

# Integrating DFIG based wind turbine to the grid With Solid-State Transformer by Replacing the Fundamental Transformer

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April 25, 2018

## Abstract

Wind power is most uncontrollable source and making it to interface with the grid is most challenging one, mainly in terms of permanence and power quality. Mostly the fundamental frequency step-up transformer is used to interface the wind energy conversion system with the grid. Thus the paper proposes a new method of replacing this fundamental frequency transformer by superior solid state transformer (SST) which is a power electronic based device. It provides enhanced operation and system performance by controlling the active power to and from the Rotor side converter(RSC) thereby eliminating the Grid side converter(GSC). Thus simulated results show good quality performance for the projected system.

**Key Words:** Solid-state transformer, doubly fed induction generator, power electronic transformer

## 1 INTRODUCTION

In recent years the renewable energy sources have been playing a vital role in power systems and particularly the wind based energy systems are widely used for energy production process [1]. Nowadays wind turbines which are DFIG based ones are incorporated for wind energy conversion systems due to its adjustable speed generators and its potential to be built economically even for high power levels, which is even off-shore applications[2][3].

Thus the Doubly-Fed Induction generator based wind turbines has a rotor circuit which is connected to a network of back-to-back converter made up of Rotor Side converter (RSC) and Grid Side converter(GSC)[3].

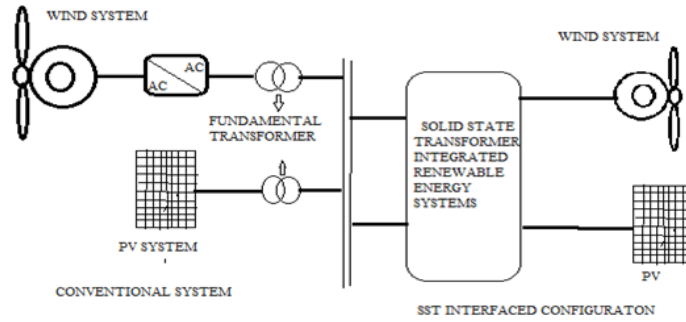


Fig 1. SST interfaced grid

Nowadays power electronics based grid system incorporates this solid state transformer which acts as the major element in the system. [4]-[11].

Fig 1. Shows the system with SST integrated with the grid as mentioned in [4]. Energy crisis for large penetration of renewable energy sources lead to produce the power with regulated voltage and frequency to meet the grid code. Thus SST plays a vital role to provide enhanced performance in grid connected systems[5]-[6]. Moreover the implementation of silicon carbide which uses high voltage in the solid state transformer has been further used and detailed in [7]-[8]. Solid state transformer acts as a emerging technology for future distribution of power in terms of electronics based system which in turn helps in adaptable and controllable form of

network[9]. The grid integrated DFIG based wind turbine is interfaced with the Solid state transformer and conducts the system capability [10]. Thus the proposed system interfaces the grid integrated DFIG based wind turbine with the Solid state transformer thereby enhancing the performance and stability.

## 2 PROPOSED SYSTEM MODELING

### A. Description of the proposed system

The scheme for the proposed network is been illustrated in fig 2(b), whereas the regular structure of DFIG is depicted through the fig 2(a). The projected system shows that the traditional transformer is been modified and replace by an Solid State transformer such that the controller which is nearer to the DFIG is termed as the machine Interface controller(MIC). It is used to eliminate the Grid side controller of the regular DFIG configuration. Therefore the Machine Interface Controller is used to maintain the voltage variations at a constant level on the Grid side. The High frequency stage converters are used to mainly used to control the DC bus which is of low voltage in magnitude. The main objective of this DC bus is to transfer the active power from the stator terminals and from the rotor side controller (RSC) to the grid. Thus to regulate the DC bus voltage a shift in the phases of AC voltages which are of high frequency is been introduced, thus controlling power transfer through the high frequency stage converters. The grid interface controller that is used to connect the system with the grid and provides reactive power support when the generation of the wind goes below the nominal value.

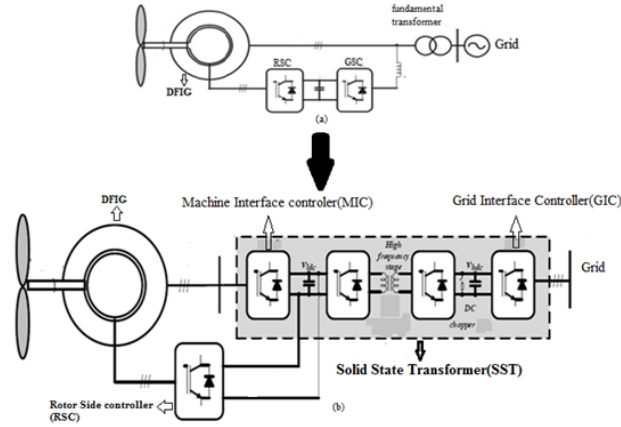


Fig. 2 (a)Representation of the fundamental transformer with the standard DFIG design (b)projected SSTbasedDFIGsystem

### B.DFIG Model

The Doubly Fed induction generator is mostly prevalent due to its variable speed operation with the increasing capacity of wind power plant. Recently the improvement in fault ride through capability problem has become more significant.

$$\lambda_{sd} = L_{ls}i_{sd} + L_m(i_{sd} + i_{rd}) \quad (1)$$

$$\lambda_{sq} = L_{ls}i_{sq} + L_m(i_{sq} + i_{rq}) \quad (2)$$

$$\lambda_{rd} = L_{lr}i_{rd} + L_m(i_{sd} + i_{rd}) \quad (3)$$

$$\lambda_{rq} = L_{lr}i_{rq} + L_m(i_{sq} + i_{rq}) \quad (4)$$

The voltage equations for the stator are given as,

$$V_{sd} = r_s i_{sd} - \omega \lambda_{sq} + \frac{d\lambda_{sd}}{dt} \quad (5)$$

$$V_{sq} = r_s i_{sq} - \omega \lambda_{sd} + \frac{d\lambda_{sq}}{dt} \quad (6)$$

The below equations shows the rotor side voltages at the d and q axis synchronous frame as in [4].

$$V_{rd} = r_r i_{rd} - (\omega - \omega_r) \lambda_{rq} + \frac{d\lambda_{rd}}{dt} \quad (7)$$

$$V_{rq} = r_r i_{rq} + (\omega - \omega_r) \lambda_{rd} + \frac{d\lambda_{rq}}{dt} \quad (8)$$

The machine torque equation can be derived as given below by Using (1)-(7),

$$T = \frac{\lambda_{sd} L_m}{L_s} i_{qr} \quad (9)$$

Thus the system is modeled and designed as per the configurations mentioned in the reference paper [4] such that the machine torque can be controlled by maintaining the stator flux in the d-axis the projected system.

### 3 PROJECTED SYSTEM CONTROL

To control the proposed system in the network the control modules such as Rotor side Controller, Machine interface controller, Grid interface Controller are used in the system thereby eliminating the grid side controller.

### A. Rotor Side Control

This Rotor side control is mainly responsible for the speed variation in the system as shown in fig.(3) thereby tracking the maximum rotor speed and compares it with the measured rotor speed. Thus the difference between the rotor speed is measured and the resultant error is been processed by the PI controller in order to produce the reference torque for the machine. The details pertaining to the rotor side control is as mentioned in [4].

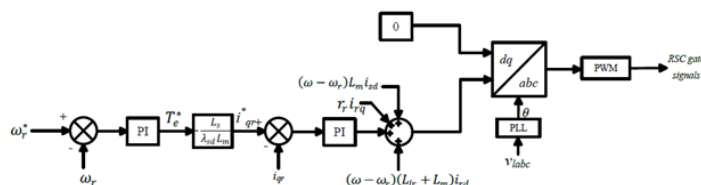


Fig.3 Rotor Side controller

### B. Machine interface controller

The MIC controller as in fig (4) is used to connect the stator terminal to the high frequency stage converters. The generated reference voltage is been compared with the output voltage of the converter thereby achieving the control in the system. A voltage about 5.75kV is produced and maintained constant without any voltage variations.

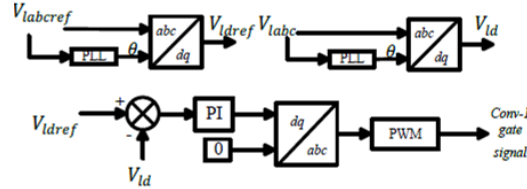


Fig.4 Machine Interface control

### C. Control of High frequency phase

The control of high frequency phase can be used to transform the DC bus which is of low voltage to a DC bus of high voltage by comparing the reference voltage with the voltage that has been measured. Thus the difference in the voltage is obtained as the error value that has been given to the PI controller to produce the required phase shift as in shown in fig(5) mentioned in [11]-[12].

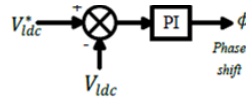


Fig 5. High frequency control

## 4 RESULTS

### D. Grid interface control

The grid interface control as in fig(6) is used to connect the SST with the grid and provides the reactive power support. In this proposed system the reactive power is generated by comparing the obtained value and the reference value that has given to the PI controller to produce the effective result.

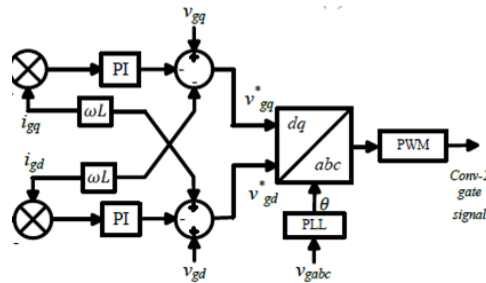


Fig 6.Grid Interface Control

## 5 SIMULATION ANALYSIS OF THE PROJECTED SYSTEM

The projected system is verified by the simulated results and the developed model using SIMULINK and SimPowerSystems tools in the MATLAB. The system parameters for the proposed configuration is given in Table 1. Thus the performance of the system is carried out effectively and the results validate the enhanced controlled operation of the network.

TABLE 1

| S.No | SYSTEM       | PARAMETER                                    | VALUE        |
|------|--------------|----------------------------------------------|--------------|
| 1    | Wind Turbine | Nominal power                                | 1.5KW        |
| 2    |              | Nominal wind speed                           | 15m/s        |
| 3    | Generator    | Nominal apparent power                       | 1.66 MVA     |
| 4    |              | Nominal frequency                            | 50 Hz        |
| 5    |              | Stator to rotor turns ratio                  | 575/1975     |
| 6    |              | Resistance value of stator                   | 0.0023 p.u.  |
| 7    |              | Inductance value of stator                   | 0.18 p.u.    |
| 8    |              | Rotor resistance                             | 0.0016 p.u.  |
| 9    |              | Rotor inductance                             | 0.16 p.u.    |
| 10   |              | Inertia constant                             | 0.685 s      |
| 11   | SST          | Inductance of the High frequency transformer | 5.96 $\mu$ H |

### STATOR VOLTAGE AND CURRENT

Fig.7 Represents the voltage and current at stator, during the operation of the wind turbine at normal condition, thereby producing the constant stator terminal voltage of about 5.75KV. The constant grid current which is produced is about 300A without any deviations.

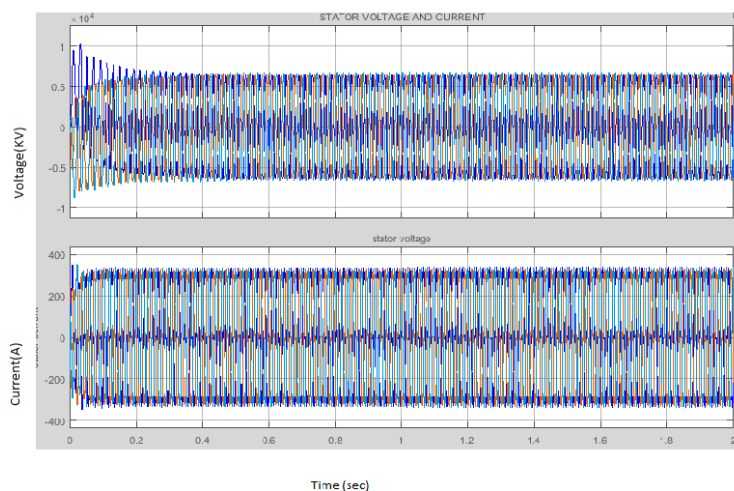


Fig .7 Voltage and Current waveform at Stator

### VOLTAGE AND CURRENT AT GRID

The proposed configuration is simulated and the fig(8) shows the voltage and current waveform of grid, during the operation of wind turbine thereby producing about 25kV and 200A of constant voltage and current. This shows that the system efficiency is increased with producing stable values without any deviations.

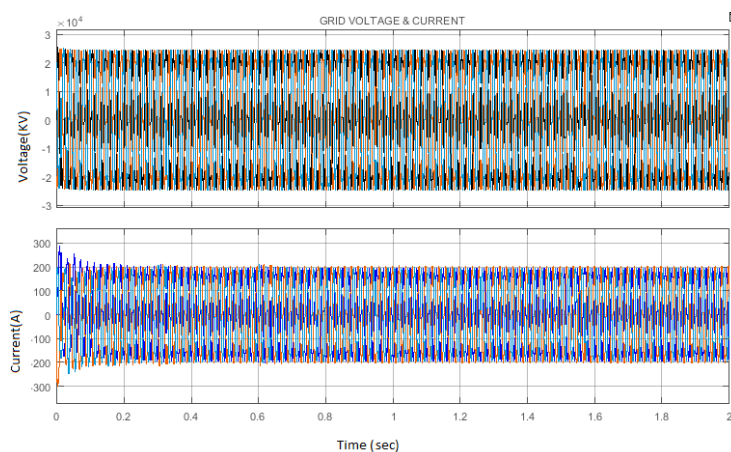


Fig.8 Grid voltage and current waveform

### REAL AND REACTIVE POWER

In the proposed configuration the wind turbines produce a total active power of about 450kW as in the fig(9).It also has the ability of reactive power support as in fig (10)when the generation of the wind turbine goes below the nominal value that is during lower wind speed of 13m/s and at about 4 , the reactive power is supplied at about 15Mvar.

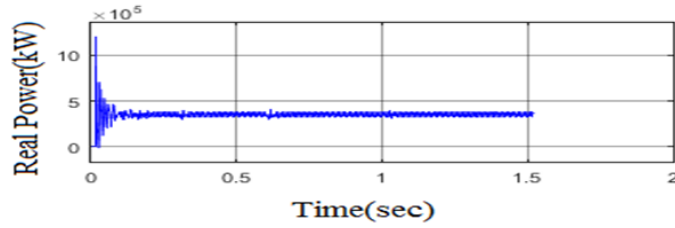


Fig 9 Real power

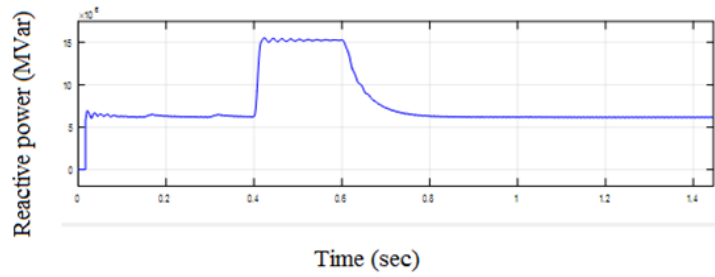


Fig 10 Reactive power

## 6 Conclusion

Thus the system is simulated for the proposed configuration that allows the integration of SST with the Grid connected DFIG based system. It is more advantageous than the conventional transformer such that it is smaller in size, improves the power quality with harmonic isolation and has the capability to maintain a constant output. Therefore the significance of the proposed configuration is to interface the grid connected DFIG based system through SST by replacing the conventional transformer. Since the MIC is used to regulate the active power to and from the RSC, the GSC is eliminated

## References

- [1] Global Wind Report, Annual market update, 2014, Global Wind Energy Council.
- [2] S. Muller, M. Deicke, R. W. De Doncker, Doubly fed induction generator systems for wind turbines, *IEEE Ind. App. Mag.*, vol. 8, no. 3, pp.26-33, May/Jun. 2002.
- [3] R. Pena, J. Clare, and G. Asher, Doubly fed induction generator using back-to-back converters and its application to variable-speed wind-energy generation, in *Proc. Inst. Electr. Eng. Elect. Power Appl.*, vol.1 43, no. 3, pp. 231241, May 1996.
- [4] X. She, A. Q. Huang and R. Burgos, Review of Solid-State Transformer Technologies and Their Application in Power Distribution Systems, *IEEE J. Emerg. Sel. Topics Power Electronics*, vol. 1, no. 3, pp. 186-198, Sept. 2013.
- [5] J. L. Brooks, Solid State Transformer Concept Development, Naval Material Command, Civil Engineering Laboratory, Naval Construction Battalion Ctr., Port Hueneme, CA, 1980.
- [6] X. She, X. Yu, F. Wang and A. Q. Huang, Design and Demonstration of a 3.6-kV120-V/10-kVA Solid-State Transformer for Smart Grid Application, *IEEE Trans. Power Electron.*, vol. 29, no. 8, pp. 3982- 3996, Aug. 2014.
- [7] S. Madhusoodhanan, A. Tripathi, D. Patel, K. Mainali, A. Kadavelugu, S. Hazra, S. Bhattacharya, K. Hatua, Solid-State Transformer and MV Grid Tie Applications Enabled by 15 kV SiC IGBTs and 10 kV SiC MOSFETs Based Multilevel Converters, in *IEEE Trans, Ind. App.*, vol. 51, no. 4, pp. 3343-3360, July-Aug. 2015.
- [8] Fei Wang, Gangyao Wang, A. Huang, Wensong Yu, Xijun Ni, Design and operation of A 3.6kV high performance solid state transformer based on 13kV SiC MOSFET and JBS diode, in *Proc. IEEE Energy Conversion Congress and Exposition (ECCE)*, Sept. 2014.

- [9] Y. Jie, Z. Wu and S. Bhattacharya, Power dispatch strategy in microgrid integrated with solid state transformer, in Proc. IEEE Power Eng. Soc. Gen. Meeting, 2013, pp. 1-5.
- [10] Imran Syed, VinodKhadkikar, Replacing the Grid Interface Transformer in Wind Energy Conversion System With Solid-State Transformer, IEEE Trans. Ind. Electron., vol. 32, pp. 2152 - 2160, May 2017.
- [11] G.G. Oggier, R. Leidhold, G. O. Garcia, A. R. Oliva, J. C. Balda, F. Barlow"Extending the ZVS Operating Range of Dual Active Bridge High-Power DC-DC Converters," Power Electronics Specialists Conference, 2006. PESC '06. 37th IEEE, Jeju, 2006, pp. 1-7.
- [12] G. G. Oggier, G. O. Garca and A. R. Oliva, "Switching Control Strategy to Minimize Dual Active Bridge Converter Losses," IEEE Trans. Power Electron. , vol. 24, no. 7, pp. 1826-1838, July 2009.
- [13] X. She, A. Q. Huang, F. Wang and R. Burgos, Wind Energy System With Integrated Functions of Active Power Transfer, Reactive Power Compensation, and Voltage Conversion, IEEE Trans. Ind. Electron., vol. 60, no. 10, pp. 4512-4524, Oct. 2013.
- [14] E.ONNetz GmbH., Bayreuth, Germany, Grid codeHigh and extra high voltage, Apr. 2006.
- [15] J. E. Huber, J. W. Kolar, Volume/weight/cost comparison of a 1 MVA 10 kV/400 V solid-state against a conventional low-frequency distribution transformer, in proc. IEEE Ener. Conv. Cong. and Expo. (ECCE), pp. 4545-4552, Sept. 2014.