over SCIG-based WECS in terms of possibility of eliminating the need for gearbox. Thus, they are called gearless-PMSG and geared-SCIG,respectively. Fig.1 and Fig. 2. shows typical topologies for SCIG- and PMSG-based standalone WECS, respectively. Since PMSG is self-excited, a three-phase diode rectifier can be used as the generator-side converter, as shown in Fig. 2.In contrast, a VAR compensator, such as a capacitor bank, is required to excite the SCIG if a three-phase diode rectifier is to be used, as in Fig.1.
In both topologies shown in Fig.1 and Fig2, two-level pulse width modulated voltage-source inverters (PWM-VSI) are used as the load-side converters.

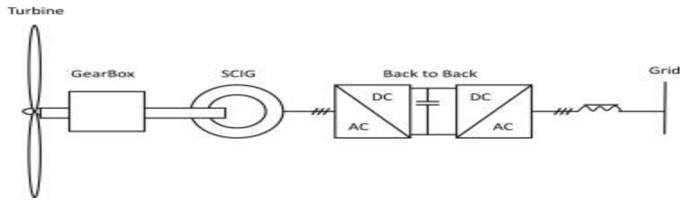


Fig.1: SCIG-based standalone WECS with generator-side diode bridge rectifier

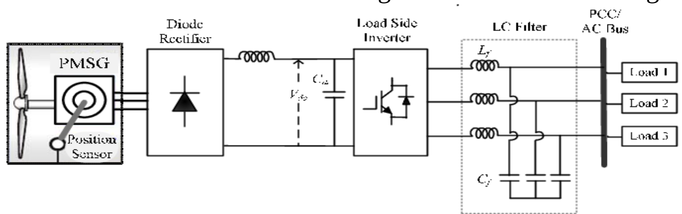


Fig. 2. PMSG-based direct-drive standalone WECS with generator-side diode bridge rectifier

a)Efficiency: Due to presence of permanent magnets in PMSG, it is not necessary to supply magnetizing current to the stator for a constant air-gap flux. Therefore, the stator current is only responsible for producing the torque component and hence PMSG, when compared to SCIG, will operate at a higher PF, leading to higher efficiency. SCIG, in contrast, needs to be connected to an external VAR source, in order to establish the magnetic field across the air gap. This results in a low power factor and efficiency. In general, induction generators are less efficient than synchronous generators with comparable ratings [2].

b)Reliability: Reliability of a wind turbine can be measured by frequency and duration of failures in the system [3]. The gearbox requires regular maintenance and is not immune to failure. If it fails, the repair required is a major task. Studies have shown that the gearbox has a very long downtime per failure when compared with other components of WECS [4]. Thus, the elimination of gearbox in direct-drive PMSG-based WECS can significantly improve the reliability of the system. However, direct-drive systems feature higher number of failures in generator and power electronic converters [5] due to direct transfer of wind turbine rotor torque fluctuations to the generation side; however, the downtime of direct-drive systems due to power electronics or generator failures is definitely much shorter than those of gearbox in indirect drive systems. Although gearless design is an advantage for PMSG-based WECS over SCIG-based WECS, the fact that the reliability of PMSG can be affected by permanent magnet's demagnetization and change of characteristics under harsh environmental conditions (such as high temperatures), is considered a serious disadvantage.As far as the generator type is concerned, real data has shown that synchronous generator- based turbines suffer higher failure rates than those using induction generators [6].

c)Control Complexity: In variable-speed WECS, the generator shaft speed is controlled to achieve MPPT, which is of key importance in wind energy systems.SCIG is one of the simplest machines in terms of control requirements. Control techniques suitable for SCIG, such as direct field oriented, indirect field oriented and direct torque control,are very well-known and well-established. In contrast, one of the drawbacks of PMSG is its control complexity, which is caused by the fact that the magnet excitation cannot be varied and hence the output voltage of PMSG will vary with load. This problem can be solved by capacitive VAR compensation or an electronic voltage controller, adding to the control complexity. Zero d-axis current, maximum torque per ampere and unity power factor, are three common methods of PMSG control [2].

d)Cogging Torque and Noise: In PMSG, the interaction between the magnets of the rotor and the slots of the stator generates an undesirable torque, called cogging torque, which causes fluctuations in torque and speed of the shaft. Cogging torque results in vibration and noise in the machine, especially at low speed and hence it can negatively affect the cut-in speed of the PMSG turbine ADDIN ZOTERO_ITEM.Unlike PM synchronous machines, the phenomenon of cogging torque is not significant ininduction machines. However, a geared-SCIG-based wind turbine has another source of noise as a result of presence of gearbox in the drive train [2]. In summary, both gearless-PMSG and geared-SCIG WECS have a source of noise, which is not so important if the turbine is installed far away from the community. However, the cogging torque of PMSG does always matter, as it affects the cut-in speed and hence the total kWh production of the wind turbine,leading to a lower capacity factor. Nevertheless, cut-in speed for SCIG-based wind turbine is also restricted by the generator threshold speed, below which the machine excitation is not possible. Thus, capacity factor is negatively affected by limitation of cut-in speed in both PMSG and SCIG wind turbines.

e)Cost: Compared to the geared-SCIG system, the gearless-PMSG system saves on the cost of gearbox. However, the multi-pole structure adds to the cost of gearless-drive PMSG system.Moreover, PM generators are generally more expensive than induction generators due to the high price of magnets.

For cost comparison purposes, a 30kW wind turbine is selected as an example for small wind turbines in off-grid applications. Such a turbine can supply power to a small village, a large farm or a small enterprise, when equipped with an energy storage system. Table 2.1 shows the prices for a gearless-drive PMSG-WECS and a geared-drive SCIG-WECS with similar power ratings (i.e., 30kW) [1]-[3]. The comparison reveals the cost advantage of geared-SCIG turbine with respect to gearless-PMSG turbine. The combined cost of SCIG and gearbox is around 50% of PMSG cost. Although the price difference depends on power rating and varies from one manufacture to another, and from one country to another, the price ratio between geared SCIG and gearless PMSG systems are currently significant due to the involvement of PM materials in the latter system.

Operation and maintenance (O&M) cost is another contributor to a WECS overall cost. O&M cost includes costs of regular inspection, repair, spare parts and insurance [4]. When comparing geared-SCIG and gearless-PMSG systems, the O&M is mainly associated with gearbox and generator. The O&M cost for geared-SCIG is expected to be relatively high due to the presence of gearbox, which requires regular maintenance and expensive spare parts if a repair is needed [5]. On the other hand, the gearless-PMSG's O&M cost is due to high rate of failures in generator and power electronic converters, but it is still much lower than the gearbox maintenance cost. Insurance of a wind turbine is also counted as a part of O&M expenses. The insurance of a geared-SCIG turbine is considerably affected by the gearbox. The cost of replacing a gearbox can reach 10% of the original construction cost of the wind turbine, which defeats the advantage of low capital cost in a geared-SCIG wind turbine.

The combination of a diode rectifier and a dc/dc converter is less expensive than a switch-mode voltage-sourced rectifier. The former configuration is commonly used in small-scale, standalone PMSG systems [6]. If the same configuration is to be used with SCIG, there will be an extra cost due to the need for external exciter. However, capital cost comparison should be conducted, considering all system components.

On the other hand, the insurance cost is generally proportional to capital cost and hence a gearless-PMSG turbine's insurance is negatively affected by its high capital cost, which is expected to increase further in future due to unreliable supply of permanent magnet material in the global market. In summary, although the presence of gearbox in a geared-SCIG turbine adds to the O&M expenses, its overall cost, including capital cost, is still lower than that of a gearless-PMSG wind turbine.

Table. 1: Cost Comparison(In RS.) of 30kW PMSG- and SCIG-Based WECSs.

Component	**SCIG [112]**	**PMSG [111]**
Blades (3- Horizontal axis)	2,76,190	1,50,520
Gearbox	None	3,43,498
Generator	9,51,400	99,400
Controller (including rectifier,dump load and inverter)	6,03,500	6,12,730
Lead Acid Batteries (144 kWh)	5,96,400	5,96,400
Total	**24,27,490**	**18,02,548**

Based on the comparison from the viewpoints of efficiency, reliability (particularly the length of gearbox downtime), and external excitation requirements, the direct-drive PMSG system represents the preferred topology for small-scale, standalone WECS. On the other hand, based on the comparison from the viewpoints of reliability (particularly the failure rate of generator and power converters), machine size and weight, control simplicity, and overall cost, the indirect-drive SCIG system wins against the direct-drive PMSG system. Moreover, PMSG might face a real problem in future due to shortage and monopoly of permanent magnet supply.

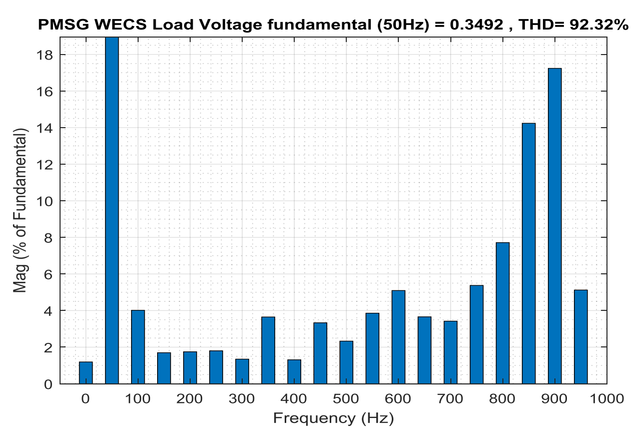
The resources of permanent magnets, especially the Neodymium type, are almost entirely limited to China. This fact is raising concerns about shortage of PM supply in the near future as a result of considerable increase in demand that is expected due to proliferation of Hybrid Electric Vehicles and Electric Vehicles that commonly use PM synchronous machines for their traction motors [6].

V. SIMULATION RESULTS :

Table I Comparison of SCIG and PMSG at various wind speeds.

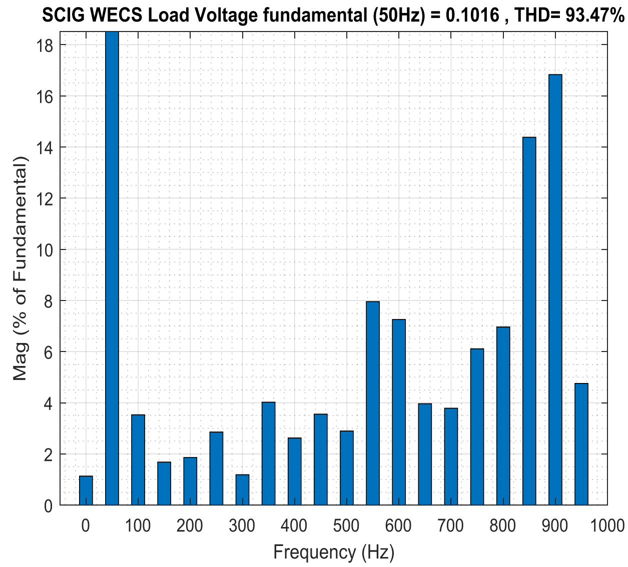
SCIG RESULTS:

Wind Speed (m/s)	Load Votage THD	Fundamental Voltage	Load Current THD	Fundamental Current
8	92.7 %	0.21	92.8 %	0.4508
10	92.74 %	0.10581	93.21 %	0.3456
12	93.47%	0.1016	93.88 %	0.2212
13	93.46 %	0.07863	93.22 %	0.1708
15	93.37 %	0.03486	93.30%	0.07611



PMSG RESULTS :

Wind Speed (m/s)	Load Votage THD	Fundamental Voltage	Load Current THD	Fundamental Current	Active Power output
8	104.16%	0.01204	105.35 %	0.001256	0.0000686
10	92.59 %	0.153	92.76 %	0.01684	0.000476
12	92.00 %	0.3679	92.43 %	0.04022	0.004023
13	93.11 %	0.5563	91.42 %	0.06141	0.004847
15	91.82 %	0.7305	92.45 %	0.07924	0.01147



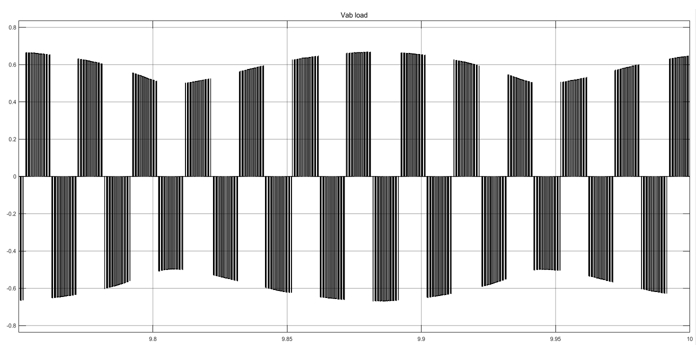


Fig. PMSG WECS Load Voltage

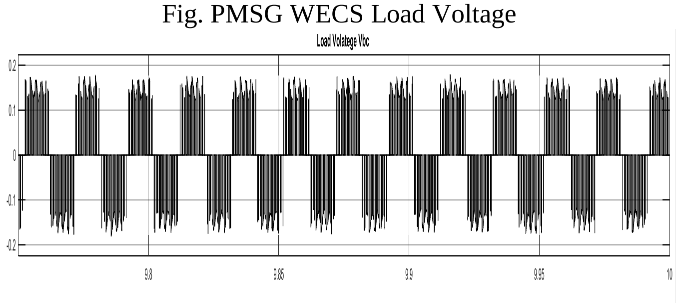


Fig. SCIG WECS Load Voltage

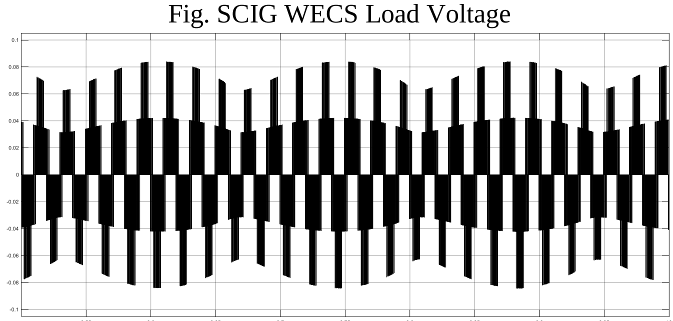


Fig. PMSG WECS Load Current

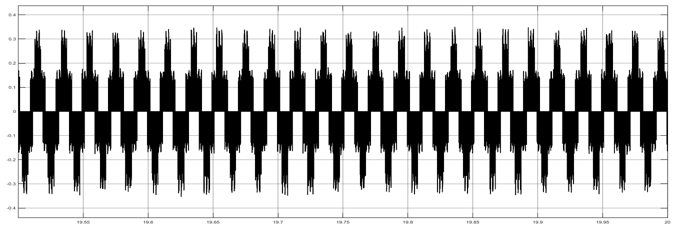


Fig. SCIG WECS Load Current

VI. CONCLUSION:

The performances of two stand-alone WECS configurations based on SCIG and PMSG were compared in this paper. Both systems had two level full-scale power converters. The comparisons were conducted at various wind speeds for voltage and current harmonic distortions of both generators. The models were developed using MATLAB SimPowerSystem toolbox.In terms of generated power, SCIG is less efficient than PMSG at low and high wind speeds. Permanent-magnet synchronous generators are used by these technologies due to special characteristics of PMSG such as low weight and volume, high performance, and no need of external power supply for permanent magnet excitation. The PMSG overcomes the induction generator and other generators, owing to its performance without absorbing the grid power. However, SCIG is a competitor to PMSG at medium wind speeds.

REFERENCES:

[1]. Z. Alnasir and M. Kazerani, Senior Member, IEEE Electrical and Computer Engineering, “Performance Comparison of Standalone SCIG and PMSG-Based Wind Energy Conversion Systems” 978-1-4799-3010-9/14, 2014 IEEE CCECE 2014 Toronto, Canada.

[2] P.K. Sen, and J.P. Nelson, “Application guidelines for induction generators,” International Conference on Electrical Machines and Drives, 1997,pp. WC1/5.1-WC1/5.3.

[3] F. Spinato, P.J. Tavner, G. Bussel, and E. Koutoulakos, “Reliability of wind turbine subassemblies,” IET Renewable Power Generation, vol. 3, no. 4, pp. 387- 401, 2009.

[4] J. Ribrant, and L. Bertling, “Survey of failures in wind power systems with focus on Swedish wind power plants during 1997-2005,” IEEE Power Engineering Society General Meeting, 2007, pp. 1-8.

[5] P.J. Tavnet, G. Bussel, and F. Spinato, “Machine and converter reliabilities in wind turbines,” 3 rd IET International Conference on Power Electronics, Machines and Drives 2006, pp. 127-130.

[6] E. Echavarria, B. Hahn, G.J.W. Brussel, and T. Tomiyama, “Reliability of wind turbine technology through time,” Journal of Solar Energy Engineering, vol. 30, no. 3, pp.0310051-0310058, 2008.