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Dual Stator Induction Generator For Rural Electrification

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Abstract

The paper presents an electromechanical auto synchronized wind energy conversion system (WECS) for larger penetration of renewable energy sources (RES) in the rural electrification systems. The architecture of the WECS uses two stator windings at power frequency which provides harvesting of power to flow from WECS to load and to grid side when the generated power is in access. Asymmetrical six phase machine is modeled and analyzed for power transaction between WECS to grid and load, grid to load in absence of energy harnessing from wind. A simulation study is done on a 3.75 KW Dual Stator Induction Generator (DSIG). The performance of the proposed system is evaluated and results show effective transfer of power to the load under perturbing load/source side conditions.

Keywords: DSIG; Wind Energy Conversion System; Renewable Energy; SCIG, THD.

INTRODUCTION

Demand for electrical power is increasing day by day so new and better ways of power generation and power transfer are being explored everywhere, but demand and supply parity is a distant dream for developing and underdeveloped countries. Use of renewable sources of power generation is highly encouraged for inducting power to fulfill the deficit demand. Amongst various renewable sources wind energy has proven to be a clearer and better solution [1]. Many types and topologies for wind generator systems have been practiced, each with its own advantage and disadvantage over the other scheme [1]. For having a deep penetration of renewable into the grid it is preferred to have distributed generating systems rather than larger units at specific places. Small induction generators are considered to be the promising solutions taking into consideration for larger penetration of power [1]. Low cost and maintenance free nature of squirrel cage induction generators (SCIG) give them a upper hand over doubly fed induction generators (DFIG) [2] [3]. Also in grid connected mode, reactive power demand is fully catered by grid itself or sometimes a capacitor is connected at point of common coupling to decrease the reactive power demand from grid side. Wide range of operating speed and rated back to back converter makes DFIG a suitable choice for higher generation ratings, but for low rating generating units DFIG becomes costly when compared with SCIG as the installation and running costs of DFIG are more making the payback period to become very long[4-5]. So for smaller generating units which can be installed for rural loads or at small community / residential areas fixed speed SCIG’s offer suitable and sustainable solution, where their accumulated generation has an effect of reducing the overall average grid loading [4-5]. Pump loads are commonly occurring rural load in association with small residential loads. For improving power factor of the supply and limited voltage regulation a capacitor bank is often used. Tapped power from wind is utilized locally, but during light load conditions the excess power is transferred to the grid.

Induction generators directly connected to grid suffer from major drawback in terms of intermittency of power due to fluctuating wind speed and these are reflected in their electrical responses (like voltage and frequency fluctuation). Many a times due to larger variation in speed out of the cut-in and cut-off range, after the machine attains stall condition demanding large magnetizing current every time speed breaks into cut-in speed. Another problem the wind generator faces is due to low voltage at the point of common coupling. The low voltage ride through (LVRT) capability marks the merit of SCIG for its robust grid connection [2] [6] [7].

A new type of SCIG with two stators, with same number of poles, magnetically coupled via same air gap and single rotor (DSIG) is proposed as a new solution for such kind of smaller distributed wind energy generating units [8-9]. Grid is connected to one stator terminal of DSIG and local load is connected to other stator terminal of DSIG. Power is routed to the local load via air gap thus providing galvanic isolation. In case of low wind speed DSIG acts as transformer and transfers power from the grid to the local load. As power is transferred to load end via magnetic circuits there are least chances of grid side harmonic disturbances reaching the local loads or vice-versa. As wind speed goes post cut-in speed the DSIG generates and supplies power to its local load, for higher speed the power after catering to the local loads pushed to the grid side to imitate/ use grid as storage. In all the cases DSIG always draw reactive power from the grid for its excitation, not only reduced in quantum due to coupling of only one side to the grid but also due to auto compensation because of loads on other side.

The paper presents DSIG connected to a three phase grid on one set of stator winding and with load on other side. The study on the effects of loading at one side of DSIG with different types and combinations of load like unity power factor load, lagging power factor load, non-linear load and dynamic load etc. has been considered. Prime mover enacting wind turbine is run at different speeds near synchronous speed with a slip of ± 4% to study the source side perturbations. This has been validated through simulation done using MATLAB/SIMULINK.

SYSTEM CONFIGURATION

Block diagram of considered system is shown in Fig. 1. The Figure shows that DSIG is connected to three phase grid through one set of three phase stator winding and the local loads are applied at the other three phase stator winding. Reactive power required by DSIG is provided by grid and thus requirement of any static or dynamic VAR compensator is eliminated. When local loads are connected to off grid side winding of DSIG and wind speed is less than synchronous speed and the DSIG is not generating any power the requisite power (active and reactive both) demanded by the load is drawn from grid side.

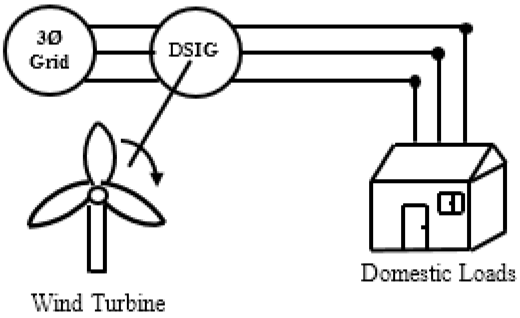


Figure 1: Block Diagram

MATHEMATICAL MODELLING

Two balanced three phase windings displaced to each other by 30˚ (asymmetrical) is assumed for modeling of DSIG; considering following assumptions:

- Air-gap is uniform and the windings are sinusoidally distributed around the air-gap.
- Magnetic saturation and core-losses are neglected.

The following voltage equations are written in d-q axis for DSIG in synchronous reference frame:

$$[V_{qs1}] = [R_{s1}].[i_{qs1}] + \text{þ}[\chi_{qs1}] + \omega[\chi_{ds1}] \quad (1)$$

$$[V_{ds1}] = [R_{s1}].[i_{ds1}] + \text{þ}[\chi_{ds1}] - \omega[\chi_{qs1}] \quad (2)$$

$$[V_{qs2}] = [R_{s2}].[i_{qs2}] + \text{þ}[\chi_{qs2}] + \omega[\chi_{ds2}] \quad (3)$$

$$[V_{ds2}] = [R_{s2}].[i_{ds2}] + \text{þ}[\chi_{ds2}] - \omega[\chi_{qs2}] \quad (4)$$

$$[V'_{qr}] = [R'_r].[i'_{qr}] + \text{þ}[\chi'_{qr}] + (\omega-\omega_r)[\chi'_{dr}] \quad (5)$$

$$[V'_{dr}] = [R'_r].[i'_{dr}] + \text{þ}[\chi'_{dr}] - (\omega-\omega_r)[\chi'_{qr}] \quad (6)$$

Where the flux linkages are expressed as:

$$[\chi_{qs1}] = [L_{ls}].[i_{qs1}] + [L_{lm}].[i_{qs1} + i_{qs2}] + [L_m].[\, i_{qs1} + i_{qs2} + i'_{qr}] \quad (7)$$

$$[\chi_{ds1}] = [L_{ls}].[i_{ds1}] + [L_{lm}].[i_{ds1} + i_{ds2}] + [L_m].[\, i_{ds1} + i_{ds2} + i'_{dr}] \quad (8)$$

$$[\chi_{qs2}] = [L_{ls}].[i_{qs2}] + [L_{lm}].[i_{qs1} + i_{qs2}] + [L_m].[\, i_{qs1} + i_{qs2} + i'_{qr}] \quad (9)$$

$$[\chi_{ds2}] = [L_{ls}].[i_{ds2}] + [L_{lm}].[i_{ds1} + i_{ds2}] + [L_m].[\, i_{ds1} + i_{ds2} + i'_{dr}] \quad (10)$$

$$[\chi'_{qr}] = [L'_{lr}].[i'_{qr}] + [L_m].[\, i_{qs1} + i_{qs2} + i'_{qr}] \quad (11)$$

$$[\chi'_{dr}] = [L'_{lr}].[i'_{dr}] + [L_m].[\, i_{ds1} + i_{ds2} + i'_{dr}] \quad (12)$$

Where, χ_{qs1}, χ_{qs2} are stator q-axis flux linkage components, χ_{ds1}, χ_{ds2} are stator d-axis flux linkage components, χ'_{qr}, χ'_{dr} are rotor q-axis and d-axis flux linkage components, i_{qs1}, i_{qs2} are stator q-axis current components, i_{ds1}, i_{ds2} are stator d-axis current components, i'_{qr}, i'_{dr} are rotor q-axis and d-axis current components, L_{ls} is stator leakage inductance, L_m is air gap inductance, L_{lm} is stator mutual leakage inductance, L'lr is rotor leakage inductance, þ is (d/dt), ω and ωr are synchronous flux and rotor speed, R_s and R_r are stator and rotor resistances, V_{qs1}, V_{ds1}, V_{qs2}, V_{ds2}, V'_{qr} and V'_{dr} are the stator and rotor q-axis and d-axis voltages respectively. The equivalent circuit of DSIG generator in d-q reference frame is shown in Fig. 2.

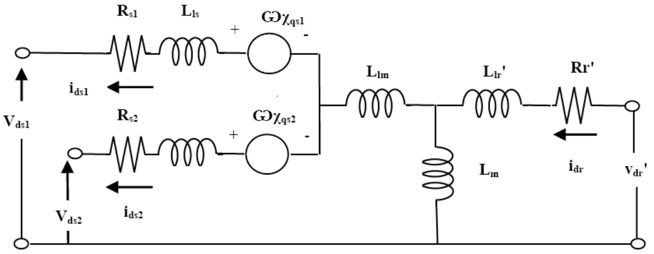


Figure 2 (a): Equivalent circuit in d-axis

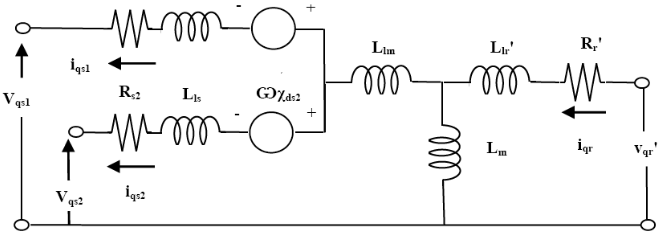


Figure 2 (b): Equivalent circuit in q-axis

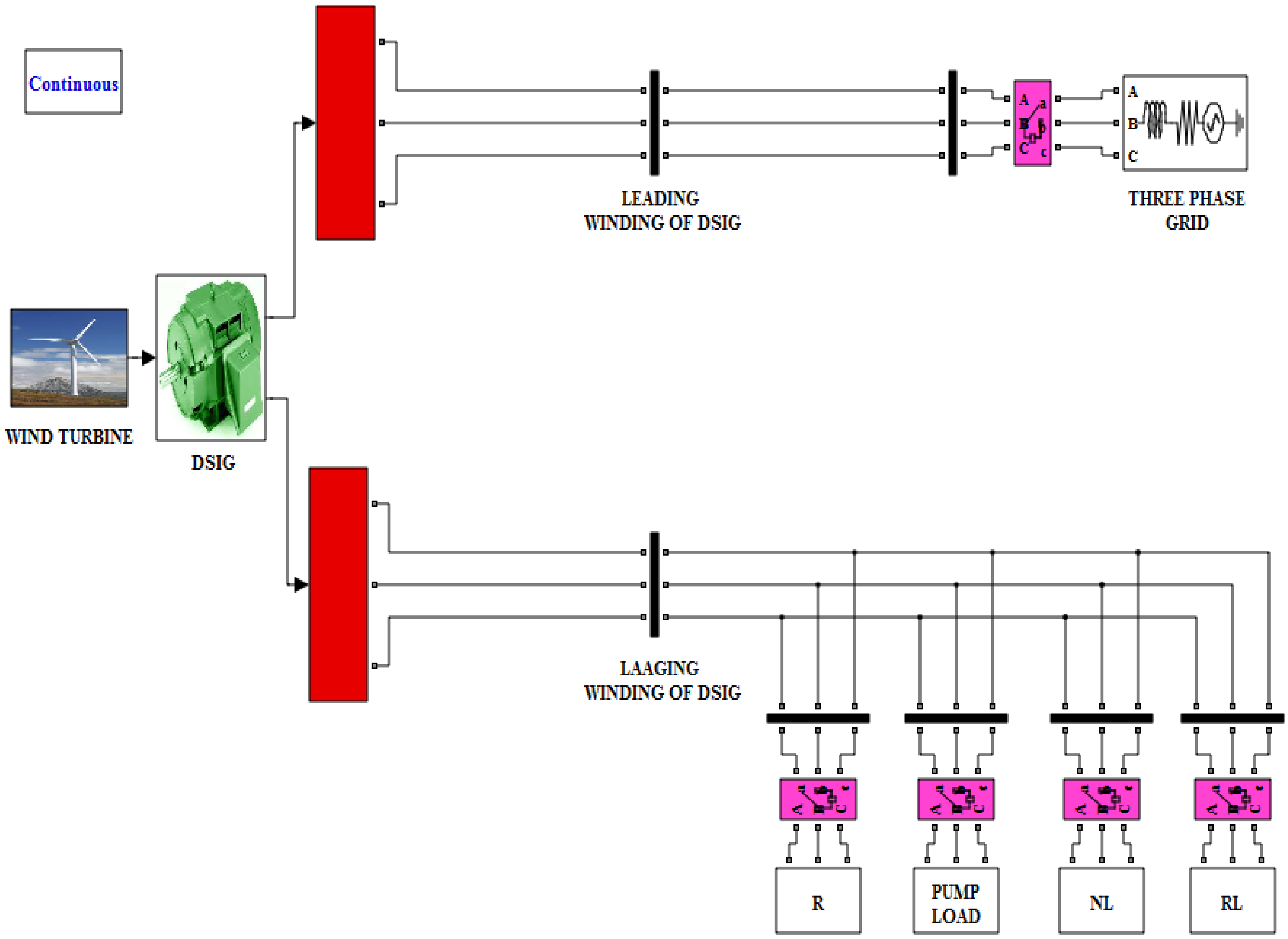


Figure 3: Simulation Diagram of Proposed System

MATLAB MODEL

The considered system is implemented under MATLAB/SIMULINK environment using SimPowerSystem toolbox as shown in Fig. 3. Leading side of DSIG is connected to a weak grid and various loadings are done on lagging side of DSIG. Two three phase stator winding sets act as filter to restrict the proliferation of harmonics to one side of DSIG to the other side of DSIG. Linear resistive load, inductive load, non-linear load and constant power load are applied to lagging side of DSIG and voltage, current; power and harmonic distortion are recorded for furthering the characteristics of DSIG. The details of different loads are given in Table 1.

Table 1: Rating of Different Loads

Type of Load	**R**	**RL**	**NL**	**Pump Load**
Value of Load	**R= 180 Ω**	**Z= 180 Ω (0.8 pf)**	**R= 255Ω, C=50µF**	**1 kW**

PERFORMANCE EVALUATION

DSIG connected to grid on leading winding side and variety of loads connected at the lagging wind side is analyzed in this paper. The analysis is done for seven different conditions pertaining to different wind speed and different types of load as shown in Fig.5 and Fig.6. Apart from Fig.5 and Fig.6 which show the voltage, current profile of grid and load side respectively, Fig. 7-10 show the total harmonic distortion (THD) of voltage and current at both sides of DSIG.

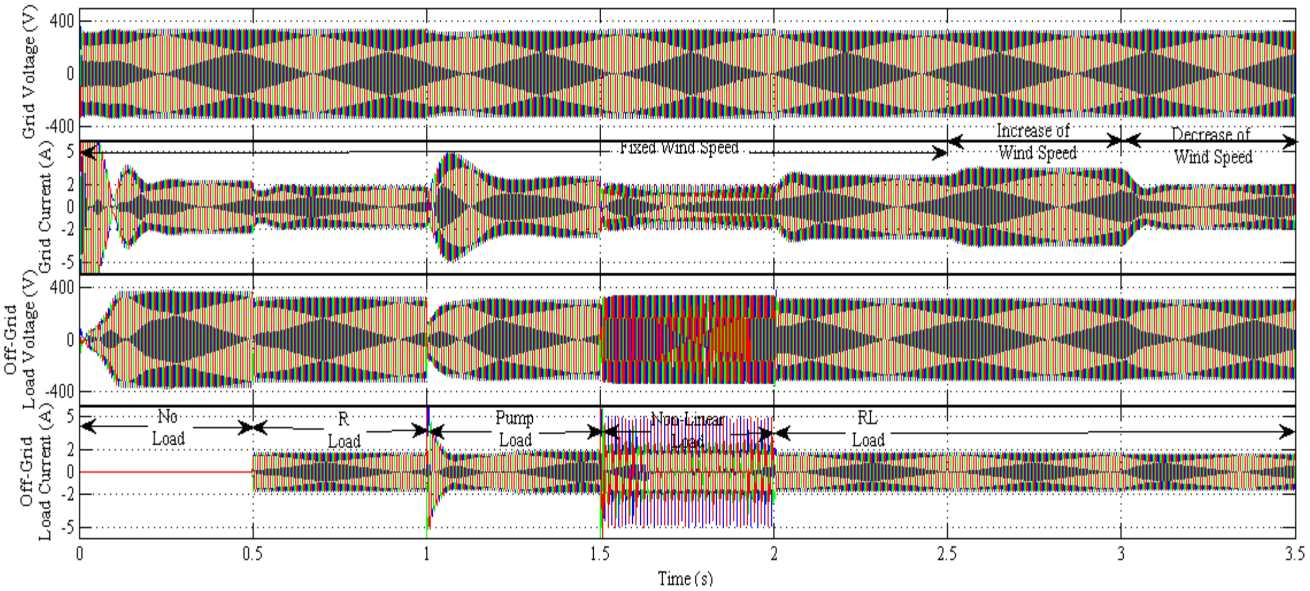


Figure 5: Voltage and Current of Grid and Load connected to both ends of DSIG

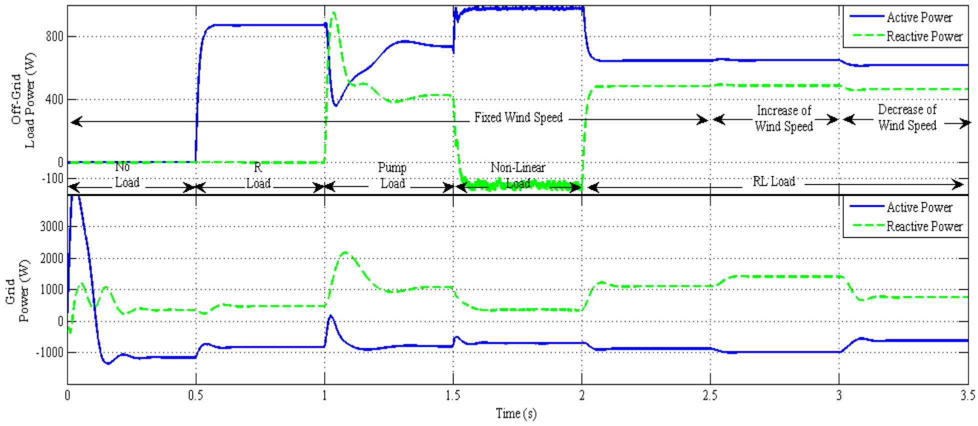
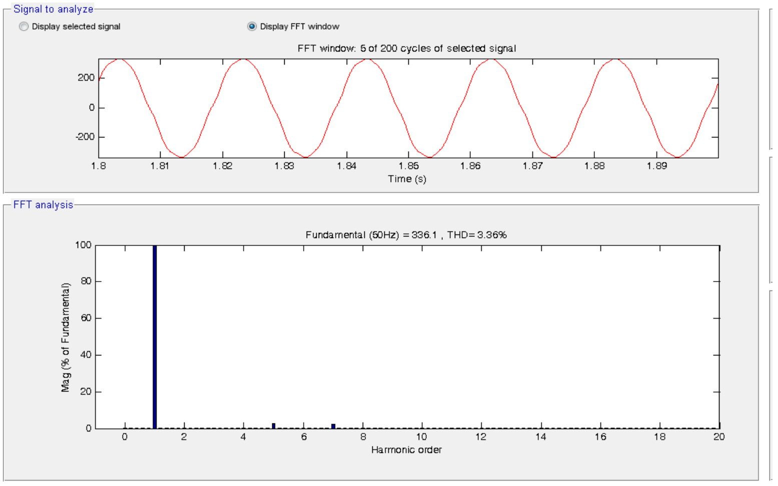


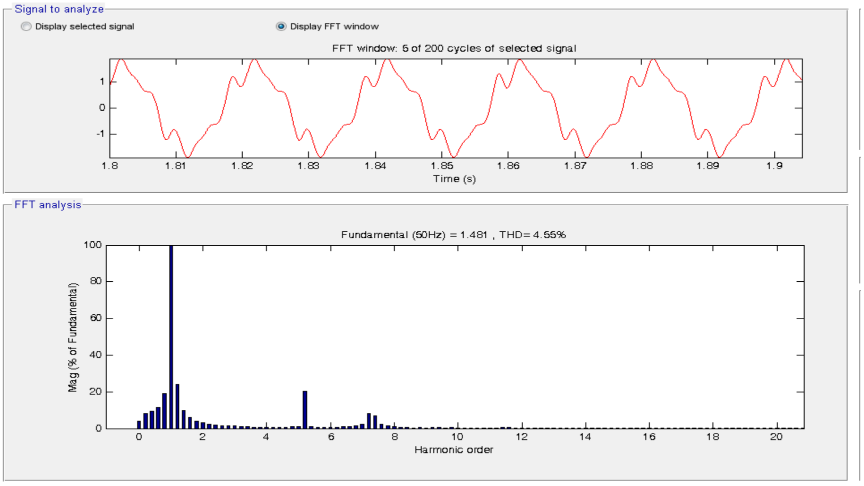
Figure 6: Active and Reactive Power of Grid and Load connected to DSIG



FFT window: 5 of 200 cycles of selected signal

Fundamental (50Hz) = 336.1 , THD= 3.36%

Figure 7: FFT of Grid Voltage when Non Linear Load is connected at off-grid side of DSIG

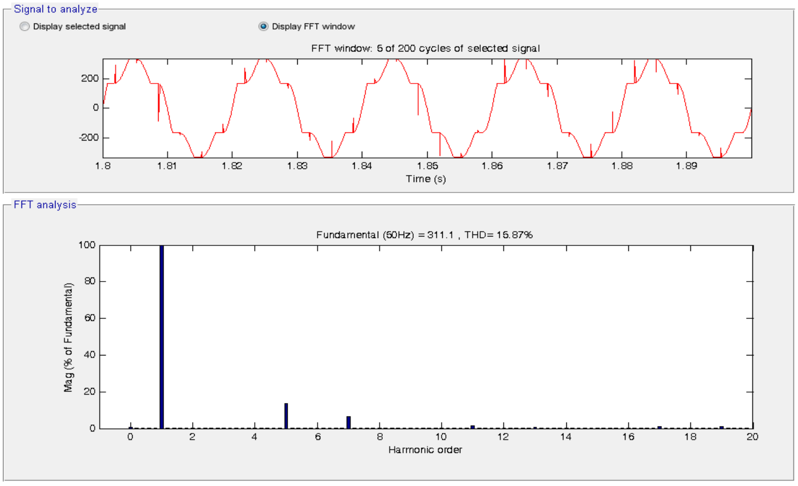


○ Display selected signal ● Display FFT window

FFT window: 5 of 200 cycles of selected signal

Fundamental (50Hz) = 1.481 , THD= 4.55%

Figure 8: FFT of Grid Current when Non Linear Load is connected at off-grid side of DSIG

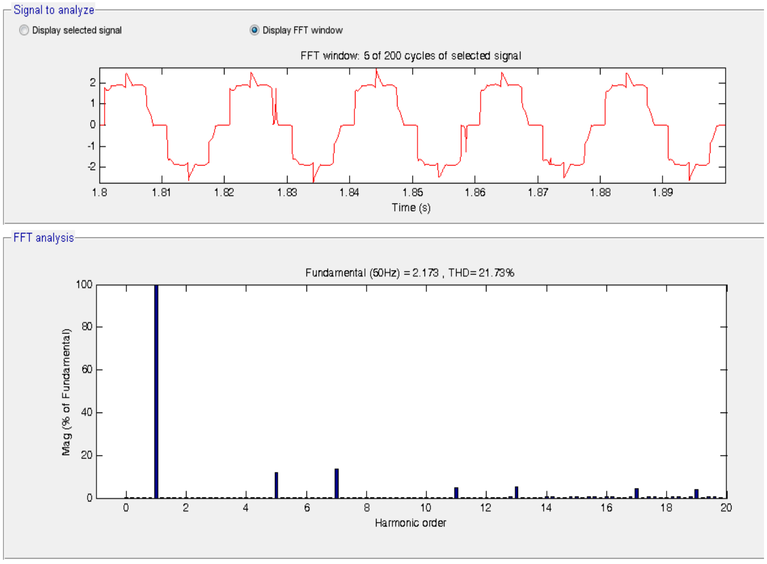


○ Display selected signal ● Display FFT window

FFT window: 5 of 200 cycles of selected signal

Fundamental (50Hz) = 311.1 , THD= 15.87%

Figure 9: FFT of Load Voltage when Non Linear Load is connected at off grid side of DSIG



○ Display selected signal ● Display FFT window

FFT window: 5 of 200 cycles of selected signal

Fundamental (50Hz) = 2.173 , THD= 21.73%

Figure 10: FFT of Load Current when Non Linear Load is connected at off grid side of DSIG

Condition 1: In this condition wind speed is sufficient for enabling the DSIG to generate electrical power and there is no load connected at the lagging winding side. The total active power generated by DSIG is fed to the grid and necessary reactive power is drawn from the grid.

Condition 2: In this condition wind speed remains same as previous and a resistive load of 180 ohms per phase is connected to lagging winding side of DSIG. The total power generated by DSIG is now divided in two portions and after catering to the local load demand the excess active power is fed to the grid. Necessary reactive power is still drawn from grid. Since the load is purely resistive the voltage and current profile are smooth and there is no harmonic distortion at grid side as well as load side.

Condition 3: With the condition of same wind speed driving DSIG and reactive power fed by grid, now the load is changed to pump load of 900 W. There is a dip in off-grid voltage instantaneously but the same recover quickly with no distortion in either voltage or current waveform of either load or grid. The active power left with DSIG after feeding the pump load is fed to grid.

Condition 4: The load is now changed and non-linear loading is applied to DSIG. The load comprises of a diode bridge rectifier feeding to a resistive load with 255 ohm resistance with 50 micro Farad capacitor on its DC bus. Wind speed is same as previous case and requisite reactive power is drawn from grid in this condition also. Due to non-linear load the voltage and current of load get distorted with more than 15 % THD in voltage and 20% THD in current. The winding structure and isolated stator windings of DSIG act as natural filter to restrict the flow of positive sequence harmonics component to the grid side. The FFT analysis of the grid side and off-grid side voltages and currents shown in Fig. 7 -10, depicts that except fifth all other harmonics have been reduced drastically. Table 2 shows the comparative values of THD for voltage and current of both grid and load.

Table 2 Voltage and Current THD with Non Linear Loading

Specification	Voltage THD	Current THD
Grid side	3.36	4.55
Load side (off grid side)	15.87	21.73

Condition 5: Wind speed is again kept constant and change in load condition is made by the application of resistive-inductive load of 0.8 power factor. The change in active and reactive component of power at load side is shown in Fig. 6. There is no distortion in voltage and current at both grid side and load side of DSIG. The remaining generated active power of DSIG after catering to the local load is fed to grid with a demand of necessary reactive power fulfilled by grid.

Condition 6: The loading condition is maintained same as previous one but the wind speed is increased resulting in more generation of active power and more requirement of reactive power by DSIG. Since the load is constant the excess power is fed to the grid, and the grid supplies the increased reactive power demanded for this condition due to increased voltage limited within the prescribed range.

Condition 7: Lastly the wind speed is decreased from in initial value, which was maintained in first five conditions, which shows that there is a decrease in active power generation and also decreases in reactive power demand raised by the DSIG. Since the generation is still more than the load requirement the remaining active power is fed to grid. The voltage and current waveforms are sinusoidal and there is no waveform distortion.

CONCLUSION

In the present scheme DSIG is connected to grid and when wind speed is good enough, i.e. above synchronous speed power is generated at power frequency as the reactive power is always supplied by grid. So this system always works on power frequency and there is no variation of frequency in the system. The total generated power of DSIG is supplied to off-grid side load and remaining to grid. Varieties of loads are applied and show that grid has a least impact of these loads when connected along with DSIG. This scheme is suitable for all those places where overall wind speed is sufficient for generation, thus it can reduce the loading on the grid. In all the modes of operation reactive power demanded by the DSIG is provided by the grid which can be reduced by using local VAR compensators / capacitor banks at either on one side or both sides of the DSIG.

REFERENCES

[1] Sajjad Tohidi, Hashem Oraee, Mohammad Reza Zolghadri, Shiyi Shao and Peter Tavner, “Analysis and Enhancement of Low-Voltage Ride-Through Capability of Brushless Doubly Fed Induction Generator,” *IEEE Trans. Industrial Electronics*, vol. 60, no. 3, March 2013.

[2] Henk Polinder, Frank F. A. van der Pijl, Gert-Jan de Vilder, and Peter J. Tavner, “Comparison of Direct-Drive and Geared Generator Concepts for Wind Turbines,” *IEEE Trans. Energy Conversion*,vol. 21, no. 3, pp. 725-73, September 2006.

[3] N. Budisan, O. Prostean, R. Boraci, I. Szeidert and V. Muller, “The Dual Induction Generator for Renewable Energy Conversion Systems. Experimental Results, Problems and Solutions,” IEEE International Joint Conferences on Computational Cybernetics and Technical Informatics (ICCC-CONTI 2010), Timisora, Romania, May 27-29, 2010.

[4] Shiyi Shao, Teng Long, Ehsan Abdi and Richard A. McMahon, “ Dynamic Control of the Brushless Doubly Fed Induction Generator Under Unbalanced Operation,” *IEEE Trans. Industrial Electronics*, vol. 60, no. 6, June 2013.

[5] Roberto Cárdenas, Rubén Peña, Salvador Alepuz and Greg Asher, “Overview of Control Systems for the Operation of DFIGs in Wind Energy Applications,” *IEEE Trans. Industrial Electronics*, vol. 60, no. 7, July 2013.

[6] Teng Long, Shiyi Shao, Paul Malliband, Ehsan Abdi and Richard A. McMahon, “Crowbarless Fault Ride-Through of the Brushless Doubly Fed Induction Generator in a Wind Turbine Under Symmetrical Voltage Dips,” *IEEE Trans. Industrial Electronics*, vol. 60, no. 7, July 2013.

[7] R.Boraci, M.Babescu, N.Budisan, A.R.Boraci, “Mathematical Model of The Two Orthogonal Three-Phase Windings Stator Generator,” 5th International Symposium on Applied Computational Intelligence and Informatics, Timişoara, Romania, May 28–29, 2009.

[8] Kostyantyn Protsenko and Dewei Xu, “ Modeling and Control of Brushless Doubly-Fed Induction Generators in Wind Energy Applications,” *IEEE Trans.Power Electronics*, vol. 23, no. 3, May 2008.

[9] Feifei Bu, Yuwen Hu, Wenxin Huang, Shenglun Zhuang, and Kai Shi, “Control Strategy and Dynamic Performance of Dual Stator-Winding Induction Generator Variable Frequency AC Generating System With Inductive and Capacitive Loads,” *IEEE Trans.Power Electronics*, vol. 29, no. 4, pp. 1681- 1692, April 2014.