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Remedial Measures to Overcome Low Voltage Ride Through Problems for Wind Turbine Driven DFIG

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Abstract: The increasing wind power generation has made the power systems more and more sensitive to various grid faults, which resulted in new grid codes. One of the most important grid codes is the low voltage ride through (LVRT), which requires the wind energy conversion systems to remain connected to the grid during voltage dips. Voltage dips mainly occur when large loads are connected to the grid or the results of grid faults like lightning strikes and short circuit events. In this project, a LVRT strategy for a wind turbine driven doubly fed induction generator (DFIG) with switch type fault current limiter (STFCL) is proposed. Doubly fed induction generators employing these technologies have some more advantages when comparing to conventional generators, such as light weight, low cost, small size, import and export of reactive power and it occupies close to 50% of the wind energy market. To overcome the LVRT issues, STFCL can be used. The STFCL is composed of snubber capacitor, a fault energy absorption bypass, isolation transformers, fault current limiting inductors. It can be inserted in series with stator branches on occurrence of grid faults, which can limit the rotor over current and weaken the rotor back electromagnetic force voltage. It can also absorb the excessive energy stored in the stator during LVRT with the fault absorption bypass so as to prevent the semiconductor switches from overvoltage. Objectives of the project is to study and analyse the performance of wind power plant with DFIG, to model the wind turbine generator (doubly fed induction generator) to check the performance under low voltage ride through conditions. Simulation is done with MATLAB/SIMULINK to study the effect of LVRT issues and the results obtained from detailed analysis are presented with necessary illustrations.

Key words: Wind Energy Conversion System · Doubly fed Induction Generator (DFIG) · Low Voltage Ride Through (LVRT) · Grid Codes

INTRODUCTION

The ratio between renewable energy sources and conventional sources is constantly increasing in many electric energy systems. This leads to introduction of more strict rules to connection of these facilities to the grid. Wind energy conversion (WEC) is the most mature renewable technologies at the moment. In order to integrate wind farms into the grid, they are requested to follow directives from a central electricity authority and participate in frequency control rather than to produce as much power as dictated by available wind. Reactive power and voltage control requirements are also becoming more stringent, as well as fault tolerance requirements like low voltage ride through (LVRT).

The utilization of doubly-fed induction generator (DFIG) in variable-speed wind turbines has increased rapidly due to their operational and economic features. It operates within a range of -30% to +40% of its rated speed. The increased penetration of wind energy into the power system has resulted in the power system operators revising the grid codes to regulate and control the operation of these renewable resources and minimize their impact on the system. A special focus in these requirements is drawn to the wind turbine LVRT capability which addresses primarily the ability of the wind turbine to remain connected to the network during grid faults also they can contribute to voltage support during and after the fault. Under the new grid codes the wind turbine generators (WTG) should remain connected to the grid

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during a voltage dip for specific period. However, the direct connection of the generator stator to the grid has made the DFIG very sensitive to grid disturbance. An abrupt change in the stator voltage will result in dc and negative sequence stator ?ux and induce high back electromagnetic force (EMF) voltage in the rotor circuit. The rotor back EMF voltage exceeds the voltage rating of the rotor-side converter (RSC) and makes the RSC lose control over rotor current under severe voltage dip conditions.

When the voltage dip occurs on the terminal of the DFIG the stator flux cannot follow the rapid change in the stator voltage and a dc component in the stator flux appears and the stator flux vector becomes almost stationary. The rotor keeps rotating and the machine slip increase, which create an overvoltage and overcurrent in the rotor. Due to these high transient currents and overvoltage during this LVRT event, special protection techniques are needed to protect the DFIG during these events. In this paper the LVRT strategy for a DFIG with a switch type fault current limiter (STFCL) is presented. STFCL is composed of fault current limiting inductors, isolation transformer, a snubber capacitor, a diode bridge, a semiconductor switches and a fault energy absorption bypass. The DFIG based WECS is one of the most popular WECSs, which occupies close to 50% of the wind energy market mainly due to its outstanding advantages such as light weight, low cost and small size.

Block Diagram

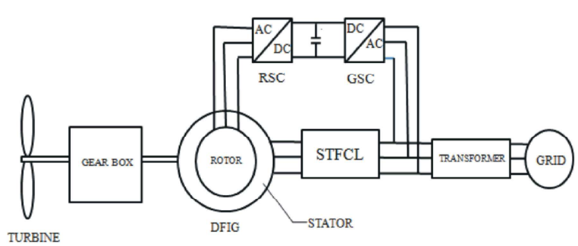

Fig. 1: Block diagram of proposed system

The block diagram shows the basic operation of the proposed system. Variable speed Wind turbine is used to convert the kinetic energy in wind into mechanical energy and it can achieve maximum energy conversion efficiency. This mechanical energy is fed to the generator through gear box which matches the low speed rotation of the wind turbine to the high speed shaft of the electrical generator. Then the mechanical energy at the Doubly fed induction generator is converted into electrical energy where the stator is directly connected to the grid and rotor is connected to the grid through power electronics converter. Transformer steps up the voltage and allows supplying it to the grid.

Wind Turbine: The mechanical power (P_W) extracted from wind energy is computed as a function of the air density (ρ), the swept area (A), the wind speed (ϑ) and the power coefficient factor (C_p) as,

$$P_W = \frac{1}{2}\rho A \vartheta^3 C_p \quad (1)$$

where the tip speed ratio (λ) is expressed as a function of the blade length (R) and the blade angular velocity (ω_b) as,

$$\lambda = \frac{\omega_b R}{v} \quad (2)$$

The relations among the developed electrical torque (T_g), the mechanical torque (T_m) and the extracted aerodynamic torque (T_w) can be described as functions of the angular velocities of the wind turbine rotor (ω_r) and the generator shaft (ω_g) as,

$$T_W - T_m = J_r \frac{d\omega_r}{dt} \quad (3)$$

$$T_m - T_g = J_g \frac{d\omega_g}{dt} \quad (4)$$

where the constants J_r, J_g are wind turbine rotor inertia and generator shaft inertia respectively.

Doubly Fed Induction Generator: The DFIG is a wound-rotor high speed induction generator. Wind turbine driven DFIG is also called as type C Wind power plant. It combines an advantage of robustness of induction generator as well as the variable speed features of synchronous generator. The power electronic converter consists of two voltage source converters connected back-to-back. Wind power plant operates within the range of -30% to 40% of the rated speed. DFIG has a slip power of 40%.The power rating for the DFIG is normally in the range of a few hundred kilowatts to several megawatts. The stator of the generator delivers power from the wind turbine to the grid and, therefore, the power flow is unidirectional. However, the power flow in the rotor circuit is bidirectional, depending on the operating conditions.

The power can be delivered from the rotor to the grid and vice versa through rotor-side converter (RSCs) and grid-side converters (GSCs), a DFIG wind energy system can harvest more energy from the wind than a fixed-speed wind energy conversion system of the same capacity when the wind speed is below its rated value.

The rotational speed of the rotating magnetic field is called as synchronous speed.

$$N_3 = \frac{120\times f}{p}(rpm) \tag{8}$$

The difference between the synchronous speed (N_s) and actual speed (N) of the rotor is called as slip.

$$\%slips = \frac{Ns - N}{Ns}\times 100 \tag{9}$$

There are two modes of operation. One is sub synchronous mode and another one is super synchronous mode. The active power P always goes out from the stator and is put into the grid, independent of the operation state either super synchronous or sub synchronous, whereas the rotor absorbs power when operating as motor (at sub synchronism) and delivers it when operating as a generator (at super synchronism).

The equivalent circuit of a DFIG referred to stator side and rotor side are shown in Fig. 2. The dq-axis voltage equations for the DFIG is given below:

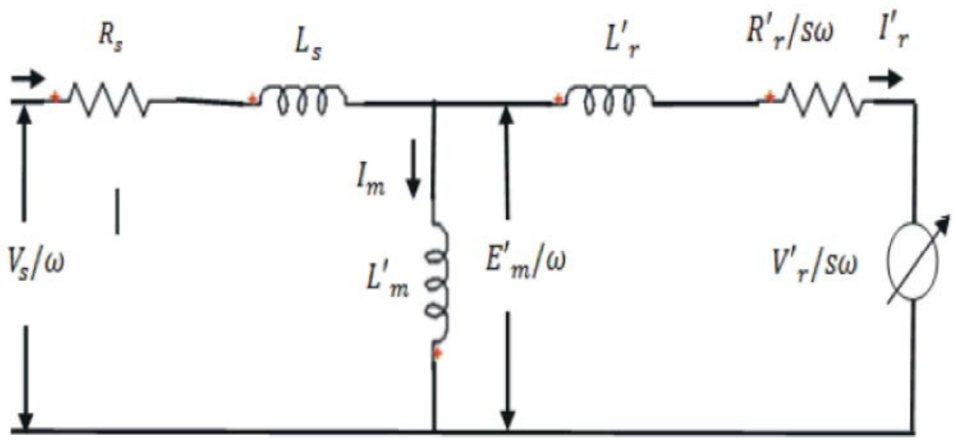

Fig. 2: Equivalent circuit of DFIG

Stator Equations:

$$V_{dx} = i_{ds}R_s + \omega_s\psi_{qs} \tag{10}$$

$$V_{qs} = i_{qs}R_s + \omega_s\psi_{ds} \tag{11}$$

Rotor Equations:

$$V_{dr} = i_{dr}R_r - S\omega_r\psi_{qr} + \frac{d}{dt}\psi_{dr} \tag{12}$$

$$V_{qr} = i_{qr}R_r - S\omega_r\psi_{dr} + \frac{d}{dt}\psi_{qr} \tag{13}$$

Flux linkage:

$$\psi_{qs} = L_s i_{qs} + L_m i_{qr} \tag{14}$$

$$\psi_{ds} = L_s i_{ds} + L_m i_{dr} \tag{15}$$

$$\psi_{qr} = L_s i_{qr} + L_m i_{qs} \tag{16}$$

$$\psi_{dr} = L_s i_{dr} + L_m i_{ds} \tag{17}$$

The electromagnetic torque *Te* can be expressed by dq axis flux linkages and currents is mentioned below:

$$T_e = \frac{3}{2}\frac{P}{2}(\psi_{ds}i_{qs} - \psi_{qs}i_{ds}) \tag{18}$$

During operation the direct connection of the generator stator to the grid has made DFIG more sensitive to grid disturbance which leads to over current, overvoltage and over torque. In order to overcome this issue an additional device is required.

LOW Voltage Ride Through: Low Voltage Ride Through (LVRT) is one of the most dominant grid connection requirements to be met by Wind Energy Conversion Systems (WECS). Disconnection of wind turbine generators from the grid is one of the major issues that may occur due to shortage of power. To overcome these issues new grid codes have been developed which regulate the interconnection of wind turbine generator into the grid. Grid code is issued by the Central Electricity Authority (CEA). The required LVRT behavior is defined in grid codes issued by the transmission system operators in order to maintain system stability Grid codes vary from country to country according to the requirement.

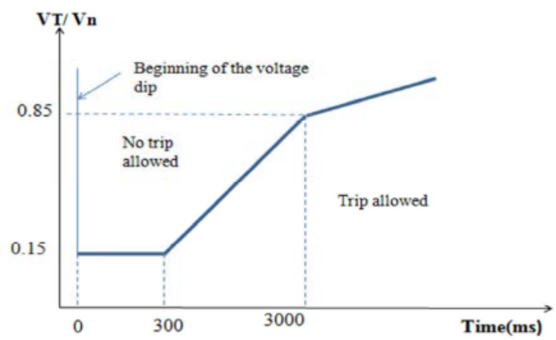

Fig. 3: LVRT requirements

Fig. 3 Shows the LVRT requirements in India. As per the Indian grid code wind turbines are allowed to disconnect as low as 0.15 p.u. Variable wind speed leads to variable wind power generation, which creates the voltage fluctuations. Voltage dips occurs, when large loads are connected to the grid or a result of grid faults like lightning strikes or short circuits. Because of the significant share of renewable, if too many generating plants disconnect at the same time the complete network could break down, a scenario is also called a "blackout". When a grid voltage dip appears, power-generation plant should support the system during fault condition by injecting reactive power and to remain connected in the grid. Grid codes are planned according to the operational purposes under normal and exceptional circumstances. It is designed to permit improvement in the electricity transmission, distribution and generation.

Operating Principles of STFCL: STFCL consists of a diode bridge, isolation transformers, fault current limiting inductors (L_l), semiconductor, snubber capacitor and a fault energy absorption bypass (R_a, C_a). C_f is used to reduce the sudden changes in the overvoltage and its capacitance is very low. Ra is used to limit the surge current flowing into Ca where its capacitance is relatively large. During normal operating condition S_d is turned on and Li will be bypassed. When a fault occurs, S_d is turned off, where the fault current is initially limited by shunt impedance of L_l and R_aC_a branch. The stator current charges Ca and the excessive energy stored in the stator is eventually discharged. When the voltage in Ca reaches the steady state value, no more current will be flows into the diode bridge and the fault current inductors are inserted in the stator branches where it limits the stator over current and weakens the rotor back EMF voltage. Fig. 4 shows the topology of STFCL.

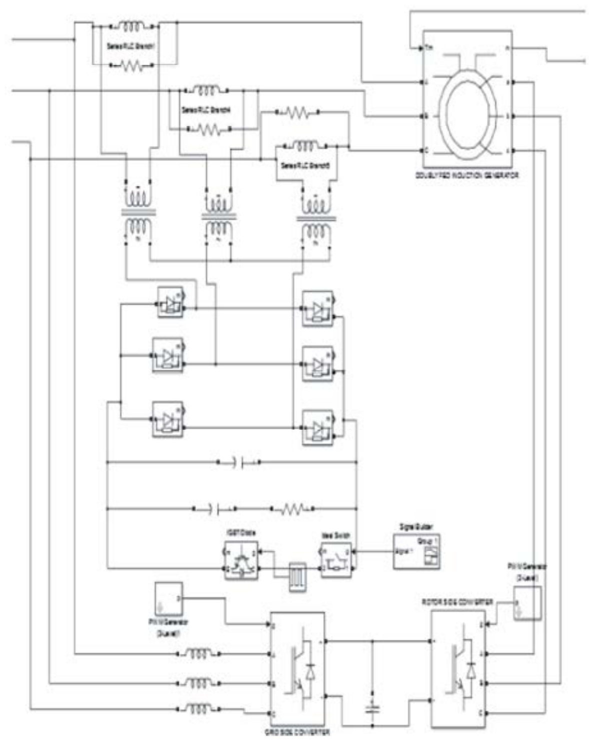

Fig. 4: STFCL Topology

Simulation And Results: Fig. 5 shows the simulation diagram of Doubly fed induction generator associated with wind turbine. The wind turbine is designed with pitch control mechanism. The VI measurement block is to get the waveforms of voltage and current in per unit.

The above graph shows the power curve of wind turbine for different wind velocity. The power output of this wind turbine is 1.5 MW. Hence the wind turbine is designed with pitch control mechanism.

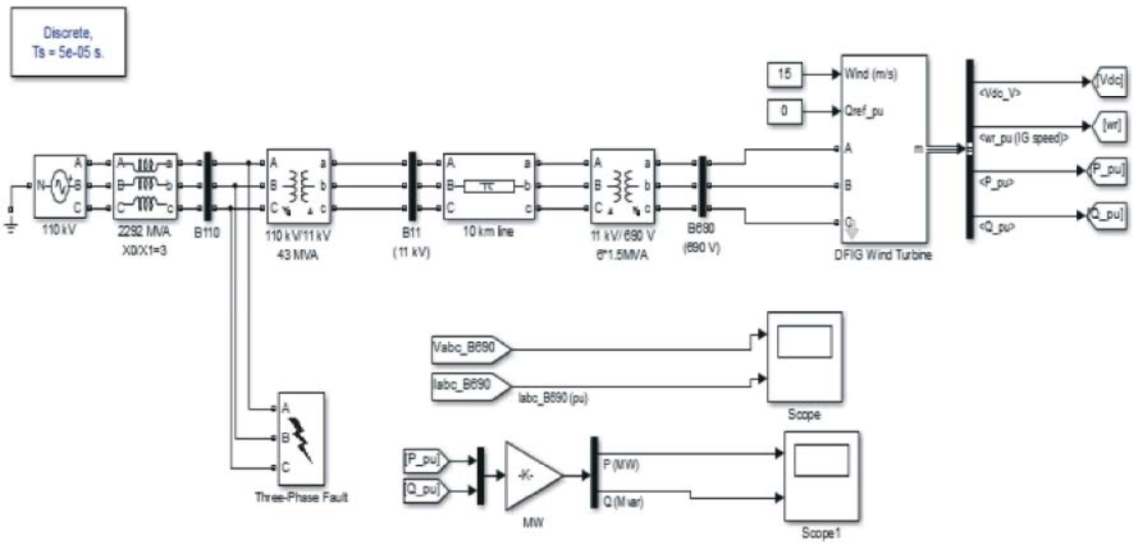

Fig. 5: Simulation Diagram

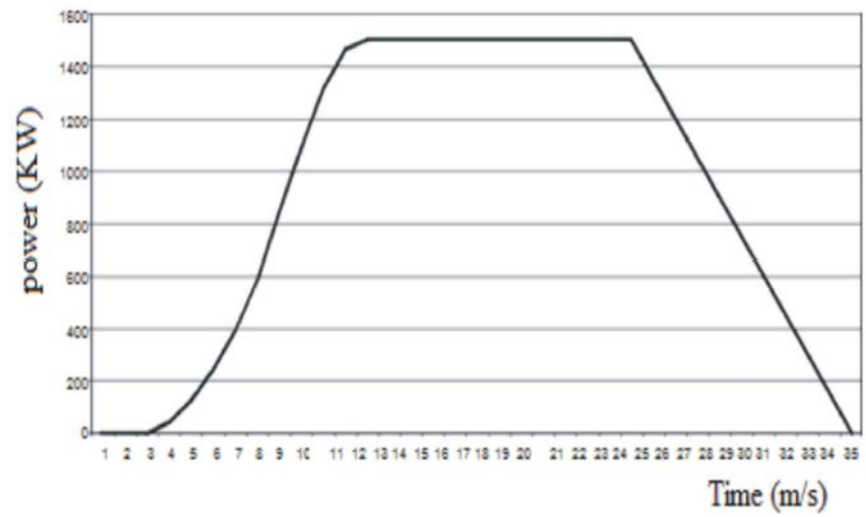

Fig. 5: Wind turbine power curve

Fig. 6: Rated wind speed

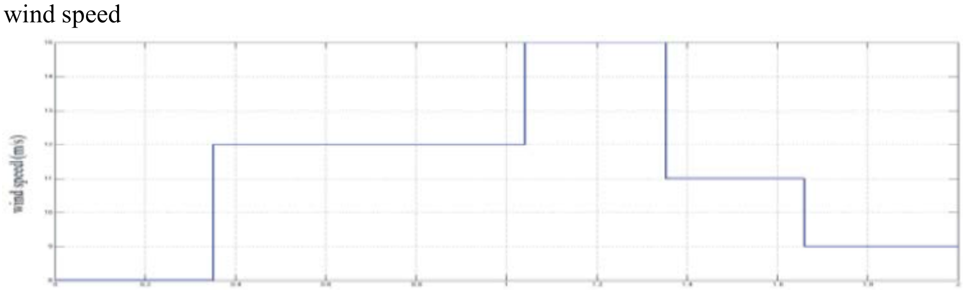

Fig. 7: Step change in wind speed

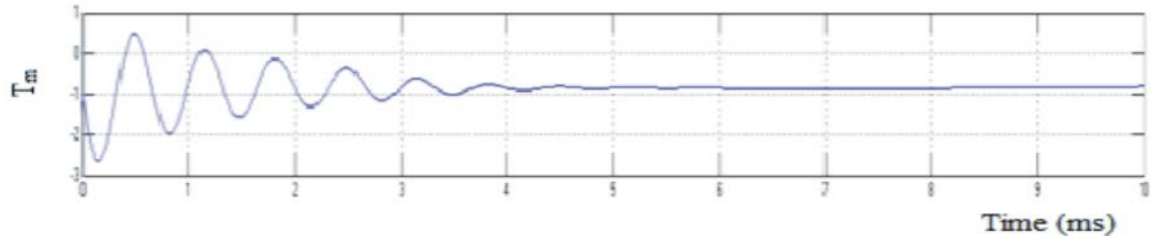

Fig. 8: Mechanical Torque

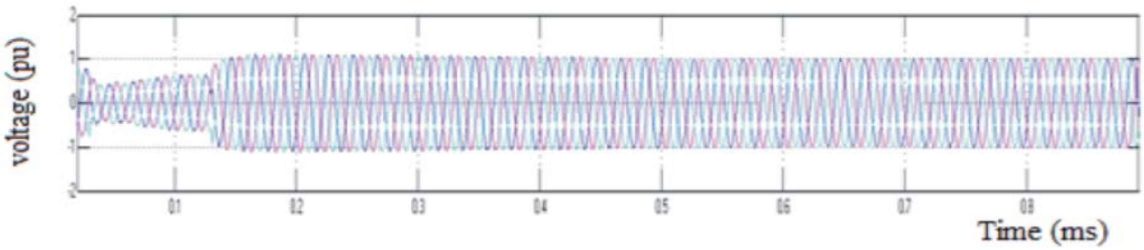

Fig. 9: Grid voltage under normal operating condition

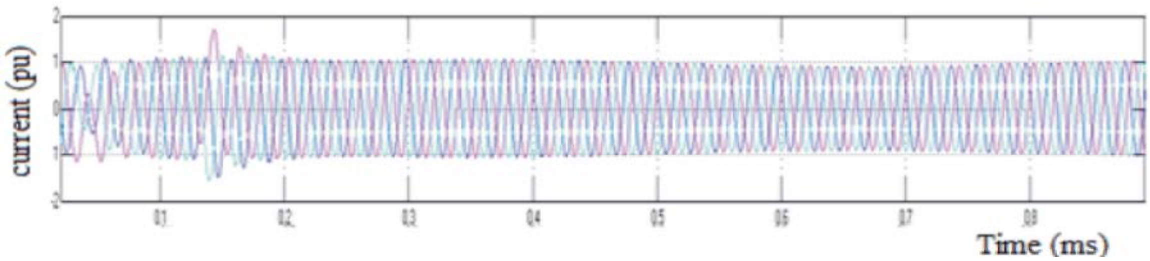

Fig. 10: Grid current under normal operating condition

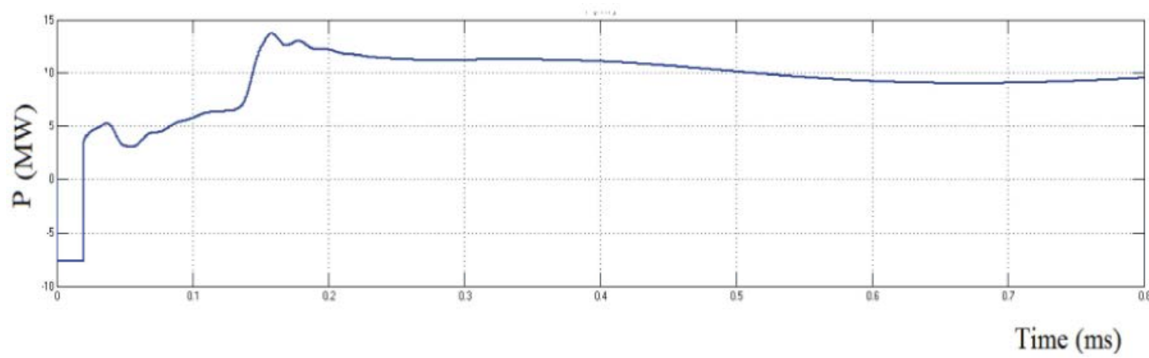

Fig. 11: Active Power under normal operating condition

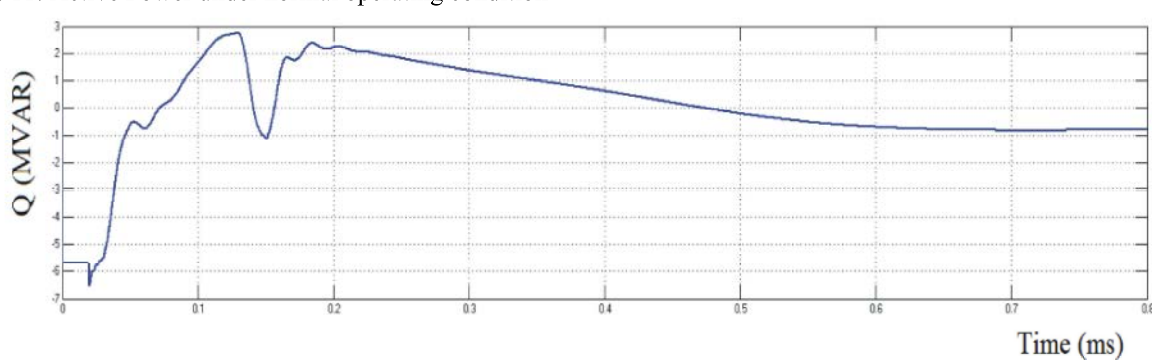

Fig. 12: Reactive power under normal operating condition

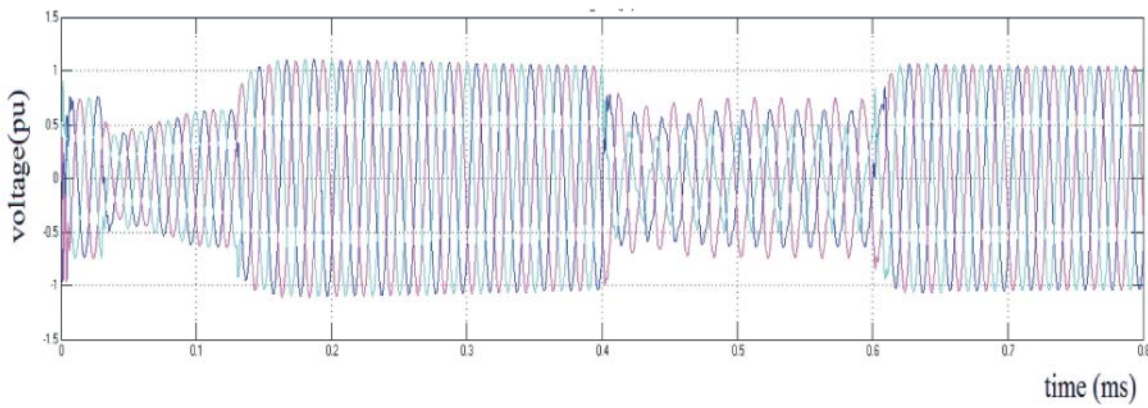

Fig. 13: Output voltage under LVRT

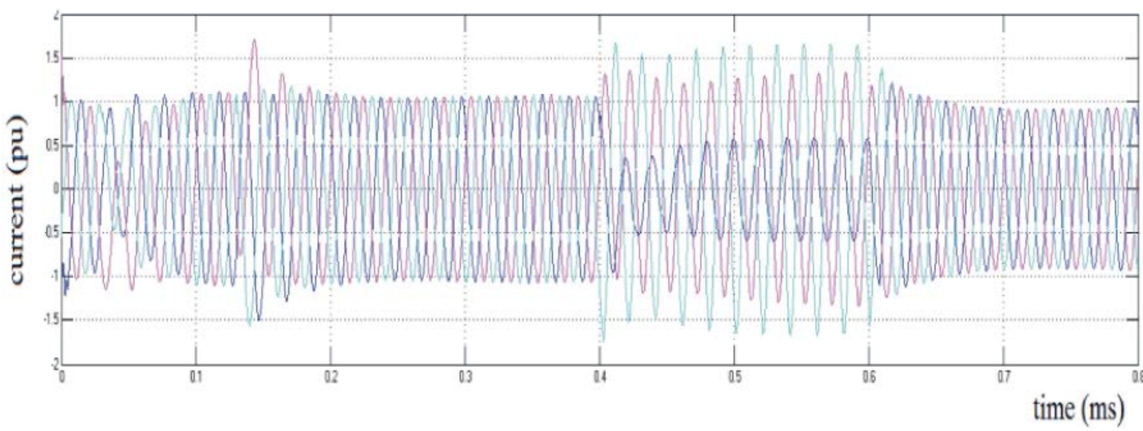

Fig. 14: Output current under LVRT

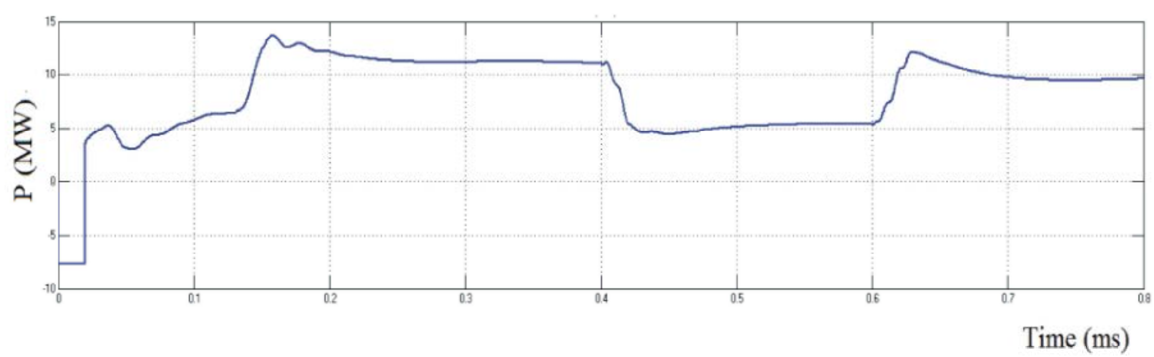

Fig. 15: Active Power under Low voltage issue

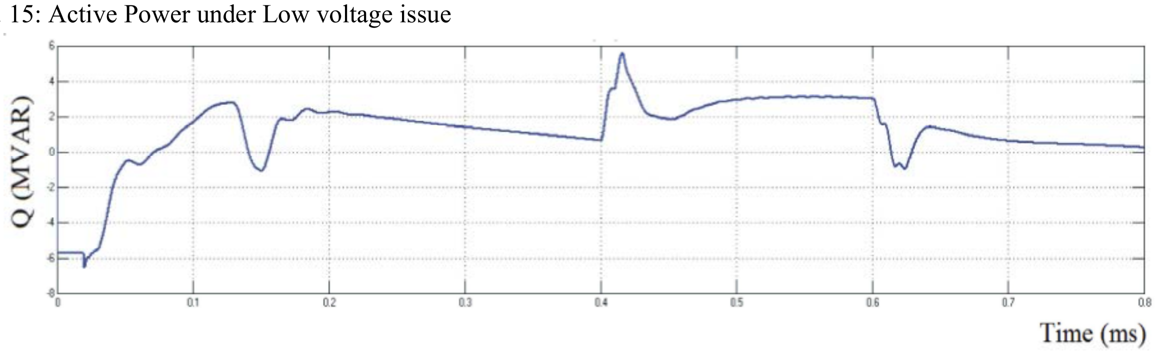

Fig. 16: Reactive Power under Low voltage issue

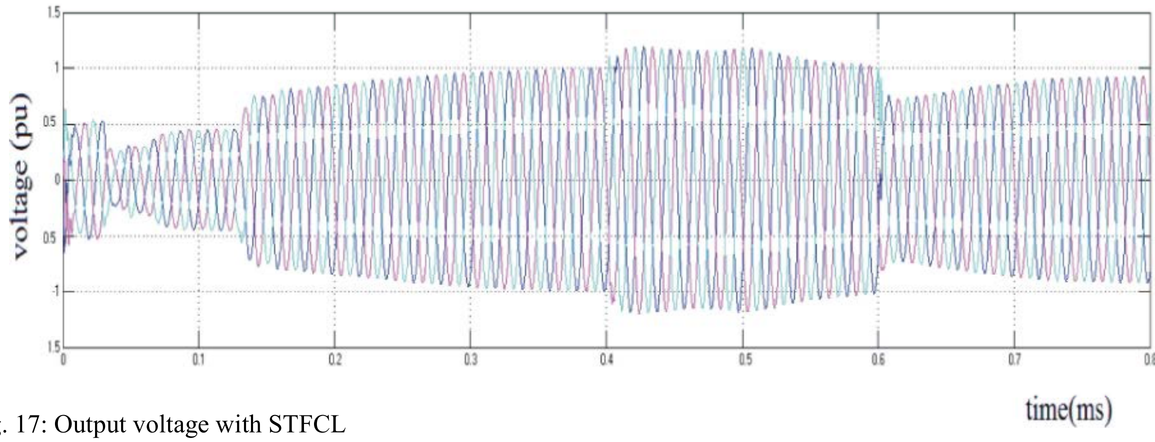

Fig. 17: Output voltage with STFCL

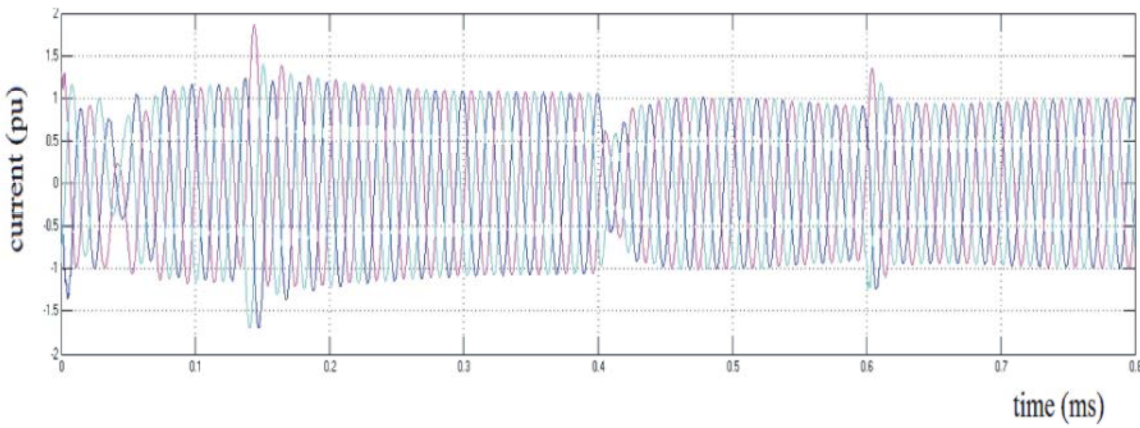

Fig. 18: Output current with STFCL

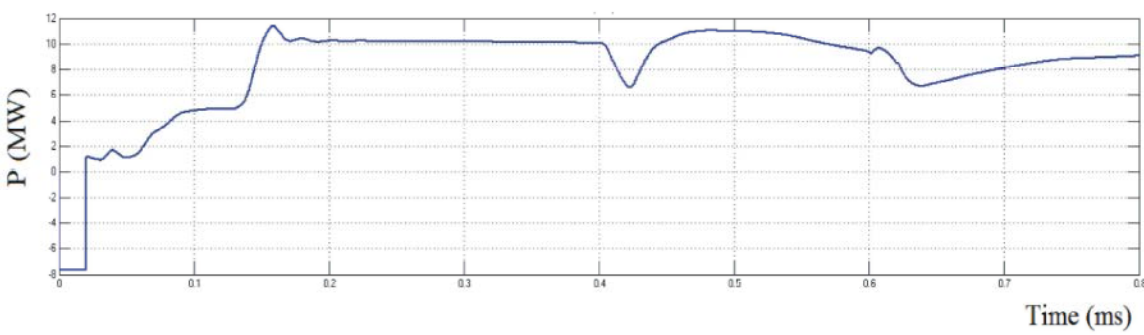

Fig. 19: Active Power with STFCL

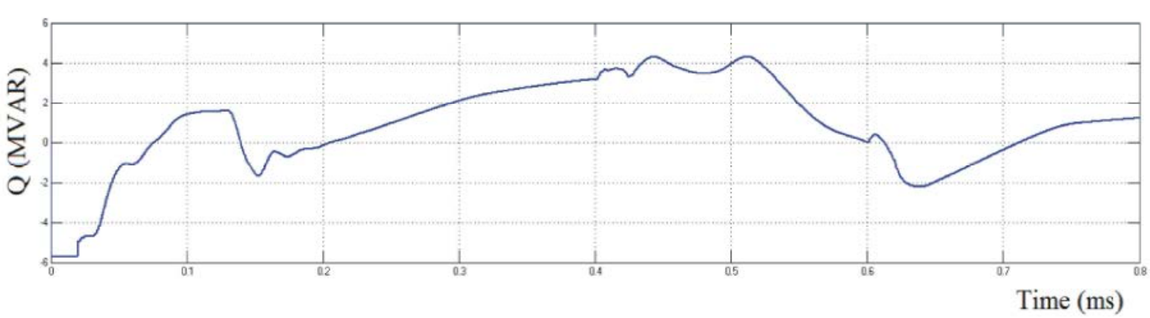

Fig. 20: Reactive Power with STFCL

The above Fig. 9 shows the graph between toque (N-m) and time (ms). it is in the range 8.185 kN-m.

Fig. 9 and Fig. 10 shows the output voltage and output current under normal conditions respectively. Initially it has the voltage fluctuations due to grid integration during the time range of 0 to 0.15(ms). Fig. 11 and 12 shows the Active power and Reactive power respectively during the normal condition where as six wind turbines are connected to made a wind farm. Each wind turbine range is 1.5 Mw so that the wind farm gives the power in the range of 9 MW.

Fig. 11 and Fig. 12 shows the output voltage and output current under low voltage conditions respectively. Three phase fault is introduced over a period of 0.4 to 0.6 (ms). Voltage dip and over current are shown in the above graph). Fig 15 and 16 shows the Active power and Reactive power respectively during low voltage issue whereas the active power got dip in the fault period of 0.4 to 0.6.

Fig. 13 and Fig. 14 shows the output voltage and output current response with STFCL.Hence the voltage dip occurred due to grid fault is compensated using STFCL. Fig. 19 and 20 shows the Active power and Reactive power respectively during low voltage issue whereas the active power is compensated with the help of STFCL during the fault period of 0.4 to 0.6.

CONCLUSION

LVRT issue in wind turbine driven DFIG leads to disconnection of wind turbine from grid. This is mainly due to power electronic converter which is sensitive to the low voltage problems. If voltage dip occurs at the grid side, it affects the generator causing the mismatch between the power being produced and delivered to the grid. To overcome this issues STFCL can be implemented whereas it has outstanding LVRT enhancing capability. Therefore the wind turbine remains connected to the grid under this issue. The STFCL inserts fault-current-limiting inductors into the stator branches upon occurrence of a grid fault, which helps weaken the rotor back EMF voltage and reduce the rotor over current. The LVRT capability of RSC is therefore effectively strengthened. It absorbs the excessive energy stored in the stator and helps prevent semiconductor devices from overvoltage during the LVRT process and also help the DFIG to ride through the most serious grid fault, which will not request much additional cost. An understanding of wind turbine driven DFIG is made by conducting a detailed simulation study from the developed MATLAB/ SIMULINK model for various operating conditions.

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