Position/Speed Sensor Less Control for PMSG Offshore Wind Farms and its Integration using VSC based Multi Terminal HVDC System

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Abstract— This paper demonstrates the design of Permanent magnet Synchronous Generator (PMSG) suitable for offshore Wind farms and reviews the state-of-the art and highly applicable mechanical position/speed sensor less control schemes for PMSG-based variable-speed Wind Energy Conversion Systems. In these Voltage Source Converters (VSC) Multi Terminal High Voltage Direct Current (HVDC) transmissions technology is used to integrate with main grid. Due to enormous advantages of VSC system, it facilitates fast Active and Reactive power control and relatively lower losses. VSCs have a limited transmission capacity due to limitations on IGBT and capacitors ratings. For these reasons, a multi-terminal HVDC (MTDC) transmission system, which can extract and deliver power from and to several terminals and provide power to more than one terminal, is an attractive method for offshore wind power transmission. MTDC system and the results show that the system can operate effectively under a variety of operating conditions.

Key words: Permanent Magnet Synchronous Generator, Wind Turbine, Voltage Source Converters, HVDC

I. INTRODUCTION

An auspicious wind turbine concept for modern wind turbines is the variable speed wind turbine with multi pole permanent magnet synchronous generator (PMSG).

A multi pole synchronous generator connected to a power converter can operate at low speeds, so that a gear can be omitted [1]. Since a gearbox causes higher weight, losses, costs and demands maintenance [2]. A gearless construction represents an efficient and robust solution; The efficiency of a PMSG wind turbine is thus assessed to be higher than for other concepts [3]. This can be very beneficial especially for offshore applications.

Moreover, due to the permanent magnet excitation of the generator the DC excitation system can be eliminated reducing again weight, losses, costs and maintenance requirements. The efficiency of a PMSG wind turbine is thus assessed to be higher than for other concepts. However the disadvantages of the permanent magnet excitation are the still high costs for permanent magnet materials and a fixed excitation, which cannot be changed according to the operational point.

Typically, existing and potential offshore wind farms may be located as far as 100-150 km from the shore. For this reason, high voltage direct current (HVDC) transmission technology becomes a feasible and economical solution compared to HVAC transmission. . Compared to HVAC, VSC HVDC transmission is able to flexibly control active and reactive power, and can alleviate the propagation of voltage and frequency fluctuations due to wind variations in wind strength [4]. The fact that HVDC transmission lines can be routed underground eliminating hazards such as corona makes HVDC attractive and environmentally friendly. DC can also transport relatively more power at the same voltage/insulation level as AC. Therefore, HVDC transmission is considered an effective way of connecting offshore wind farms to the main grid. Single line diagram of WECS and its integration is shown in fig(1)

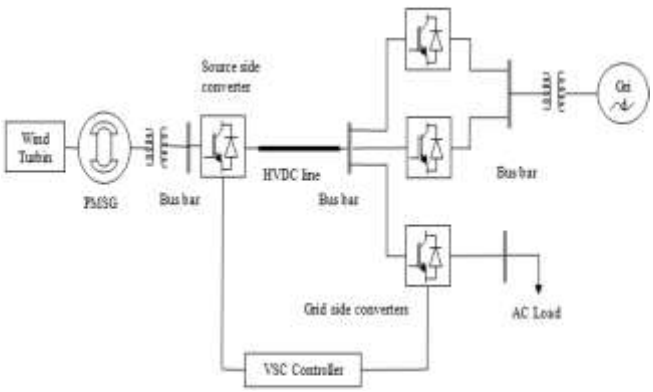

Fig. 1: WECS and its Integration

II. MODELING OF WIND TURBINE

Wind energy conversion system is a complex system converting wind energy to rotational energy and then to electrical energy. The output power or torque of a wind turbine is determined by several factors like wind velocity, size and shape of the turbine, etc. A dynamic model of the wind turbine, involving these parameters, is needed to understand the behavior of a wind turbine over its region of operation. By studying its modeling, it is possible to control a wind turbines performance to meet a desired operational characteristic [5]. In the following pages we will look at different performance characteristics and variables that play an important role in wind power generation, by deriving the speed and power relations. The control principles of the wind turbine are also discussed in this section.

Mechanical Power extracted by the rotor (P) is given by

$$P = \frac{1}{2}\rho \cdot A \cdot V_{\omega}^{3} \cdot C_p$$

ρ _ Air density in kg/ m^3
A _ Area swept by the rotor blades in m^2
V_ω _ Wind Speed In m/sec
Cp _ Coefficient of Power
$Cp=0.5[(116/\lambda_i)-0.4\cdot\beta-5]e^{-21/\lambda i}+0.0068\cdot\lambda$
λ _ Tip Speed ratio (Keep the TSR constant at the optimal level at all times) [6]
β _ Pitch angle of the blade

$$\lambda = \frac{WR}{V\omega}$$

W _ Rotor angular speed in rad/sec
R _ Rotor blade radius in meter

$$\frac{1}{\lambda_i} = \frac{1}{\lambda + 0.088\beta} + \frac{0.035}{\beta^3 + 1}$$

Pitch Angle controller will starts at when the wind speed reaches to its rated or above rated value. Up to cut in to rated speed will maintain zero for Optimum power extraction from the wind [5].

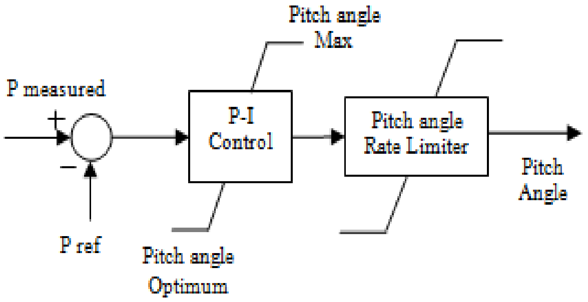

Fig. 2: Pitch Angle Controller

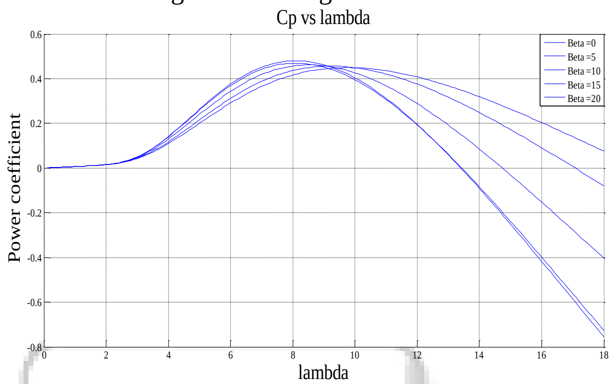

Fig. 3: Power Coefficient vs. TSR Characteristics of Wind Turbine

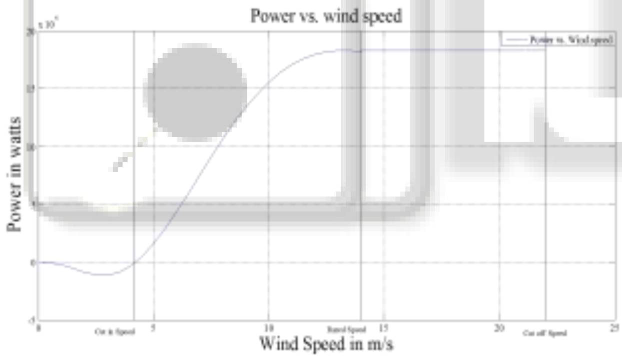

Fig. 4: Power vs. Wind Speed Characteristics of Wind Turbine

Basic parameters of the Wind Turbine are given in Table I

Parameter	Symbol	Value and Unit
Rated Power	$P_{turbine\ rated}$	3MW
Turbine diameter	d	120 m
Rated Wind Speed	Vω	5.4/14/21 m/s
Rotor speed	W	9.329 rpm
Controlling technique used is Pitch Angle control		

Table 1: Parameters of Wind Turbine

III. MULTI-POLE PMSG

The Permanent Magnet Synchronous Machine block operates in either generator or motor mode. The mode of operation is dictated by the sign of the mechanical torque (positive for motor mode, negative for generator mode). The sinusoidal model assumes that the flux established by the permanent magnets in the stator is sinusoidal, which implies that the electromotive forces are sinusoidal.

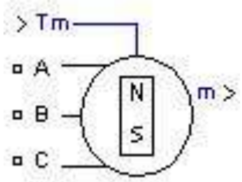

Fig. 5: PMSG

1) Sinusoidal Model Electrical System

This equations are expressed in the rotor reference frame (qd frame) [7].

$$\frac{d}{d}i_d = \frac{1}{L_d}v_d - \frac{R}{L_d}i_d + \frac{L_q}{L_d}P\omega_r i_q$$

$$\frac{d}{d}i_q = \frac{1}{L_q}v_q - \frac{R}{L_q}i_q + \frac{L_d}{L_q}P\omega_r i_d - \frac{\lambda P\omega_r}{L_q}$$

$$T_e = 1.5P[\lambda i_q + (L_d - L_q)i_d i_q]$$

where (all quantities in the rotor reference frame are referred to the stator)

L_q, L_d _ q and d axis inductances
R _ Resistance of the stator windings
Iq, i_d _ q and d axis currents
vq, v_d _ q and d axis voltages
ω_r _ Angular velocity of the rotor
λ _ Amplitude of the flux induced by the permanent magnets of the rotor in the stator phases
P _ Number of pole pairs
Te _ Electromagnetic torque

The Lq and Ld inductances represent the relation between the phase inductance and the rotor position due to the saliency of the rotor. For example, the inductance measured between phase a and b (phase c is left open) is given by:

Where θ_e represents the Electrical Angle

$$L_{ab} = L_d + L_q + (L_q - L_d)\cos(2\theta_e + \frac{\pi}{3})$$

The Basic parameters of the PMSG are given in Table II

Parameter	Symbol	Value and Unit
Rated generated power	$P_{gen\ rated}$	25MW
Rated Mechanical Speed	$\omega_{g\ rated}$	4.73 rad/sec
Stator Resistance	R_s	50 μΩ
Stator d-axis inductance	L_{ds}	5.5 mH
Stator q-axis inductance	L_{qs}	3.75 mH
Permanent magnet flux	ψ_f	137.5 Wb
Pole pairs	P	30

Table 2: Generator Parameters

IV. VOLTAGE SOURCE CONVERTER (VSC)

VSCs are using insulated gate bipolar transistor (IGBT) valves and pulse width modulation (PWM) for creating the desired voltage wave form. VSC converter technology provides rapid and independent control of active and reactive power without needing extra compensating equipment; the reactive power can be controlled at both terminals independently of the DC transmission voltage level the commutation failures due to disturbances in the AC network can be reduced or even avoided if VSC-HVDC technology is used self (forced) commutation with voltage source converters permits black start, which means that the VSC is used to synthesize a balanced set of three phase voltages as a virtual synchronous generator

Controlling of converter station is shown in fig(6)

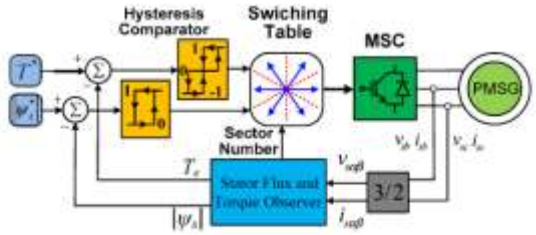

Fig. 6: Schematic diagram of a DTC for a PMSG-based WECS

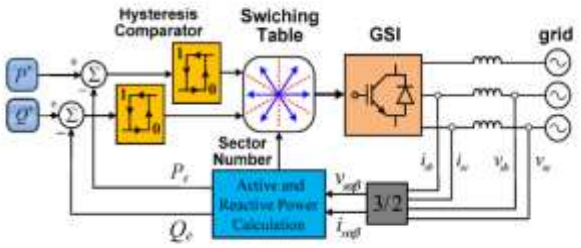

Fig. 7: Schematic diagram of a DPC for a PMSG-based WECS.

V. MULTI-TERMINAL HVDC SYSTEM (MT HVDC)

A multi-terminal HVDC transmission system consists of three or more converter substations, some of them working as inverters while the other ones as rectifiers. Depending on the positioning of the converter substations, two basic arrangements of the multi-terminal HVDC system can be obtained: series multi-terminal HVDC system and parallel multi-terminal HVDC system.

A VSC multi-terminal HVDC (MTDC) system has superiority over a two-terminal HVDC system, in that it facilitates gradual expansion of distributed networks, the input and output power can be controlled flexibly in order to increase the total power transportation capacity and to reduce the converter station costs, to effectively utilize the existing assets and to provide greater flexibility, MTDC HVDC systems, which can reduce the number of required converter stations[4].

MTDC system and the results show that the system can operate effectively under a variety of operating conditions. Specially, a fault occurring on the AC network of one inverter terminal had little impact on the other AC systems supplied via other terminals. The paper concludes that MTDC for urban is a potential alternative to a classical AC distribution system in urban areas of large cities.

The bellow fig shows MT HVDC system.

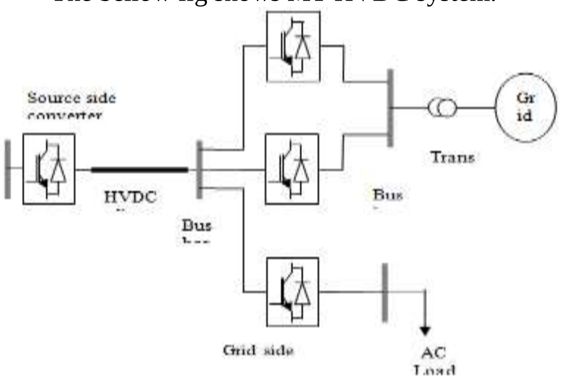

Fig. 8: Single line diagram of MT HVDC (AC load connected to terminal I and the grid is connected to other terminals)

A. Fault Ride-Through Capability

To demonstrate that the improved fault ride-through capability of the Multi-terminal HVDC system based on voltage source converter is shown in fig(). Three phase fault is applied at terminal I, with duration of 0.133sec (0.01-0.15sec). It can be observed that the voltage magnitude at bus collapse during the fault period as reactive power capability of the converter decreases. Despite voltage collapse at bus, the VSC contributes limited current to the fault.

B. Filters Specification:

Three phase 100μF capacitive filter is used in Grid side to filter the output and 500mF capacitor is used for filtering source side converter output.

VI. SIMULATION RESULTS

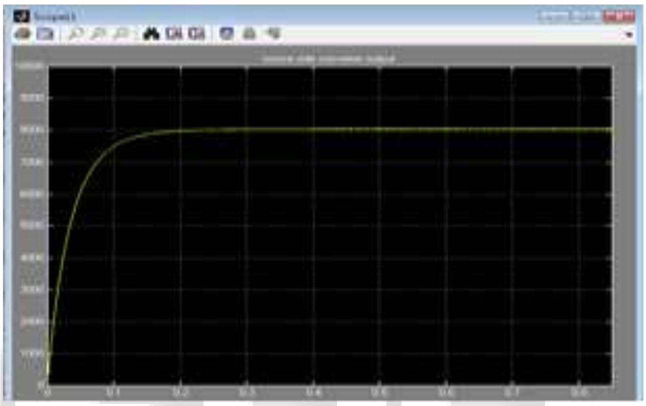

Fig. 9: Voltage output across source side converter

A. Results under Pre Fault Condition (All Terminal Outputs Are Same)

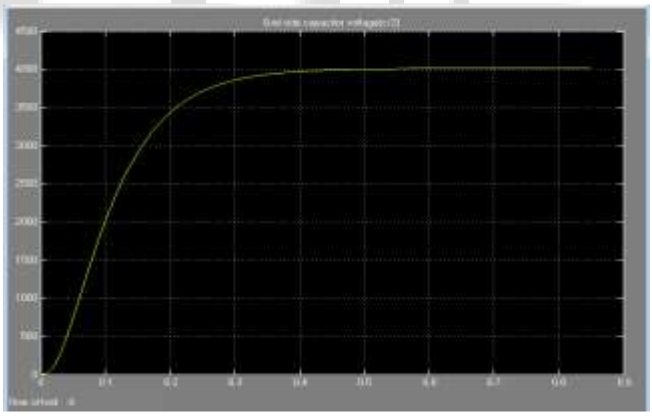

Fig. 10: Voltage across Grid side Capacitor (C/2)

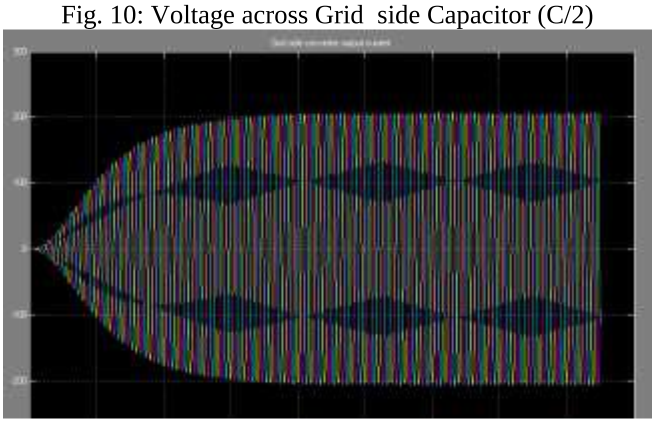

Fig. 11: Grid side converter output current

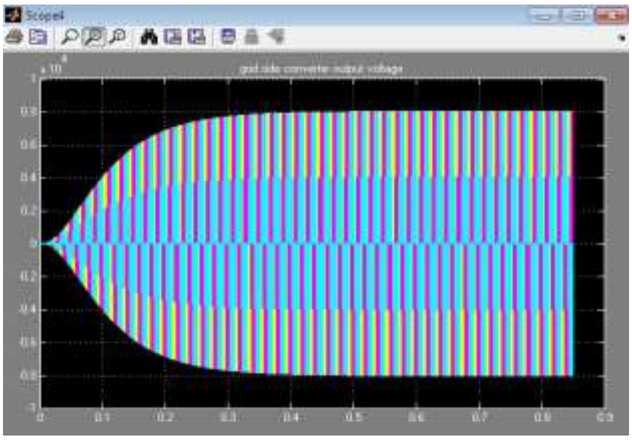

Fig. 12: Grid side converter output voltage

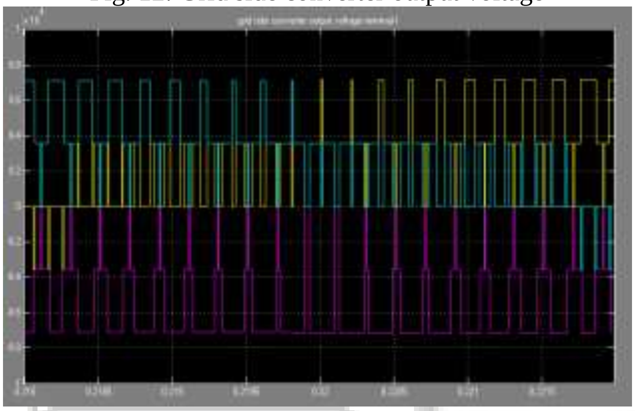

Fig. 13: Stretched output's of Grid side converter

1) Results under Symmetrical fault condition (Symmetrical fault applied at terminal II)

Fig. 14: Voltage across Grid side Capacitor (C/2)

a) Output's at terminal-I

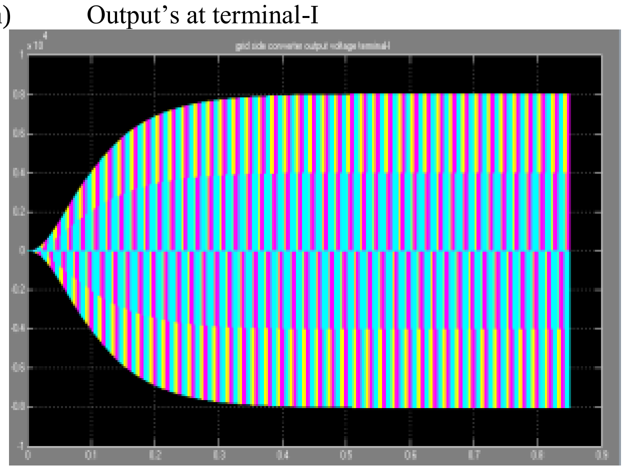

Fig. 15: Grid side converter output voltage

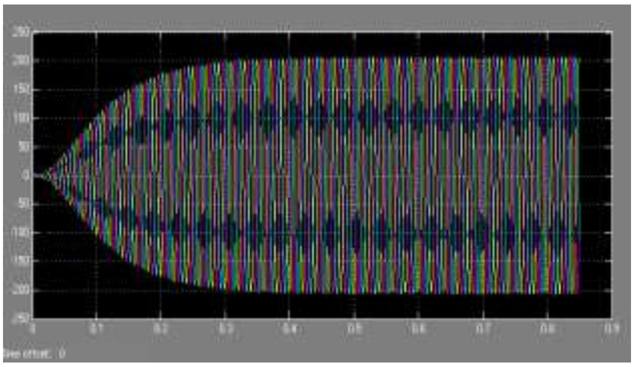

Fig. 16: Grid side converter output current

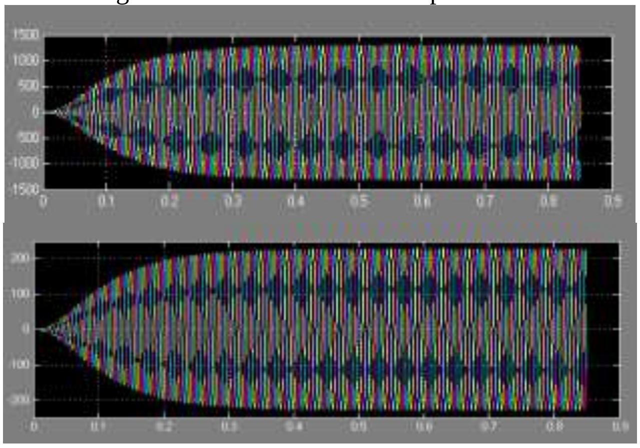

Fig. 17: Terminal-I Load voltage and current.

b) Output's at terminal-II

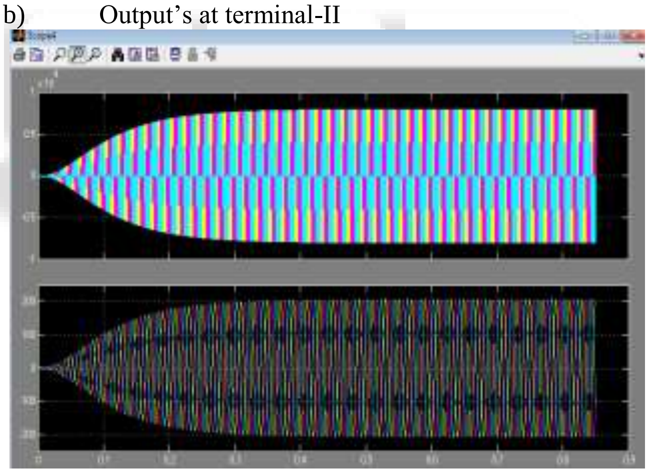

Fig. 18: Grid side converter voltage & current output

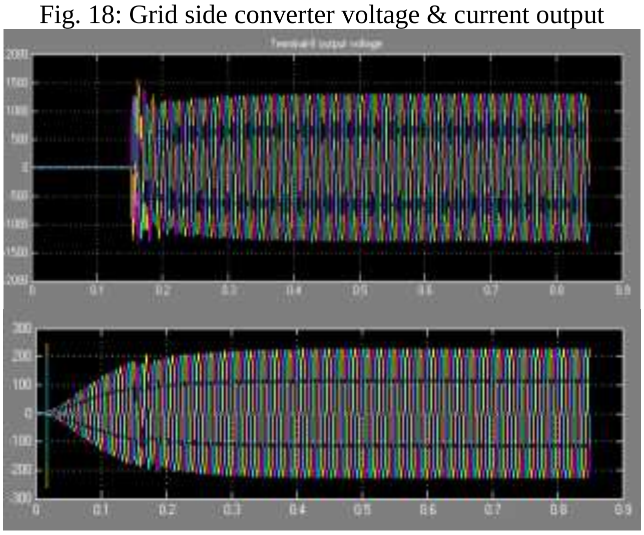

Fig. 19: Terminal-II Load voltage and current (Faulty Terminal)

VII. CONCLUSION

This paper discussed about design of Wind Turbine with multi-pole PMSG and the application of VSC based Multi-terminal HVDC network to transfer power from offshore wind farms to the grid. It was found that by using Multi-pole PMSG in Wind Generators the gear train setup is eliminated, it is worked as direct drive WGS due to these losses due to gear box is eliminated. And the use of multi-terminal HVDC system may improve reliability against loss of a converter and due to applications of VSC Controlling of Active and Reactive powers and frequency control. VSC multi-terminal HVDC system providing reactive power support without increasing the risk of converter failure by controlling the current under faulty state in the terminal.

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[11] Gabriele Michalke, Anca D. Hansen, Thomas artkopf, [8] explained the control strategy of a variable speed wind turbine with multipole permanent magnet synchronous generator (PMSG) and full scale IGBT power converter, i.e. control of VSC controller.
[12] Jiebei Zhu, Campbell Booth, [10] discussed about the VSC HVDC system advantages andfeatures of multi-terminal HVDC transmission systems and its variety of operating conditions.