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Recovering the voltage dip analysis with STATCOM of DFIG in multi-machine wind farm

***Abstract**. In this study, voltage dip analysis of the wind power plant that is connected to 6 MW Double Feed Induction Generator (DFIG) was performed. During the operation of Multi-machine wind farm that is connected to network adaptation between 10 MVAr STATCOM and system was provided. Purpose of this adaptation, 3-phase fault analysis is to be able and the elimination of problems that may occur with induction motor run-stop.*

***Streszczenie.** Zaprezentowano analizę spadku napięcia w elektrowni wiatrowej podłączonej do generatorów indukcyjnych 6 MW typu DFIG. Analizę przeprowadzono na przykładzie wielomaszynowej farmy wiatrowej podłączonej do sieci z systemem 10 MVAr STATCOM. (**Analiza spadków napięcia w wielomaszynowej farmie wiatrowej z układem STATCOM**)*

Keywords: DFIG, STATCOM, voltage dip
Słowa kluczowe: generator DFIG, DSTATCOM, farmy wiatrowe.

Introduction

As a consequence of the increased environmental pollutions and that the use of energy has become limited all around the world, interest of renewable energy sources started to increase. The most important one of those is wind power [1]. Largely powerful wind power stations are manufactured as and they facilitate power systems. However, variant speed of winds leads in power loss, frequency change, voltage flicker, potential difference and power changes. So instability problems occur in the power systems which are connected to wind power station [2]. Flexible Alternative Current Transmission System (FACTS) equipments are used in resolving of those problems. Generally, FACTS devices are composed of Static Synchronous Compensator (STATCOM), Static Var Compensator (SVC), Static Synchronous Series Compensator (SSSC), Thyristor Controlled Series Compensator (TCSC) and Unified Power Flow Controller (UPFC). Low, as a result of his work on wind power plants, During the voltage stability and transient state stability he improved speed and angular speed and terminal voltage of wind farm [3]. It was observed that STATCOM is effective in eliminating of the quality problems which may occur at the power systems which work by connecting to wind power plant [4]. The design of STATCOM as a hybrid-battery energy storage provides active power, reactive power and voltage profiles to obtain more stability [5]. It was observed by the study that STATCOM gives efficient results on providing Steady-State and dynamic controlling at wind power stations [6]. Thanks to developing with different controls structures of wind power plant, STATCOM was seen to be important for stability analysis [7]. By meeting of the needs of reactive power in wind power stations, the study shows that STATCOM makes system controlling more reliable than normally used groups of capacitors [8, 9]. In order to recover the voltage flicker analysis, the instability states that may occur is prevented by using of STATCOM in wind power plants [10, 11]. Also in static and dynamic load analysis, in the bus voltage and reactive power changes of STATCOM, healing results are observed [12]. In wind power plants adapt to complex power systems, STATCOM gives better results on oscillation and subsynchronous resonance analysis than when the system normally works [13]. It is seen that HVDC, Offshore and hybrid works of wind power plant, STATCOM has an efficient role on system security [14].

Double feed induction generator

The doubly fed induction generator is the most commonly used machine for wind power generation. The rotor terminals are fed with a symmetrical three-phase voltage of variable frequency and amplitude. DFIG circuit model is illustrated in Fig.1 [15].

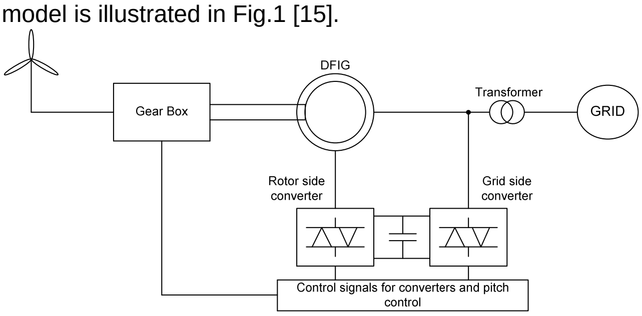

Fig.1. DFIG circuit model

Using the generator convention, the following set of dynamic equations results,

(1) $$V_{ds} = -R_s i_{ds} - W_s \psi_{qs} + \frac{d\psi_{ds}}{dt}$$

(2) $$V_{qs} = -R_s i_{qs} - W_s \psi_{ds} + \frac{d\psi_{qs}}{dt}$$

(3) $$V_{dr} = -R_r i_{ds} - SW_s \psi_{qr} + \frac{d\psi_{dr}}{dt}$$

(4) $$V_{qr} = -R_r i_{qs} - SW_s \psi_{dr} + \frac{d\psi_{qr}}{dt}$$

where: v – is the voltage, R_s – is the stator resistance , R_r – is the rotor resistance, i – the current, W_s – the stator electrical frequency, Ψ – the flux linkage and S – the rotor slip [16]. From the above set of dynamic equations d and q indicate the direct and quadrature axis components and s and r indicate stator and rotor quantities. The d – q reference frame is rotating at synchronous speed with the q axis a head of the d axis. It calculated using the following set equations,

(5) $$\psi_{ds} = -(L_s + L_m) i_{ds} - L_m i_{dr}$$

(6) $$\psi_{qs} = -(L_s + L_m) i_{qs} - L_m i_{qr}$$

(7) $$\psi_{qs} = -(L_s + L_m) i_{qs} - L_m i_{qr}$$

(8) $$\psi_{qr} = -(L_r + L_m) i_{qr} - L_m i_{qs}$$

with L_m is the mutual inductance L_s and L_r, are the stator and rotor leakage inductances respectively. The changes in generator speed that result from a difference in electrical and mechanical torque can be calculated using generator equations,

(9) $$\frac{dW_s}{dt} = \frac{1}{2H}(T_m - T_e)$$

(10) $$T_e = \psi_{dr} i_{qr} - \psi_{qr} i_{dr}$$

where: H – inertia constant, T_m – mechanical torque [17].

STATCOM

The STATCOM is modeled by a voltage source connected to the power system through a coupling transformer. The voltage of the source is the output of a voltage-sourced converter realizing the STATCOM. As shown in Fig. 2.

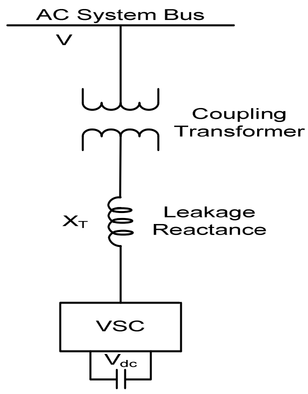

Fig.2. STATCOM circuit model

STATCOM connection is ac system bus. AC system voltage and the voltage-sourced converter terminal voltage is the same. This ensures that there is sending of only reactive power and no real power between the STATCOM and the AC system. The expressions sending current flowing from the STATCOM to the system and the reactive power injection are given as,

(11) $$I_s = \frac{V_2 - V_1}{X_T}$$

(12) $$Q_s = V_1^2\left(\frac{V_2 / V_1 - 1}{X_T}\right)$$

where: V_1 – AC system voltage, V_2 – voltage source converter terminal voltage, X_T – leakage reactance [18-19]. STATCOM transient stability is be effect operation parameter. These parameters are given as

(13) $$P - VI\cos(\delta - \theta) = 0$$

(14) $$Q - VI\sin(\delta - \theta) = 0$$

(15) $$P - V^2 G + kV_{dc}VG\cos(\delta - \alpha) + kV_{dc}VB\sin(\delta - \alpha) = 0$$

(16) $$Q + V^2 B + kV_{dc}VB\cos(\delta - \alpha) + kV_{dc}VG\sin(\delta - \alpha) = 0$$

where: P – active power, Q – reactive power, δ – bus voltage angle, θ – voltage source converter voltage angle, G – conductance, B – suseptance, k – modulation index, V_{dc} – capacitor voltage, α – capacitor voltage angle [20].

Wind Farm and STATCOM controller

Wind farm and STATCOM controller loops given Fig.3. After subtraction of the wind speed, active-reactive power values and reference values. By means of Proportion Integrated (*PI*) control method, the value of the desired signal of the wind controller is obtained. Desired signal value reaches to the bar which will be controlled through the control block. In STATCOM, bus voltage and capacitor voltage control bar by voltages depending on the reference values, differences through the control block.

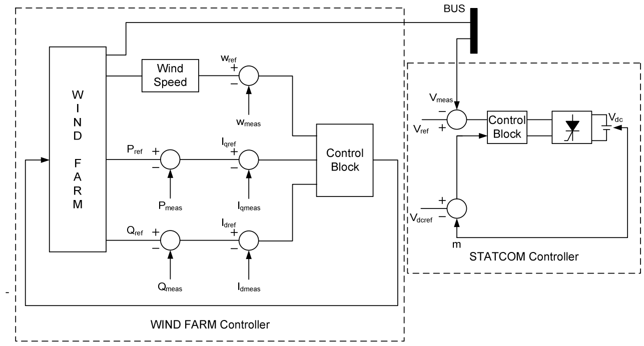

Fig.3. Wind Farm and STATCOM controller adaptation system

Voltage Dip Analysis

This standard is the fundamental reference for power quality monitoring instruments as it defines the methods for measurement and interpretation of results for power quality parameters in 50/60 Hz A.C. supply systems. Some basic definitions from are recalled in the following. Supply voltage dips are reductions of the voltage magnitude at a point in the electrical system below a specified threshold chosen for the purpose of detecting and followed by voltage recovery after a short period of time (dip duration), from half a cycle to a few seconds [21]. Their magnitudes depend on the short circuit level of the grid and the proximity of the fault to the affected bus bar. Their durations depend on the clearing time of the fault. After the fault is removed the system voltage may recover to a value higher than its pre-fault value [22]. Three phase fault and the short-term activation and deactivation of the induction motor come at the beginning of the problems that are generally created by voltage dip

Simulation of Study

In this study, 400V, 50 Hz and 6 MW wind farm is used .The wind farm generates power with the induction generator in it. The wind farm produces voltage regulation dependent on the voltage value of capacitor included in the back to back convertor with the control of the system frequency depending on the convertor, network voltage is assured to be equal. Simulated system is illustrated in Fig.3

Moreover, thanks to a booster transformer, voltage was raised from 400 volt to 34.5 KV. Network voltage and frequency values are regarded to be 154 KV 50 Hz. In the network, the voltage was reduced from 154 KV to 34.5 KV with the use of transformer as in the wind farm.

In the system, number 3 bus is connected to the network, number 1 bus is connected to wind farm, and number 2 bus has been examined as the bus that is involved in the area where the network and wind farm has been converted to 34.5 KV. In this simulation study, STATCOM 10 MVA has been used. The part to which wind farm has been attached a capacitor group with 11.5 MVAr. The aim is to analyze the circumstances in which number 2 bus is 3 phase fault; induction machine with 2.82 MW get into operation; and both 3 phase fault and induction machine get into operation, through STATCOM. Time required for the induction machine to outage and 3 phase fault to get into operation is between 0.3 and 0.45 seconds. In the second plan; however, induction motor gets in and outage within 0.3 and 0.4 second. The parameter values wind farm and STATCOM have taken on. In this study are shown on Table 1

System adaptation of DFIG and STATCOM is illustrated in Fig.4.

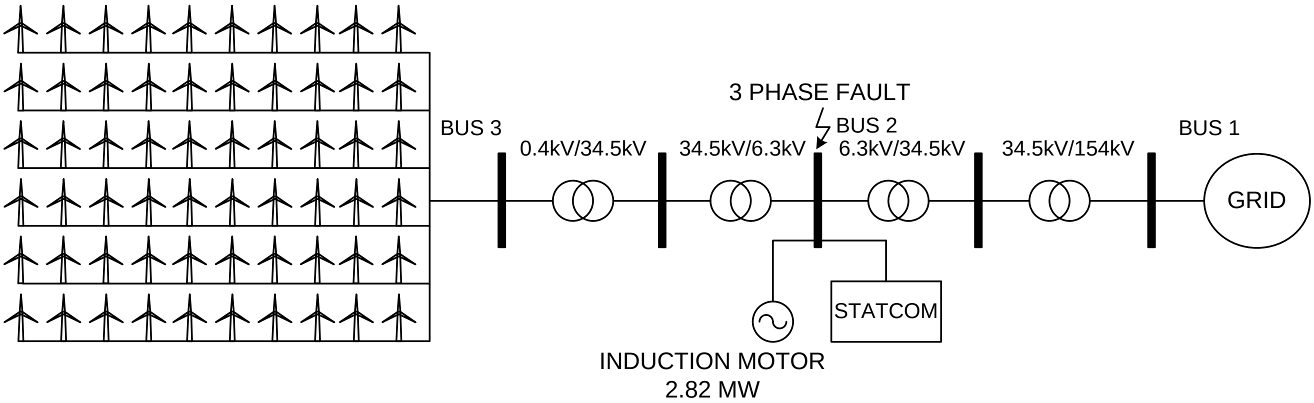

Fig.4. Simulation of System

Table 1. System parameter values

Wind Farm		STATCOM	
Grid voltage regulator gains	Kp=3 , Ki=400	STATCOM AC voltage regulator	Kp=5 Ki=1000
Power regulator gains	Kp=1.2, Ki=5.7	STATCOM DC voltage regulator	Kp=0.001 Ki=0.02
DC bus voltage regulator gains	Kp=0.02, Ki=0.5	Current Regulator	Kp=0.3 Ki=10
Stator Parameter	Rs=0.00706 Ls=0.171	Converter Impedance	R=0.0073 L=0.22
Rotor Parameter	Rr=0.005 Ls=0.156		

Simulations Results

In multi-machine wind turbines, at bus-2, three phase fault and rotor speed, bus voltage, bus-2 active and reactive power changes, DFIG rotor current and voltage changes, STATCOM voltage and reactive power changes are illustrated between Fig.5 and Fig.14

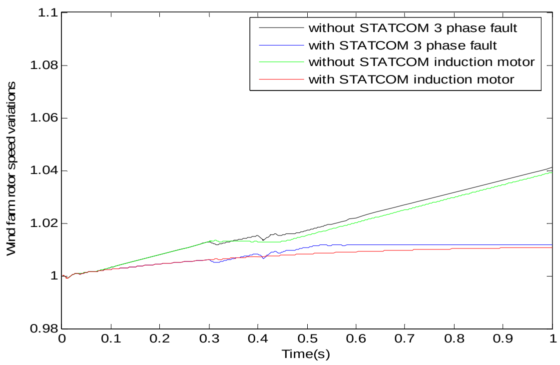

Fig.5. DFIG rotor speed variations

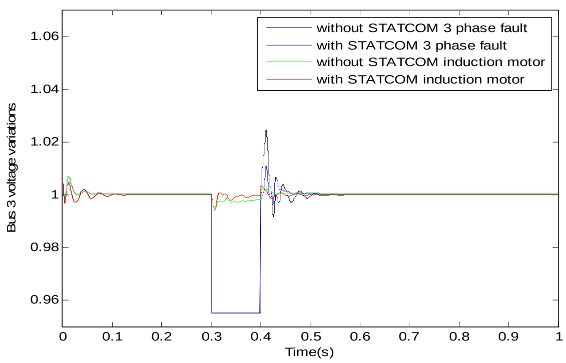

Fig.6. Bus 3 voltage variations

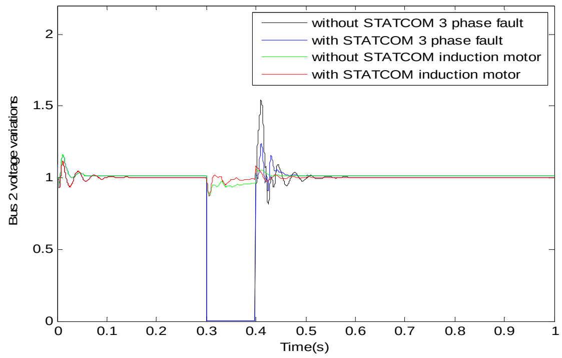

Fig.7. Bus 2 voltage variations

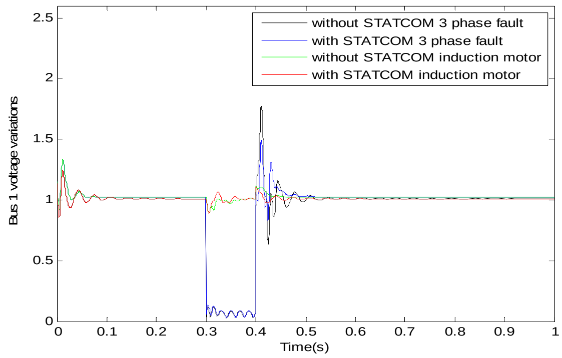

Fig.8. Bus 1 voltage variations

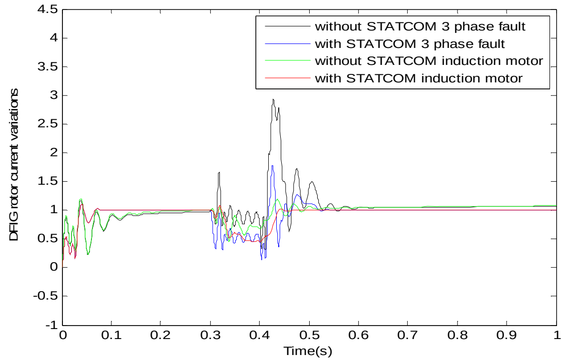

Fig.9. DFIG rotor current variations

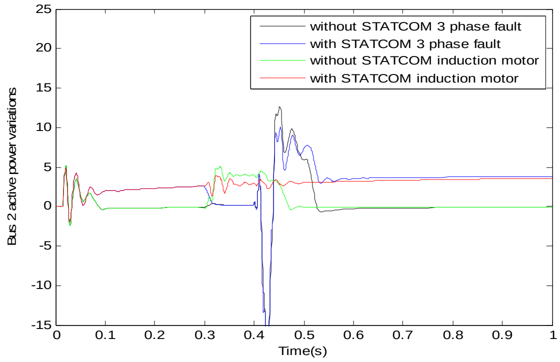

Fig.10. Bus 2 active power variations

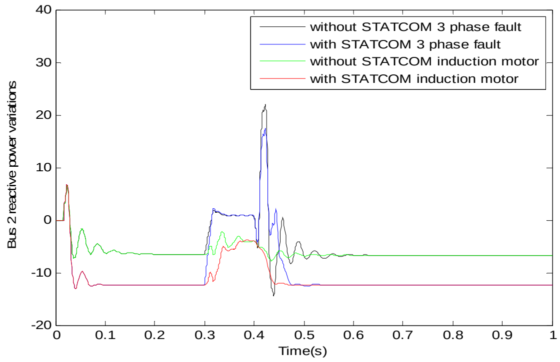

Fig.11. Bus 2 reactive power variations

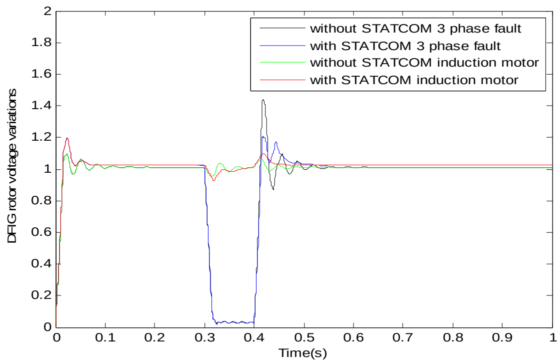

Fig.12. DFIG rotor voltage variations

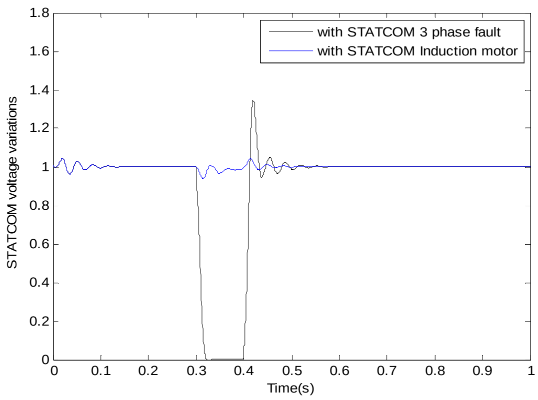

Fig.13. STATCOM voltage variations

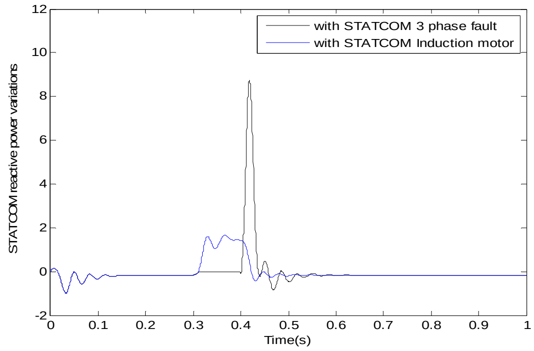

Fig.14. STATCOM reactive power variations

According to the results, during the three phase fault at bus-2, bus-3 is not affected so much however bus-1 is affected. During activation and deactivation of the induction motor it is observed that the connected bus voltage raised to 0.95 p.u from 0.77 p.u value.

During both three phase fault and activation and deactivation of the induction motor, rotor speed, bus voltage, bus-2 active and reactive power changes, DFIG rotor current and voltage changes, STATCOM voltage and reactive power changes are illustrated between Fig.15 and Fig.24.

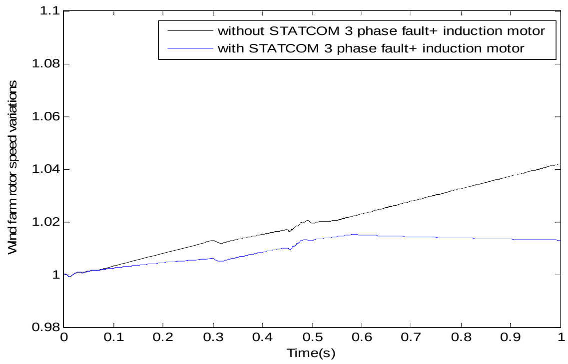

Fig.15. DFIG rotor speed variations (3 phase fault+induction motor)

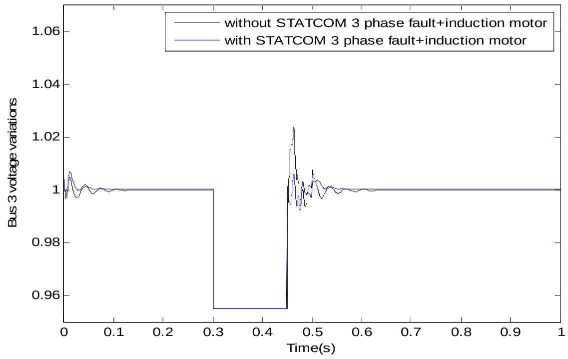

Fig.16. Bus 3 voltage variations (3 phase fault+induction motor)

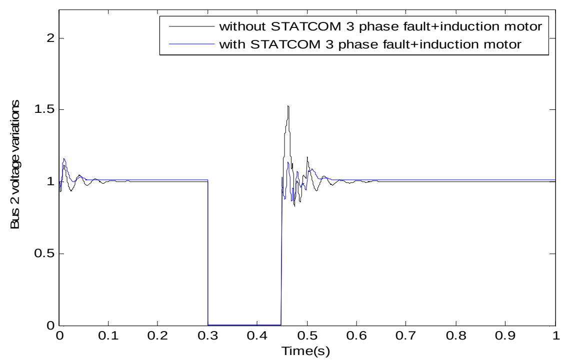

Fig.17. Bus 3 voltage variations (3 phase fault+induction motor)

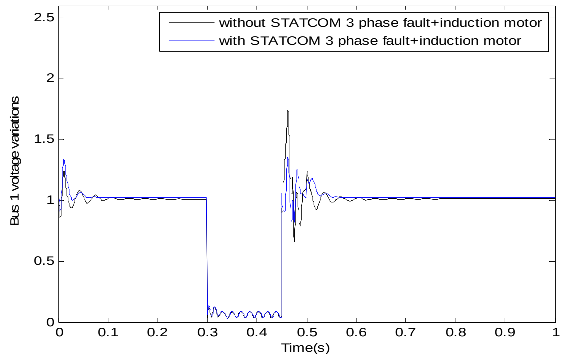

Fig.18. Bus 1 voltage variations (3 phase fault+induction motor)

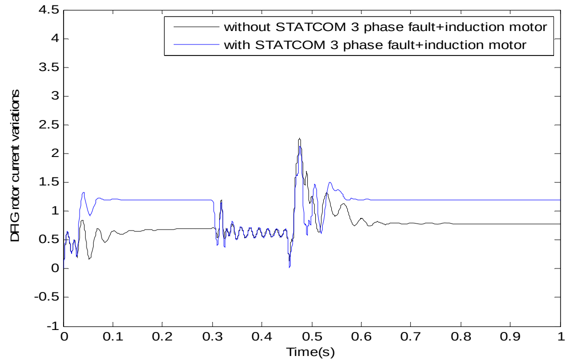

Fig.19. DFIG rotor current variations (3 phase fault+induction motor)

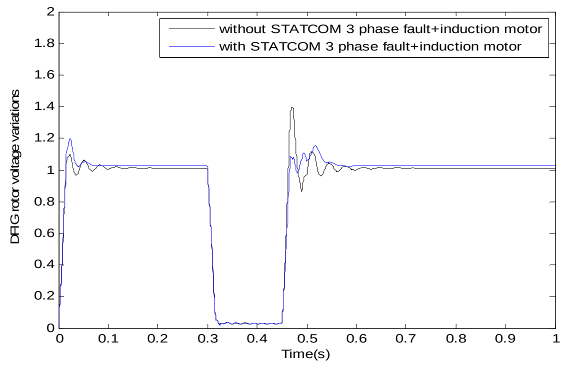

Fig.20. DFIG rotor voltage variations (3 phase fault+induction motor)

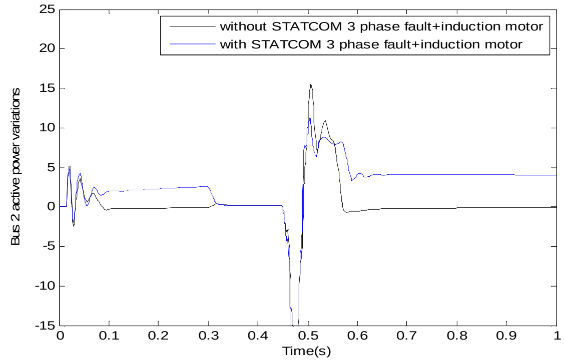

Fig.21. Bus 2 active power variations (3 phase fault+induction motor)

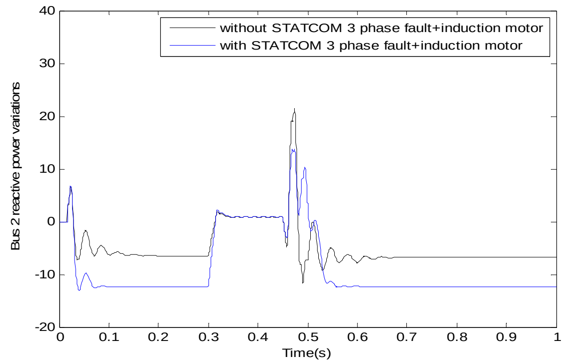

Fig.22. Bus 2 reactive power variations (3 phase fault+induction motor)

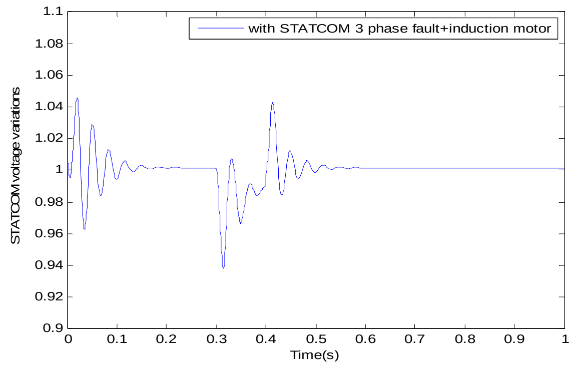

Fig.23. STATCOM voltage variations (3 phase fault+induction motor)

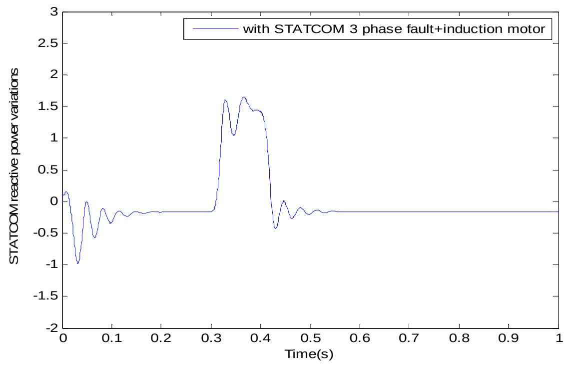

Fig.24. STATCOM reactive power variations (3 phase fault+induction motor)

According to the obtained results when STATCOM is connected to the system, rotor speed and stator voltages, bus voltages and active and reactive power become steady-state within a short period of time.

Conclusion

In wind power stations, it was seen that, STATCOM gives efficient results in eliminating the problems which may occur during both three phase fault and activation and deactivation of the induction motor. It is seen from the figures that although the induction motor is activated and deactivated in three phase fault, oscillations continues. Rotor speed change, bus voltage changes, current changes, bus-2 active and reactive power changes become steady-state in a short period of time after instability state. The oscillations which occur in voltage dip problems are also smothered. As seen in STATCOM voltage and reactive power changes, STATCOM has an important role on regulating system reactive power. Besides, it is observed that providing the adaptation of the STATCOM on multi-machine wind power plants can be advantageous in many respects.

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