Themed Section : Engineering and Technology
© 2018 IJSRSET | Volume 5 | Issue 3 | Print ISSN: 2395-1990 | Online ISSN : 2394-4099

Eliminating Grid Side Converter and Using Solid State Transformer In Wind Energy Conversion System

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ABSTRACT

In wind energy conversion systems, the fundamental frequency step-up transformer acts as a key interface between the wind turbine and the grid which creates the power losses in the system. Recently, there have been efforts to replace this transformer by an advanced power electronics based solid-state transformer (SST). This paper proposes a configuration that combines the doubly fed induction generator (DFIG) based wind turbine and SST operation. The main objective of the proposed configuration is to interface the turbine with the grid while providing enhanced operation and performance. In this work, SST controls the active power to/from the rotor side converter (RSC), thus, eliminating the grid side converter (GSC). The proposed system meets the recent grid code requirements of wind turbine operation under fault conditions. Additionally, it has the ability to supply reactive power to the grid when the wind generation is not up to its rated value. A detailed simulation study is conducted to validate the performance of the proposed configuration.

Keywords : Solid State Transformer ,doubly fed induction generator ,power electronic transformer ,fault ride through.

I. INTRODUCTION

Over the last decade, the penetration of renewable energy sources has been increasing steadily in the power system. In particular, wind energy installations have grown rapidly with global installed capacity increasing from 47.6 GW in 2004 to 369.6 GW[2]. Amongst the many technologies that exist for wind energy conversion systems (WECS), doubly fed induction generators (DFIG) have been prevalent due to variable speed operation[1], high power density and lower cost. DFIG based WECS consist of an induction generator whose stator is directly connected to the grid while its rotor is connected via back to back converters known as the rotor side converter (RSC) and grid side converter (GSC), respectively.

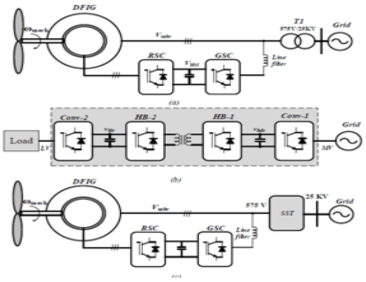


FIG:DFIG with RSC and GSC

The generator is normally operated at a range of 500 V- 700 V and is connected to the transmission network (11-33 kV) through a transformer that acts as an integral part of the WECS to interface the wind turbine and the grid.[5] Recently, there has been much interest in developing an alternative to the traditional fundamental frequency transformer using solid-state devices. The solid-state transformer (SST) achieves voltage conversion through a series of power electronics devices while offering multiple advantages, such as, smaller size, improved power quality and fault tolerant features.

A power distribution system based on SST advanced in solid state technology have made SST more liable today leading to increased research in feasibility and physical realization.

A promising 10 KVA prototype has been developed and presented further the use of high voltage silicon carbide power devices for SST has been explored and presented.SST can act as a interface between the grid and generation sources. However research showing the detailed configuration for integrating existing technologies is limited[7]. Here work is reported on using SST in a micro grid based on renewable resources.SST is used to interface a wind park based on squirrel cage induction generator (SCIG) with the grid. However a detailed analysis on fault ride through requirement and reactive power support has not been conducted.

A new configuration is proposed that combines the operation of DFIG based WECS and SST[1]. This configuration acts as a interface between and grid while eliminating the GSC of DFIG. Moreover, it is essential to have fault ride through (FRT) incorporated in DFIG system to meet the grid code requirements. In the proposed work, the developed configuration allows DFIG to ride through faults seamlessly, which is the aspect (FRT) has not been addressed in the earlier work on SST interfaced WECS.

The SST technology has enhanced the power quality as compared to the normal step- up transformer. The SST acts as a key interface between the wind turbine and the grid. The main objective is to provide the regulated voltage in the power system and enhance the power quality[9] .The control techniques is proposed in the system. The RSC control technique explained in the system defines the two way injection and ejection of real and reactive power to the system .

The DFIG is used for the variable speed operation ,high power density and lower cost. The stator of DFIG is directly connected to grid while the rotor is connected to back- to- back converter known as Rotor side converter(RSC) AND Grid side converter(GSC).The SST performs the operation of voltage conversion through the power electronics devices for compensation purpose[6]s. It implements smaller size ,improved power quality and fault tolerance features. Reactive power is not supported in (SCIG) squirrel cage induction generator. so we go for DFIG. The DFIG based wind turbine system is the lightest among the current wind system. DFIG along with SST provides further reduction in volume and weight.[7]

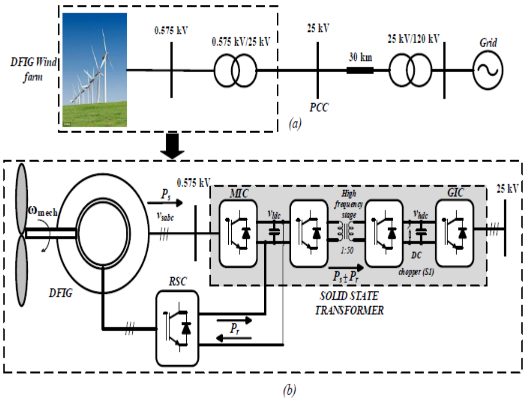
Thus the system utilizes the SST along with the DFIG promotes the high power quality and voltage regulation. This will be achieved through the matlab simulation which proposes the wind turbine model and the simulation mode[8]l. Moreover , it is essential to have fault ride through(FRT) incorporated in DFIG system to meet the grid code requirements.

II. PROPOSED SYSTEM DESCRIPTION

The widely used DFIG based WECS configuration is shown in. The stator terminals of the machine are connected directly to the grid while the rotor terminals are connected via back to back converters. The RSC allows for variable speed operation of the machine by injecting or drawing active power from the rotor. The GSC maintains the DC link by transferring the active power from the rotor to the grid or vice versa. The step up transformer T1, is the interface between the DFIG system and grid.

Three stage SST configuration is shown in where it connects the grid to a distribution load. Conv-1 is a fully controlled three-phase converter connected to the high voltage grid (11-33 kV). It draws real power from the grid and maintains the high voltage DC bus. This high voltage DC is converted to high frequency AC voltage by a half bridge converter (HB-1) which is then stepped down using a smaller sized high frequency transformer. This transformer provides the galvanic isolation between the grid and load. A second half bridge converter (HB-2) converts the low voltage AC to low voltage DC voltage . This DC bus supports conv-2 which maintains the three-phase/single phase supply voltage to the load by producing a controlled three phase voltage. The configuration thus performs the function of a regular transformer allowing for bi-directional power flow using a series of power electronics devices [5-10].

This paper presents the configuration, that the fundamental frequency transformer is replaced by the SST. The proper control of SST converter that is close to the stator of DFIG, addressed as machine interfacing converter (MIC), can aid the machine in its operation[2]. Thus, it is proposed to eliminate the GSC in the DFIG system configuration by incorporating its role in SST.



(a) Regular DFIG configuration and (b) Proposed SST based DFIG configuration.

. A. Solid State Transformer(SST)

The solid-state transformer (SST) achieves voltage conversion through a series of power electronics devices while offering multiple advantages, such as, smaller size, improved power quality and fault tolerant feature where it connects the grid to a distribution load. Conv-1 is a fully controlled three-phase converter connected to the high voltage grid (11-33 kV). It draws real power from the grid and maintains the high voltage DC bus. This high voltage DC is converted to high frequency AC voltage by a half bridge converter (HB-1) which is then stepped down using a smaller sized high frequency transformer. This transformer provides the galvanic isolation between the grid and load. A second half bridge converter (HB-2) converts the low voltage AC to low voltage DC voltage (Vldc) . This DC bus supports conv-2 which maintains the three-phase/single phase supply voltage to the load by producing a controlled three phase voltage. The configuration thus performs the function of a regular transformer allowing for bi-directional power flow using a series of power electronics devices. SST was used in an SCIG based WECS replacing the step-up transformer between the turbine and grid. It was shown that SST can improve the voltage profile at the terminals of the SCIG.In [21], it has been reported that a DFIG based wind turbine is the lightest amongst the current wind systems which also explains its wide commercial use. Moreover, in the proposed configuration, the GSC present in traditional DFIG systems is removed making the machine setup further lighter. On the other hand, SST being used in an AC/AC system is expected to be 25% smaller in volume than traditional low frequency transformer . Thus, the use of SST to interface a DFIG based wind system can be expected to provide further reduction in weight and volume when compared to other wind systems with the fundamental frequency transformer.

B. RSC and GSC

The widely used DFIG based WECS, The stator terminals of the machine are connected directly to the grid while the rotor terminals are connected via back to back converters. The RSC allows for variable speed operation of the machine by injecting or drawing active power from the rotor. The GSC maintains the DC link by transferring the active power from the rotor to the grid or vice versa. The step up transformer T1, is the interface between the DFIG system and grid.

Three stage SST configuration is shown in Fig. 2 (b), where it connects the grid to a distribution load. Conv-1 is a fully controlled three-phase converter connected to the high voltage grid (11-33 kV). It draws real power from the grid and maintains the high voltage DC bus (. This high voltage DC is converted to high frequency AC voltage by a half bridge converter (HB-1) which is then stepped down using a smaller sized high frequency transformer. This transformer provides the galvanic isolation between the grid and load. A second half bridge converter (HB-2) converts the low voltage AC to low voltage DC voltage (. This DC bus supports conv-2 which maintains the three-phase/single phase supply voltage to the load by producing a controlled three phase voltage. The configuration thus performs the function of a regular transformer allowing for bi-directional power flow using a series of power electronics devices [5-10].

As mentioned earlier, the use of SST in WECS has been explored by Xu et al. in [10]. SST was used in an SCIG based WECS replacing the step-up transformer between the turbine and grid. It was shown that SST can improve the voltage profile at the terminals of the SCIG. While the focus of [10] was on SCIG, possible configuration for DFIG systems was also showcased that is represented in Fig. 2 (c). The step-up transformer T1 in Fig. 2 (a) is directly replaced by the SS

III. CONTROL TECHNIQUES

A. RSC control

The rotor side control ensures the variable speed operation of DFIG by enabling the generator to work in super synchronous or sub synchronous modes. In super synchronous mode, the total power generated is partially evacuated through the RSC. Under sub synchronous modes, the RSC injects active power into the rotor. The RSC in the proposed converter is controlled using a decoupled synchronous frame reference. The -axis of the reference frame is aligned with the machine stator voltage. On doing this, as per (3), the torque produced by the machine can be directly controlled by controlling the -axis rotor current . Moreover, the reactive power produced at the stator terminal can also be controlled by controlling the -axis rotor current

B. MIC control

The MIC is the first stage of the SST connecting the low voltage machine output to the high frequency stage. This converter is controlled to maintain 1 p.u. voltage (0.575 kV) at 50 Hz at the stator terminals of the machine.

The control is achieved by generating a reference voltage and comparing the -axis component of the reference with the voltage at the output of the converter ( ). The power generated at the stator terminals of the machine is thus absorbed by the low voltage DC bus connected to MIC operating at 1.15 kV.

C. GIC control

While the control of other converters remains the same in fault and normal conditions, GIC is controlled differently during fault conditions. The control and operation of GIC is discussed in two modes. Fault detection switches are used that are triggered when a fault is detected. Firstly, the operation of the proposed configuration is shown under normal grid conditions. In this scenario , the wind turbine is operated at a speed of 13 $m\ s$ thus not producing peak power. The wind turbines produce a total of 4.2 MW active power. Like general DFIG, the system delivers this wind generated active power to the grid through the SST.

That is, there is no reactive power support from the GIC. The grid voltages and currents at the output of the GIC. The stator terminal voltages and machine currents at 0.575 kV

D. High frequency stage control

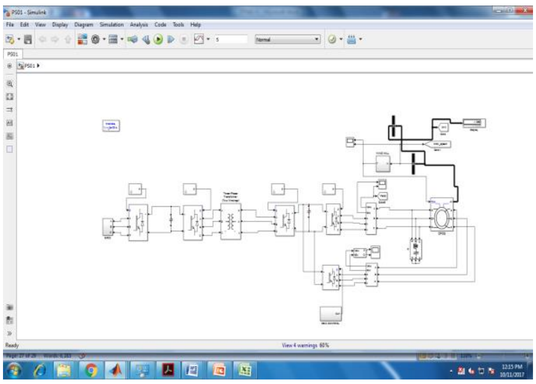
The high frequency stage transforms the low voltage DC bus voltage (1.15 kV) into high voltage DC (50 kV). The DC voltages are converted into high frequency AC voltages by the two half bridge converters. Power is transferred by introducing a phase shift between the AC voltages of the two converters linked together by a high frequency transformer.

The control objective of high frequency stage, in the proposed configuration, is to maintain the low voltage DC bus voltage at a constant level. In order to achieve this, the reference voltage $*$ is compared with the measured value and the resulting error is processed by a PI controller which produces the required phase shift ϕ that transfers the active power from the low voltage DC bus to the high voltage DC bus.

TABLE I
SYSTEM PARAMETERS

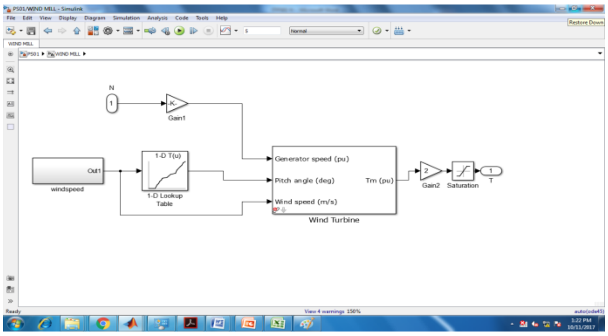
Parameter	Value
System Data	
Rated power	5 MVA
No. of wind turbines	3
Wind Turbine data	
Rated power	1.5 MW
Rated wind speed	15m/s
Generator Data	
Rated apparent power	1.66 MVA
Rated voltage	0.575 kV
No of poles	6
Rated frequency	50 Hz
Stator to rotor turns ratio	575/1975
Stator resistance, Inductance	0.0023 p.u.,0.18 p.u.
Rotor resistance, inductance	0.0016 p.u.,0.16 p.u.
Inertia constant	0.685 s
SST Data	
Low voltage DC bus (v_{ldc})	1.15 kV
operating frequency	3 kHz
HF transformer turns ratio	1:50
HF transformer inductance	5.95 μH
High voltage DC bus (v_{hdc})	50 kV

IV. SIMULATION AND EXPERIMENTAL RESULTS



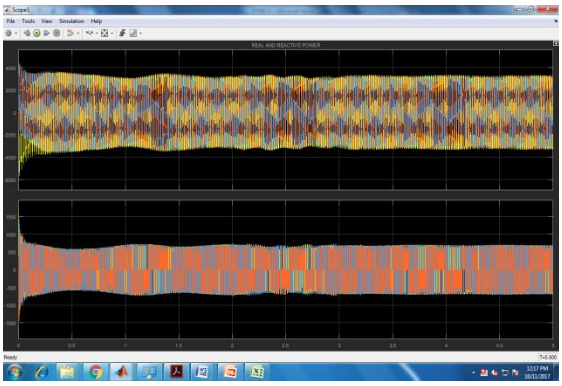
The simulation diagram is implemented in the above model which involves wind turbine, DFIG and RSC control.The variable speed operation is executed in the DFIG.The scope in every module is used to get the simulation result.

A. Wind Turbine Model



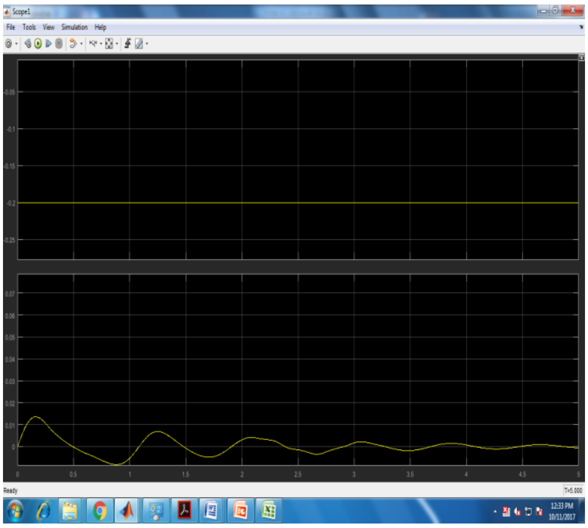
This is the wind turbine model in which the generator speed, pith angle, wind speed is calculated.

B. Simulink Output



Both the real and reactive power waveforms is implemented in simulation.

C. Windmill Waveform



The power produced by the wind turbine is implemented with the current and voltage waveforms. These are the output waveforms which experimentally obtained using MATLAB/SIMULINK.

V. CONCLUSION

In this , a new system configuration that combines DFIG and SST operation has been proposed. This configuration replaces the regular fundamental frequency transformer with advanced power electronics based SST. The key features of the proposed configuration are outlined below:

- Replacement of regular fundamental frequency transformer with SST leading to smaller footprint.
- Direct interface with SST to inject active power.
- Elimination of GSC in a standard DFIG system as the active power to/from RSC is regulated by MIC.
- Simplified DFIG control as machine supports only active power. The reactive power is supported by GIC during both normal and fault conditions.
- Seamless fault ride through operation during both symmetrical and unsymmetrical faults as per the latest grid codes.

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