Application of Solid State Transformer in DFIG Based Wind Energy Conversion System

Geethanjali.S, S.Shanmugapriya, M.Arvind, B.Srinath, S.Aadhithya

Abstract— In wind energy systems the central frequency transformer goes about as a key component between the WECS and the grid As of late there have been endeavors to supplant this transformer by a power electronics based solid state transformer This paper aims to provide a setup that incorporates the doubly fed induction generator based wind energy conversion system and Solid state transformer operation The principle target of the proposed setup is to combine the turbine with the grid while giving upgraded efficiency and performance .In this configuration SST controls the real power flow to/from the rotor side converter therefore taking out the grid side converter. The proposed framework meets the ongoing grid code necessities of wind turbine activity under fault conditions A definitive simulation is done in MATLAB to approve the execution of the proposed configuration and a prototype of the setup is also built.

Keywords-WECS, SST

I. INTRODUCTION

Wind power generation in India has grown rapidly with national installed capacity increasing from 7850 MW in 2006-07 to 34046 MW in 2017-18 [1]. The requirements differ between countries and their severity mostly depends on the wind power penetration level. Amongst the many methods that exist for harnessing wind energy through WECS, doubly fed induction generators (DFIG) have been used widely due to its ability to operate in varied speeds, its power density being high and lower cost when compared to other methods.

The stator terminals of the DFIG is connected directly to the grid and the rotor is connected to the grid by means of two back to back converters known as the Rotor side(RSC) and the grid side converter(GSC). The operating range of the DFIG is 500-700 V while the grid’s range is 11-33kV. To interface the DFIG and the grid, we use a fundamental frequency step up transformer to step up the DFIG output to the grid’s levels.

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As of recent times, interest in using solid state devices as an alternative for the fundamental frequency transformer is increasing. This is due to the fact that the SST uses a series of power electronic devices to achieve voltage conversion. The advantages of using this method include increased power quality, fault tolerance and lesser size when compared to the existing setup.

In this paper, another setup is recommended that consolidates the activity of DFIG based WECS and SST. This design goes about as an interface between the wind turbine and the grid while dispensing with the GSC of Doubly fed induction generator. Also, it is necessary to have fault ride through (FRT) included in DFIG framework to meet the grid code requirements. In this configuration, the created design permits DFIG to ride through faults flawlessly, which is the viewpoint (FRT)that has not been incorporated in the previous work on SST interfaced WECS.

Grid code requirements have been important for the improvement of wind turbine innovation Makers in the wind energy segment are continually attempting to improve wind turbines chiefly in the region of wind turbine control and electrical framework configuration so as to meet the grid code requirements This can frequently suggest greater expenses as further developed power electronic plans and progressively advanced control systems must be used. Simulation analysis are performed to study the characteristics of the wind turbines that are equipped with doubly-fed induction generators (DFIGs) during severe voltage dips due to the faults in the grid.

II. REGULAR DFIG CONFIGURATION

It has been accounted for in [2] that a wind turbine which uses DFIG is the least in weight among the present wind frameworks which too clarifies its wide business use.

The commonly used Doubly fed induction generator based wind energy conversion system configuration is depicted in Fig 2 a The DFIG's stator side terminals are connected to the grid through a step up transformer and the rotor side terminals of the DFIG are connected through back to back converters called as the rotor and grid side converters The RSC allows the machine to be operated in varying speed operation of the DFIG by supplying or absorbing real power from the rotor of DFIG. The GSC maintains the DC link which transfers the active power from rotor to grid or grid to rotor The regular step up transformer acts as the interface between the Doubly fed induction generator and grid

III. PROPOSED SYSTEM CONFIGURATION

A. Solid state transformer

The three phase SST layout is depicted in Figure 2 .The grid is connected to a load by means of power electronic devices Converter 1 is a completely controlled 3φ converter connected with the grid which draws actual power from the grid and keeps up the HVDC bus which is then changed over to AC voltage by means of a half bridge converter called HB 1 which is then stepped down utilizing a low sized transformer The AC voltage is converted to DC voltage by another half bridge converter called HB 2 So the configuration along these lines plays out the capacity of an ordinary transformer taking into account two way power flow utilizing a arrangement of power electronic devices [3-5]

B. System Description

The proposed configuration is depicted in fig The SST replaces the conventional step up transformer in the The low voltage AC input from the DFIG is converted to DC by the MIC which is responsible for transfer of real power from the stator side terminals of DFIG to the *Vldc* The required stator voltages is also maintained by the MIC .The machine interface converter MIC performs the function of GSC thus eliminating it from proposed system The comprehensive operation and control of regular GSC RSC based DFIG system is modified in this new configuration Therefore in principle regardless of any change in voltage in the grid the machine side terminal voltages can be maintained constant using the MIC. The *Vldc* transfers the real power to the grid It also transfers the real power to and from the RSC depending upon the operating conditions of RSC This *Vldc* bus is synchronized using the half bridge converters HB1 and HB2 Moreover the magnitude of the *Vldc* bus is approximately close to that of maintained by the GSC in the regular DFIG system.

The HB1 converts the DC voltage into AC voltage and transfers it to the High frequency stage. The high frequency stage steps up the low voltage AC into high voltage AC. The power transfer from *Vldc* to *Vhdc* is controlled by the high frequency stage by introducing a phase shift. This is done in order to regulate the low voltage DC bus. The HB2 converts the high voltage AC to DC and transfers it to the *Vhdc.*

A DC chopper is introduced in *Vhdc* bus to incorporate an adequate FRT in the new system. When a fault occurs in the grid, the generated power from the wind turbine is evacuated into the DC chopper through the high frequency stage. The high frequency stage controls the *Vldc* bus which in turn keeps the machine side terminals voltages constant. The Grid interface converter(GIC) again converts the DC to AC and assists in achieving the reactive current injection needed to satisfy grid code requirements. Moreover during the low wind periods the GIC will distribute reactive power support to the grid.

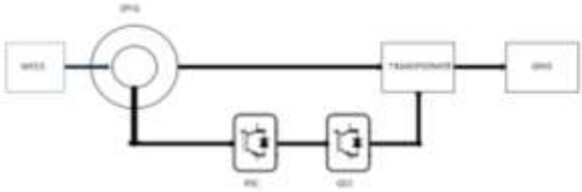

Fig 1. Regular DFIG configuration

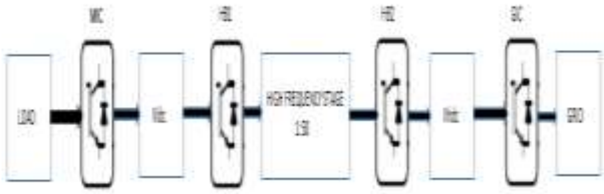

Fig.2. SST configuration

Rotor side converter(RSC):

The variable speed operation of DFIG is performed by the RSC allowing the generator to either operate in super synchronous or sub synchronous conditions The total power created is partly evacuated through the RSC in super synchronous mode The active power during sub synchronous mode is injected into the rotor by RSC.

Machine Interface Converter(MIC):

This is the first stage in SST which connects the DFIG's low voltage output to the high frequency stage. It maintains 0.575 kv at the stator terminals of the DFIG. The MIC helps in transferring the real from the DFIG to grid by sending it to the low voltage DC bus. The rated stator voltages are maintained constant by the MIC however may the severity of fault may be.

High Frequency Stage:

In this stage the voltage is stepped up to high voltage and the conversion of DC-AC and AC-DC is achieved by the two half bridge converters(HB1 and HB2). Between the two AC voltage of the half bridge converters a phase shift is introduced in order to transfer the real power by a high frequency transformer. Another main purpose of this stage is to constantly maintain the low voltage DC bus(*Vldc).*

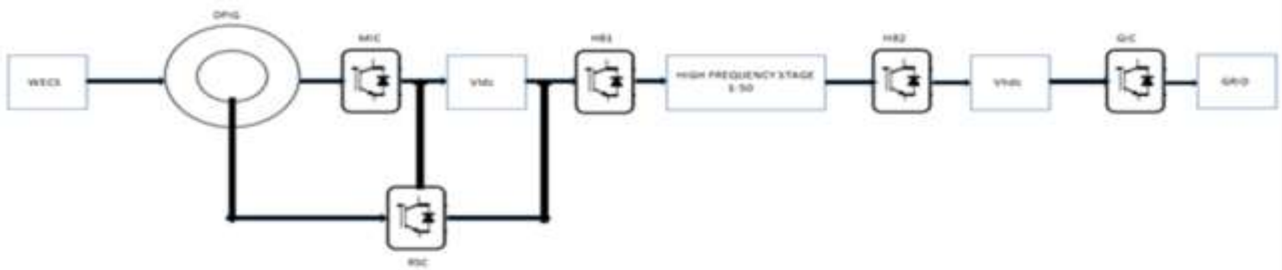

Fig.3.Proposed system configuration

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Grid interface converter(GIC):

GIC converts the stepped up DC voltage to AC voltage and sends it to the grid. The GIC unlike other converters is operated in two conditions:

Normal conditions:

The main objective of the GIC in normal conditions is to make sure the active power produced from the machine is sent to the grid. Also the GIC can provide reactive power support when the wind generated is lower than its rated value.

Fault conditions:

Under Fault conditions the main objective of the GIC is to provide reactive currents depending upon the severity of the fault and as per the grid codes.

When the fault is not that severe and the voltage dip is not more than 1 p.u. the active power can be injected into the grid as per the grid codes[6-7]. Whenever a fault occurs, if the active power can be controlled immediately, then the need of reactive power becomes less after the fault is cleared and helps in restoring the grid voltage. During a fault, the system goes into the low voltage period and the active power generation is reduced by the control system. After identifying the severity of fault, a DC chopper is employed to prevent the DC bus voltage from increasing.

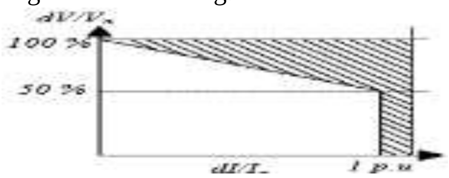

Fig .4 Reactive power requirement

IV. SIMULATION ANALYSIS AND RESULTS

A detailed simulation is carried out for the proposed configuration in SIMULINK toolbox in MATLAB. System parameters are given below.

System data:	
Rated power	5 MVA
Number of wind turbines	3
Rated power of turbine	1.5 MW
Wind speed	15 m/s
Rated apparent power of Generator	1.66 MVA
Rated Voltage of Generator	0.575 KV
Number of poles	6
Rated frequency of Generator	50Hz
Turns ratio of Stator to rotor	575/1975
Resistance of Stator	0.0023 p.u
Inductance of Stator	0.18 p.u
Resistance of Rotor	0.16 p.u
Inertia constant	0.685 s
Lvdc bus	1.15 KV
Operating frequency of SST	3 KHz
turns ratio of HF transformer	1:50
Inductance of HF transformer	5.95μH
Hvdc bus	50KV

The proposed system is performed in different conditions.

A. Normal Operation:

At first operation in normal grid condition is depicted in fig 4.2MW total real power is produced by the wind turbines. Like the conventional DFIG system, the proposed system here transfers active power to the grid shown in via the SST. During normal conditions the GIC does not provide reactive power support as there is no fault in the grid. In both the stator and grid in Fig.4 and Fig.5 there is no change in voltages and current as there is no fault occurring.

B. Fault operation:

A severe 3 phase LLL-G is introduced at 0.4-0.6s. The fig.7 shows the stator voltages and currents in fault conditions. The output of the stator voltage is 0.575 KV. As we can see there is no change in operating conditions of the turbine because the MIC constantly maintains the stator voltages in spite of severe fault conditions. The fig.6 shows the grid voltages drops to zero during fault. The grid voltage during pre-fault and post fault is 25 KV The fig shows the grid current being injected by the GIC. The GIC injects necessary grid currents depending upon the grid code requirements. So in the proposed system the turbines flawlessly ride through the fault. If in case of a less severe L-G fault the reactive power required would be less as major amount of active power is sent to the grid because of less severity in fault.

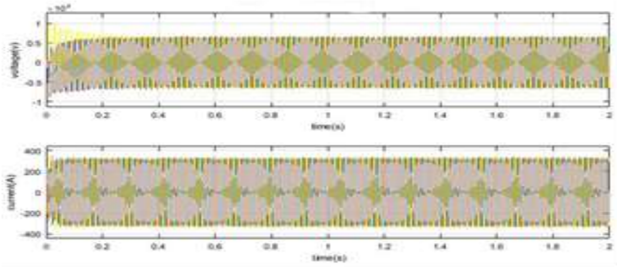

Fig.5 Normal conditions: Grid voltage and current

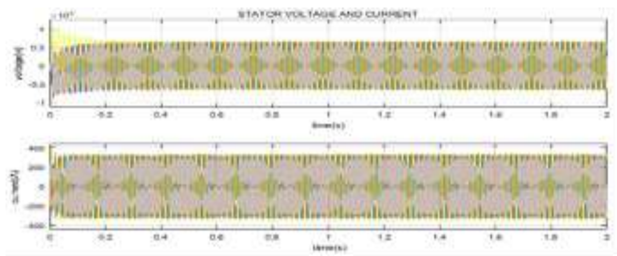

Fig.6 Normal conditions: Stator voltage and current

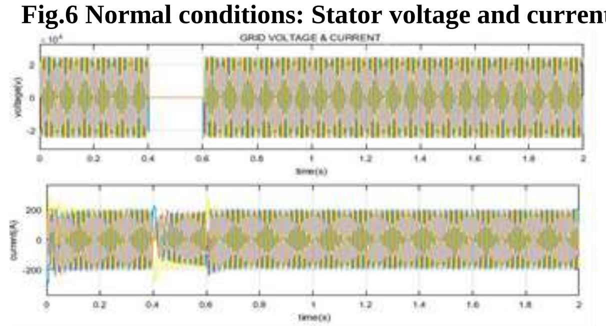

Fig.7 Fault conditions: Grid voltage and current

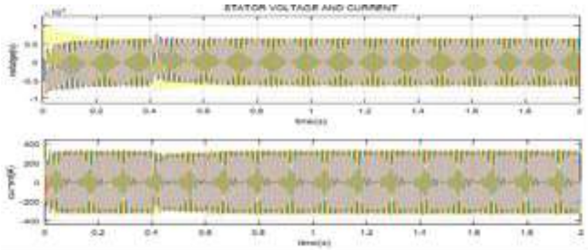

Fig. 8 Fault conditions: Stator voltage and current

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V. PROTOTYPE

A prototype of the proposed system configuration is built. The components used in the prototype are as follows

- PIC16F877a microcontroller
- Toggle switch and LED for identification
- 2X 500Ma Transformer (12-15 V)
- 2X 1A Transformer (12-15 V)
- 1X 400mA Transformer (30-40 V)
- 8x TLP250 driver circuit
- 8X 1000Ω resistors
- 7X 330 Ω resistors
- 8X 100Ω resistors
- 8X 470µF capacitors
- 16X IRF840 MOSFET
- 1X 1000µF capacitor
- Fusing resistor
- Inductor
- 230V 50Hz tube light choke
- Multi meter

A. Elements

The prototype is a combination of various different elements and the complete integration of these elements make it a working prototype. Let us discuss these elements in detail.

I. PIC16F877a :

The PIC microcontroller serves as a pulse generator for the driver circuit. It has 5 ports(A-E) and 3 timers (one 16 bit and two 8 bit timers). It allows both serial and I2C protocol. It has an input supply of 5V to Pin 1(Master Clear). It has 40 pins in which pin 1 and 11 are connected to the 5V supply. A 10K ohms resistor is connected between pin 1 and the supply. For frequency purposes a crystal oscillator of range 4-40MHz is connected to pins 13 and 14. Pins 36,39,40 are connected to the programmer through which we can dump the code to generate input pulse for the driver circuit. This is then passed through a 7805 voltage regulator which will ensure regulated voltage supply for the driver circuit. A toggle switch is connected to the PIC circuit which will introduce a phase shift to the pulse generated.

Fig.9 Pic 16f877a microcontroller

II. TLP250 driver circuit

The TLP250 driver circuit amplifies the supply voltage to required level for the Solid State transformer. It is used to drive the MOSFET circuits. The output of the converters in the SST in mainly dependent on the behavior of the gate driver circuits. The advantage of TLP250 when compared with other driver circuits is that it is optically isolated i.e. the input and the output is isolated from each other. So any changes in input voltage will not affect the output.

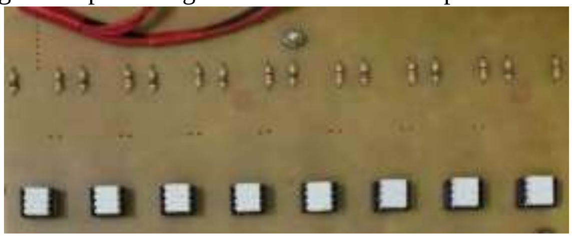

Fig 10. TLP 250

III. RC Snubber Circuit

They are the energy absorbing circuits which absorbs voltage spikes due to the inductance of circuit when the switch is open We have a resistor and a capacitor of 100 Ω and 470 µF connected in series across the switch. It also prevents any reverse current from the grid from affecting the driver circuit's operation.

Fig.11 RC Snubber circuit

IV. Solid State Transformer

Each converter of the solid state transformer is a combination of four MOSFETs (IRF840). The pulse coming from the driver circuit is passed on to these MOSFETs. The first four IRF840s act as the Machine Interface converter. It acts as a AC-DC converter. The output from the MIC is sent to the half bridge converter 1 which is denoted by the next four IRF840s.This acts as a DC-AC converter and its output is given to a 400Ma 30-40V transformer which steps up the voltage. This stepped up voltage is then sent to the second half bridge converter which is denoted by the next four IRF840s. The HB-2 acts as a AC-DC converter and the DC output is sent to the Grid Interface converter through the DC link capacitor (1000µF). The DC link capacitor provides constant DC supply to Grid Interface converter irrespective of the output from the half bridge converter 2. The Grid Interface converter which is denoted by the last four IRF840s acts as a DC-AC converter which provides supply to the grid.

The combination of a fusing resistor and an inductor serves as the grid for the prototype. The output voltage of the grid is usually in the range of 40-50V.It is connected to a tube light choke which acts as a RL load. This is done to introduce a fault in the system.

Under fault condition voltage load using a multi meter gives a value of 30-37V and at the grid it gives a value of 45V.

Further the toggle switch is switched on for a while to to compensate the load voltage which matches the grid voltage.

Fig.12 Solid state transformer

The AC supply given to the circuit is 230V which is stepped down to 5V using a step down transformer. This 5V serves as the supply for the PIC microcontroller

VI. CONCLUSION

In this paper a new configuration is proposed where the operation of DFIG and SST is combined. In the conventional system without FRT technique the value of the grid and rotor current shows a significant increase of up to 4 times the rated value. The DC link voltage between the RSC and GSC increases upto almost twice the rated value. This high voltage damages the switches of the RSC while the high current may damage the machine. In the proposed system the machine is shown to flawlessly ride through the fault. Moreover, the voltages of the DC bus are maintained at a constant value and currents in the grid and rotor side are not affected during a fault. An additional feature in this configuration is that it has the ability to inject necessary reactive currents during fault conditions.

REFERENCES

1. 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
2. R. Pena, J. Clare, and G. Asher, “Doubly fed induction generator using back-to-back converters and its application to variable-speed windenergy generation,” in Proc. Inst. Electr. Eng.—Elect. Power Appl., vol.1 43, no. 3, pp. 231–241, May 1996
3. 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
4. J. L. Brooks, “Solid State Transformer Concept Development,” Naval Material Command, Civil Engineering Laboratory, Naval Construction Battalion Ctr., Port Hueneme, CA, 1980
5. X. She, X. Yu, F. Wang and A. Q. Huang, “Design and Demonstration of a 3.6-kV–120-V/10-kVA Solid-State Transformer for Smart Grid Application,” IEEE Trans. Power Electron., vol. 29, no. 8, pp. 39823996, Aug. 2014.
6. J. M. Aga, H. T. Jadhav, “Improving fault ride-through capability of DFIG connected wind turbine system: A review,” in Proc. Int Conf. on Power, Ener. And Control, pp. 613-618, Feb. 2013
7. A. H. Kasem, E. F. EI-Saadany, H. H. EI-Tamaly, and M. A. A.Wahab, “An improved fault ride-through strategy for doubly fed induction generator-based wind turbines,” IET Ren. Power Gen., vol. 2, no. 4, pp. 201–214, Dec. 2008
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. J. M. Aga, H. T. Jadhav, “Improving fault ride-through capability of DFIG connected wind turbine system: A review,” in Proc. Int Conf. on Power, Ener. And Control, pp. 613-618, Feb. 2013.
11. A. H. Kasem, E. F. EI-Saadany, H. H. EI-Tamaly, and M. A. A.Wahab, “An improved fault ride-through strategy for doubly fed induction generator-based wind turbines,” IET Ren. Power Gen., vol. 2, no. 4, pp. 201–214, Dec. 2008.
12. L. G. Meegahapola, T. Littler, D. Flynn, “Decoupled-DFIG Fault Ride-Through Strategy for Enhanced Stability Performance During Grid Faults,” IEEE Trans. Sust. Energy, vol. 1, no. 3, pp. 152-162, Oct. 2010.
13. S. Hu, X. Lin, Y. Kang, and X. Zou, “An improved low-voltage ride through control strategy of doubly fed induction generator during grid faults,” IEEE Trans. Power Electron., vol. 26, no. 12, pp. 3653– 3665,Dec. 2011.
14. P. Kanjiya, B. B. Ambati, V. Khadkikar, “A Novel Fault-Tolerant DFIG-Based Wind Energy Conversion System for Seamless Operation During Grid Faults,” IEEE Trans. Power Sys., vol. 29, no. 3, pp. 12961305, May 2014
15. J. Lopez, P. Sanchis, X. Roboam, and L. Marroyo, “Dynamic behavior of the doubly fed induction generator during three-phase voltage dips,” IEEE Trans. Energy Convers., vol. 22, no. 3, pp. 709–717, Sep. 2007.
16. C. Wessels, F. Gebhardt, and F. W. Fuchs, “Fault ride-through of a DFIG wind turbine using a dynamic voltage restorer during symmetrical and asymmetrical grid faults,” IEEE Trans. Power Electron., vol. 26, no. 3, pp. 807–815, Mar. 2011
17. P. Flannery and G. Venkataramanan, “A fault tolerant doubly fed induction generator wind turbine using a parallel grid-side rectifier and series grid-side converter,” IEEE Trans. Power Electron., vol. 23, no. 3, pp. 1126–1135, May 2008.
18. S. Seman, J. Niiranen, and A. Arkkio, “Ride-through analysis of doubly fed induction wind-power generator under unsymmetrical network disturbance,” IEEE Trans. Power Syst., vol. 21, no. 4, pp. 1782–1789, Nov. 2006
19. J. López, E. Gubía, E. Olea, J. Ruiz, and L. Marroyo, “Ride throughof wind turbines with doubly fed induction generator under symmet-rical voltage dips,”IEEE Trans. Ind. Electron.
20. D. Xiang, L. Ran, P. J. Tavner, and S. Yang, “Control of a doubly-fedinduction generator in a wind turbine during grid fault ride-through,”IEEE Trans. Energy Converters.