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Fault Ride-Through capability of DSTATCOM for Distributed Wind Generation System

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ABSTRACT

In this paper, fault ride through analysis of a low voltage distribution system augmented with distributed wind generation using squirrel cage induction generator and distribution static compensator (DSTATCOM) is carried out through modeling and simulation study in MATLAB. The impact of unbalanced (single line to ground) fault in a low voltage distribution system in normal and severe conditions is studied and analyzed in details. Analysis on system instability is also shown in case of sever fault condition. A distribution Static Compensator (DSTATCOM) is used to improve fault ride through (FRT) capability of wind generation system by compensating positive sequence voltage. A comparison of dynamic response of the system with and without DSTATCOM and effects of DSTATCOM on voltage and generator speed are presented. The simulation results shows that DSTATCOM is capable of reducing the voltage dips and improving the voltage profiles by providing reactive power support to distributed wind generation system under unbalanced fault condition and enhances the fault ride through capability of the wind generator.

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1. INTRODUCTION

Wind energy conversion systems (WECS) are considered as distributed generations (DGs) [1-4], which are connected to the distribution network of a power system. Unlike conventional electric energy generating systems such as thermal, nuclear and hydropower plants which are centralized and are the main sources of electric power generation, DGs are decentralized and located in weaker parts of the power grid. Conventionally, wind turbines are designed with controller to get disconnected in the event of major system disturbances such as lightening strikes, equipment failures, and downed power lines. However, this loss of generation affect the stability and can lead to cascaded trip and loss of revenue. These issues lead to the necessity of a set of comprehensive grid codes. The Electricity grid codes [5-7] are the regulatory standards made by the International Electrotechanical Commission (IEC) to develop, maintain, and operate the power system grid in the most secured, reliable, economical and efficient manner. The grid codes define the operational boundary of a wind turbine connected to the network in terms of frequency, voltage tolerance, power factor and fault ride through (FRT). FRT is regarded as one of the main challenges to the wind turbine manufacturers. The wind turbine should remain stable and connected during the fault, while voltage of WECS at Point of Common Coupling (PCC) drops to 15% of the nominal value for 150 ms [8] as shown in the Figure 1. The turbine is allowed to disconnect from the grid only when the grid voltage falls below this point.

In the past few decades several types of wind turbine driven generators are currently prevalent in the industry i.e. constant speed with Squirrel Cage Induction Generator (IG), Variable Speed generators like Doubly-Fed Induction Generators (DFIGs), Direct Drive Permanent Magnet Synchronous Generator (PMSG), coupled with gearbox & full rating power converters.

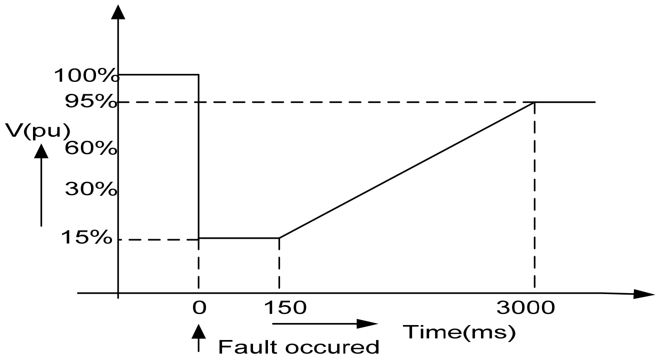

Figure 1. Fault Ride Through (FRT) capability

However, induction generator (IG) based wind energy conversion system still represent 15% of the installed wind power in Europe [9] which is significantly high and hence there is a need to enhance the performance of such type of generators. Fixed speed induction generator consumes large amount of reactive power during voltage dips, so it can easily get unstable . Earlier fixed size mechanically switched capacitors were used at the terminal of SCIG to recover the voltage drop. However, these capacitors provide the fixed compensation and they cannot enhance the transient stability performance of the system. To improve the transient stability of the system, dynamic voltage control solutions like SVC (Static VAR Compensat or) and STATCOM are more prevalent [10-12]. STATCOM has an edge over SVC in terms of its superior operational characteristics, lesser cost, smaller size etc, and moreover, it is not affected by the voltage variation at PCC. The STATCOM acts as a sink of reactive power (inductor) and source of reactive power (capacitor) which enables the STATCOM to improve the voltage profile of the system and reduce voltage fluctuation in terms of grid disturbances.

In *transmission* system STATCOM has also been used for improving transient stability margin of wind farms [13, 14], enhancing FRT capability by using indirect torque control of induction machines [15].

The use of DSTATCOM in *distribution* system to improve power quality i.e. voltage sag, voltage swell and unbalancing of the system is described [16-18]. The power quality improvement in an integrated power system with wind farms using DSTATCOM is explained [19-21]. The DSTATCOM is one of the custom power devices which injects a set of three unbalanced compensating currents to make the system balanced as compared to STATCOM which injects balanced currents.

In this paper carrier less hysteresis current control technique is used which is the simple, robust as compared to other techniques [22]. In addition to improve the voltage profile of the system as done in the previous work [23], voltage stability analysis is also done in this work by considering low value of short circuit ratio(SCR). The proposed system has been modeled and simulated using MATLAB/Simulink. The simulation results demonstrate effectiveness of DSTATCOM in developing fault ride through capability of the WECS and maintaining voltage stability of low voltage distribution system by controlling the speed of the wind generator and supplying the required reactive power.

2. SYSTEM DESCRIPTION

The proposed system consists of 11kV, 450kVA, 50Hz low voltage distribution system along with a wind generation system (WGS) connected directly to the grid and DSTATCOM as shown in Figure 2. The low voltage distribution system is radial and supplied from 11kV/415V transformer. Three phase balanced load rated at 20kW and 10kW, 12kvar is connected at the end of feeder 1 and 2 respectively. Voltage at the point of common coupling (PCC) is 415V. Wind generation system comprising of a 22kW Squirrel Cage Induction Generators (SCIG) driven by fixed speed wind turbine. A DSTATCOM supplies the lagging or leading current to manage the constant terminal voltage at PCC during fault conditions.

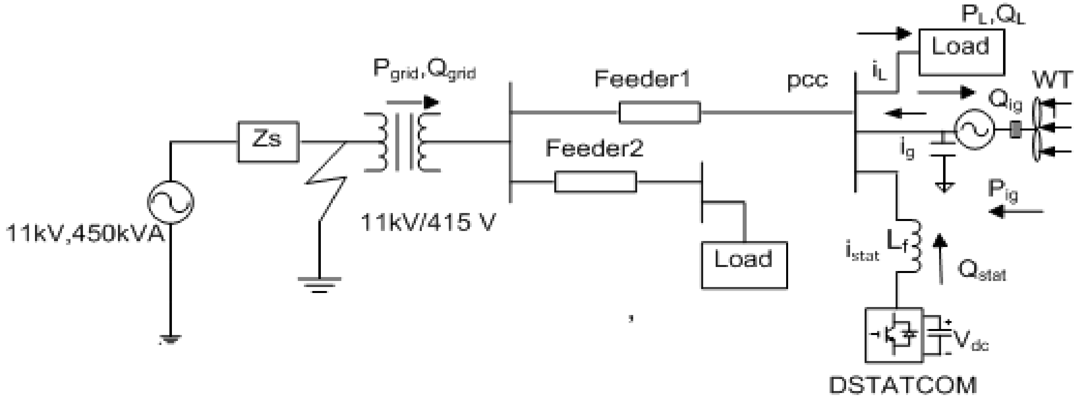

Figure 2. Basic Structure of Test System

The short circuit ratio (SCR) of the distribution system is defined as

$$R_{sc} = \frac{S_{sc}}{S_r} \tag{1}$$

Where S_{sc} – Short circuit power level of the grid
S_r – Rated turbine power level

The SCR has been reduced to 3 to simulate the severe fault condition in the weak grid system. Any grid having SCR less than 10 can be called as a weak grid [24].

3. DSTATCOM CONTROL SCHEME

The proposed control technique has been shown in Figure 3. However, carrier less hysteresis current control technique requires a balance three phase voltage at PCC. As in the case of unbalanced fault this voltage is no longer balanced, it consists of positive and negative sequence components. Therefore, in the proposed method sequence reference frame (SRF) technique is used to extract positive sequence components [25] for ideal compensation. Positive sequence components are separated by the following equations

$$\begin{bmatrix} v_\alpha \\ v_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} \tag{2}$$

$$\begin{bmatrix} {v_d}^+ \\ {v_q}^+ \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \cos(\omega_1 t) & \sin(\omega_1 t) \\ -\sin(\omega_1 t) & \cos(\omega_1 t) \end{bmatrix} \begin{bmatrix} v_\alpha \\ v_\beta \end{bmatrix} \tag{3}$$

Where ω_1 is the fundamental frequency and ${v_d}^+$ and ${v_q}^+$ are positive sequence d and q component of voltage These components are passed through low pass filter and converted back into α,β and abc coordinate to get positive sequence component as given by eq. (4) and (5) respectively.

$$\begin{bmatrix} {v_\alpha}^+ \\ {v_\beta}^+ \end{bmatrix} = \begin{bmatrix} \cos(\omega_1 t) & -\sin(\omega_1 t) \\ \sin(\omega_1 t) & \cos(\omega_1 t) \end{bmatrix} \begin{bmatrix} {v_d}^+ \\ {v_q}^+ \end{bmatrix} \tag{4}$$

$$\begin{bmatrix} v_{a^+} \\ v_{b^+} \\ v_{c^+} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} {v_\alpha}^+ \\ {v_\beta}^+ \end{bmatrix} \tag{5}$$

Similarly negative sequence components are calculated. Then the grid synchronization angle (θ) is extracted by applying the positive sequence components to phase locked loop (PLL). The grid synchronization angle is utilized to generate the in-phase unity components (ua, ub and uc) and quadrature unity components (wa, wb and wc) as given below.

$$u_a = \sin(\theta) \tag{6}$$

$$u_b = \sin\left(\theta - \frac{2\pi}{3}\right) \tag{7}$$

$$u_c = \sin\left(\theta + \frac{2\pi}{3}\right) \tag{8}$$

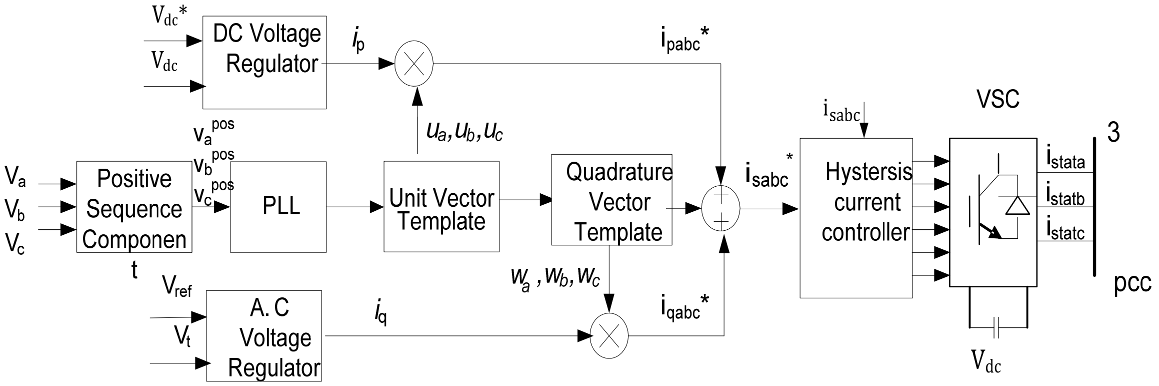

Figure 3. Control scheme of DSTATCOM

$$\begin{bmatrix} w_a \\ w_b \\ w_c \end{bmatrix} = \frac{\sqrt{3}}{2}\begin{bmatrix} 0 & -2/3 & 2/3 \\ 1 & 1/3 & -1/3 \\ -1 & 1/3 & -1/3 \end{bmatrix}\begin{bmatrix} u_a \\ u_b \\ u_c \end{bmatrix} \tag{9}$$

The in phase component of reference source currents are derived by multiplying d axis component of current i_p with unit vector template and quadrature components of reference source currents are obtained by multiplying i_q with quadrature vector template. Where i_p is the output of PI controller regulating dc bus voltage of DSTATCOM and i_q is obtained by comparing maximum value of desired A.C reference voltage (V_{tref}*) with voltage at PCC.PI controller processes the voltage error. The amplitude of reactive current to be produced by the STATCOM is decided by the output of the PI controller in AC voltage control loop.

4. SIMULATION RESULTS

Fault ride through analysis of a wind generation system is analyzed for unsymmetrical faults with and without static compensator in a low voltage distribution system. The Sign convention is positive for active/reactive power flow from wind generator and DSTATCOM towards PCC. The various fault conditions have been detailed out below showing the impact of DSTATCOM.

4.1. System Response to Single Line to Ground Fault with and without DSTATCOM in a Low Voltage Distribution System

The performance of the 11kV, 450kVA, and 50Hz low voltage distribution system is studied by simulating a single phase to ground fault at instant t=0.5s with clearance time 150ms. Figure 4 shows the positive and negative sequence component of voltage at the point of common coupling (V_{pcc},+ V_{pcc}--), rms voltages of each phase at pcc (V_{tabc}), rms voltages of each phase (V_{gabc}) near grid, speed of rotor (w), electrical and mechanical torque (T_e,T_m) without DSTATCOM. The unbalanced fault leads to negative sequence voltage at PCC. Positive sequence component of voltage V_{PCC}+ at Bus 3 and V_{ga} (voltage of phase a) at Bus 1 falls to 0.4pu and 0.5pu respectively during the fault. The speed increases to 1.16 pu and electrical torque is oscillating at double frequency due to presence of negative sequence component of current. Mechanical torque (T_m) is constant as wind speed is constant.

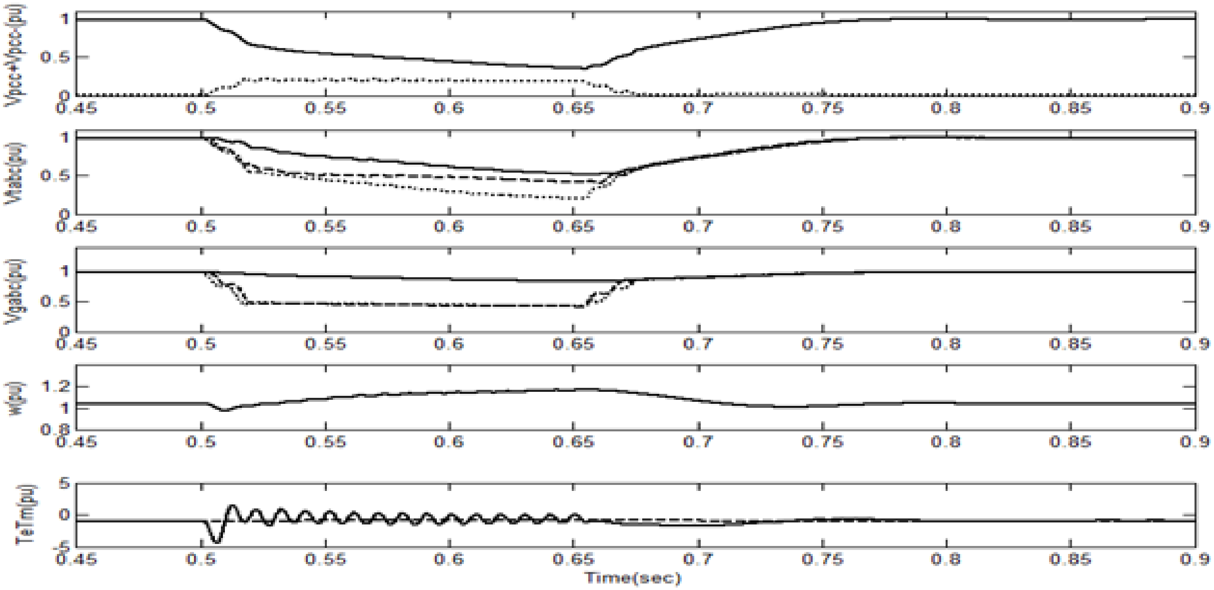

Figure 4. Performance under single line to ground fault without DSTATCOM

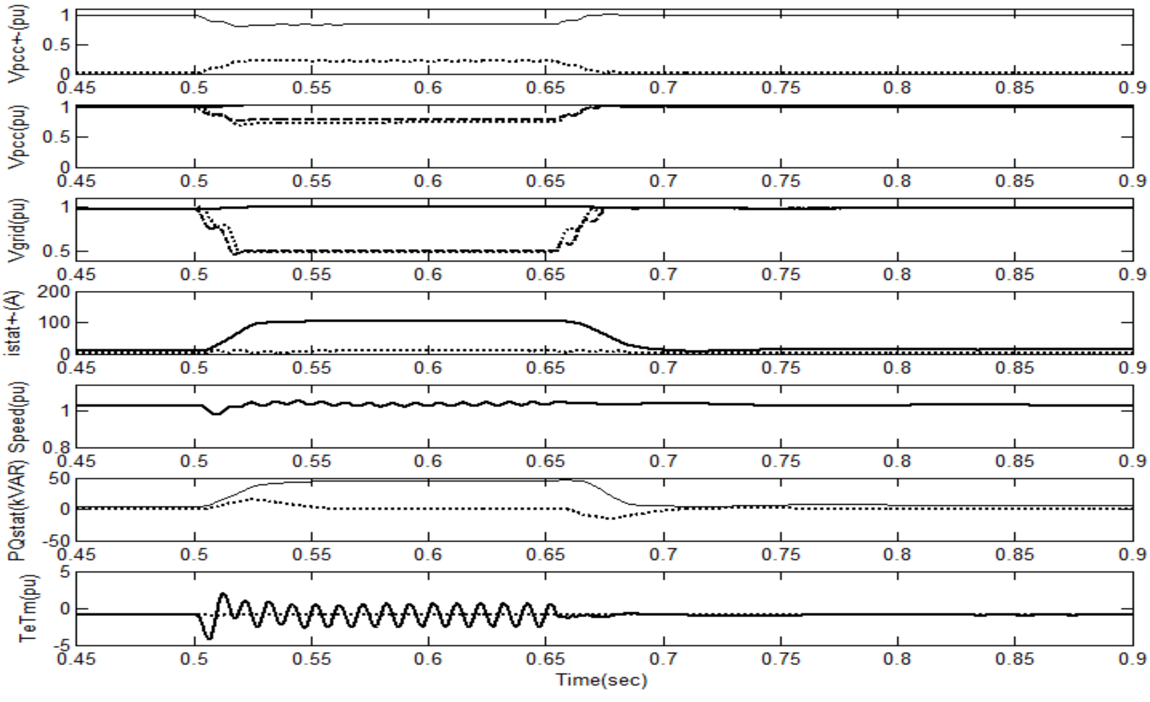

Figure 5. Performance under single line to ground fault with DSTATCOM

Figure 5 includes DSTATCOM currents (i_{stat}) and active and reactive power of DSTATCOM (P_{stat}, Q_{stat}) in addition to the results of Figure 4. It has been observed that DSTATCOM helps in reducing the positive sequence voltage dip and time to clear fault by supplying reactive power during fault. The values of voltage at point of common coupling for each phase, speed of generator and time to clear the fault for different types of fault has been given in Table1. As DSTATCOM is used to control only the positive sequence component, electrical torque (Te) is still oscillatory. In this simulation, instability problem does not arise as the system returns back to stable operation after removal of fault. However, DSTATCOM helps in improving voltage profile of the system by reducing the voltage dip and time to clear the fault.

4.2. System Response to Single Line to Ground Fault with and without DSTATCOM under Severe Fault Condition

A single line to ground fault is simulated at t=0.5s for 150ms in the same system as considered in the previous cases. However, in this case a weak low voltage distribution system with short circuit ratio of three (3) has been considered for simulation of severe fault condition. The voltage instability is a major concern in such a system. In this simulation, instability problem arises as the system does not return back to stable operation after removal of fault. Figure 6 shows that speed of induction generator monotonically increases which indicates clear instability.

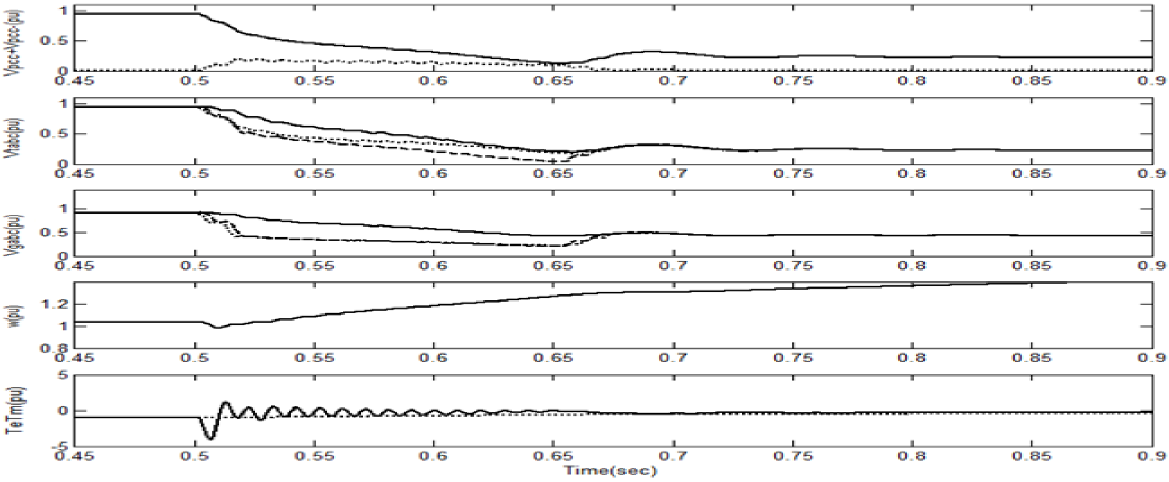

Figure 6. Simulation results under severe single line to ground fault without DSTATCOM

However, DSTATCOM helps to improve voltage stability by providing required reactive power. Figure 7 exhibits that wind generator get stabilized with the use of DSTATCOM and regain its original speed after fault clearance.

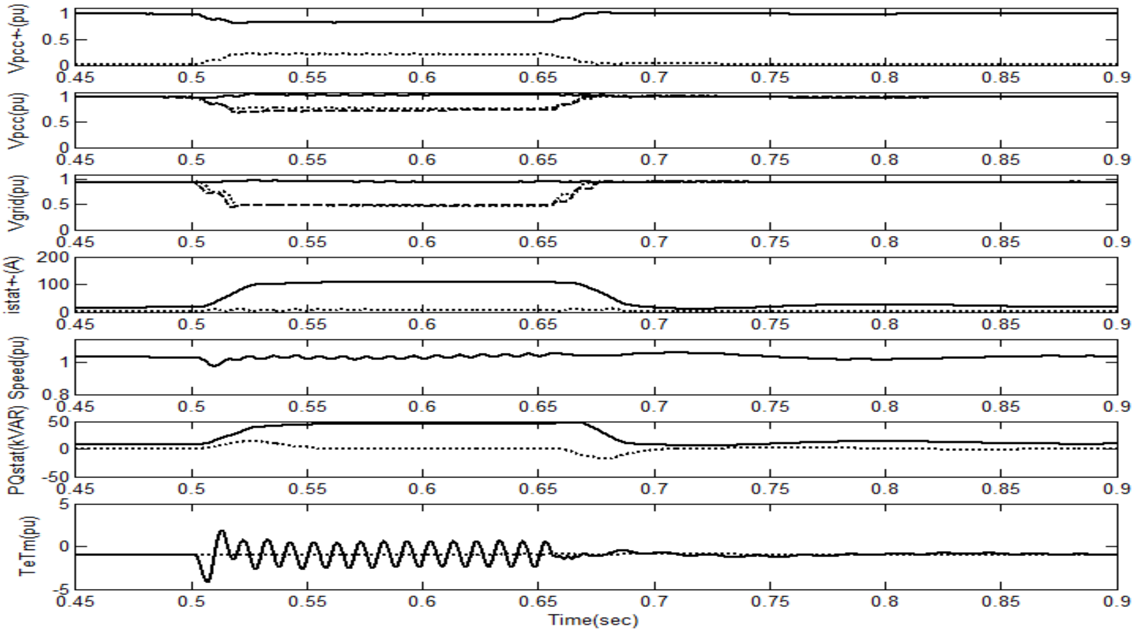

Figure 7. Simulation results under severe single line to ground fault condition with DSTATCOM

Table 1. RMS voltages of each phase for l-G fault without and with controller in a low voltage distribution system

	Rms value of each phase (line to ground fault) (pu)	Speed (pu)	Time to clear the fault (sec)	Rms value of each phase (line to ground fault)(pu) Severe case	Speed(pu)	Time to clear the fault (sec)
Without controller	V_{ta}=0.2 V_{tb}=0.5 V_{tc}=0.4	1.16	0.1	V_{ta}=0 V_{tb}=0.18 V_{tc}=0.19	increasing	Not cleared
With controller	V_{ta}=0.55 V_{tb}=1.0 V_{tc}=0.64	1.03	0.03	V_{ta}=0.55 V_{tb}=1.0 V_{tc}=0.53	1.02	cleared in 0.04

5. CONCLUSION

This paper analyzes the impact of unbalanced fault in a low voltage distribution system operating with distributed wind generation system and role of DSTATCOM in enhancing the fault ride through capability of WECS. A SCIG based WECS is being considered and effect of grid faults on electromagnetic torque and rotor speed is analyzed. Severity of fault with low short circuit ratio is demonstrated and effect of DSTATCOM in providing voltage support is described. The voltage stability of the system and FRT capability of WECS is evaluated through model equation and matlab simulation.

APPENDIX

The parameters of 11kV, 50 Hz low voltage distribution system are given below:
Feeder parameters:
R= 0.247 Ω, L=3.317mH for line length of 1km
Following are the parameters of 22kW, 415V, 50Hz, 4-pole Y - connected induction machine:
Rs = 0.251pu, Rr =0.2489pu, Xlr = Xls= 0.52pu, J = 0.304 kg-m2
DSTATCOM Parameters:
Lf = 5mH, Rf = 0.01Ω, Vdc=700volts and Cdc = 8000uF
Parameters of outer control loop (ac voltage regulator)
Kiq = 0.008, Kpq = 0.5
Parameters of DC voltage regulator
Kid = 10, Kpd = 0.6
Wind turbine Characteristics:
Turbine of rating 22kW
Cp=0.48, μ = 8.1
c1 = 0.5176, c2 = 116, c3 = 0.4, c4 = 5, c5 = 21 and c6 = 0.006

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