Application of STATCOM for Transient Stability Improvement and Performance Enhancement for a Wind Turbine based Induction Generator

CH. AppalaNarayana, D. V. N. Ananth, K. D. Syam Prasad, CH. Saibabu, S. SaiKiran, T. PapiNaidu

Abstract: Voltage stability is a key issue to achieve the uninterrupted operation of wind farms equipped with squirrel cage induction generators (SCIG) during grid faults. A Static Synchronous Compensator (STATCOM) is applied to a power network which includes a SCIG driven by a wind turbine, for steady state voltage regulation and transient voltage stability support. The STATCOM is controlled by using PQ controller technique with voltage regulation as basic scenario. The system is implemented using MATLAB/ SIMULINK. Results illustrate that the STATCOM improves the transient voltage stability and therefore helps the wind turbine generator system to remain in service during grid faults. The time to reach steady state torque and speed without using vector control or direct torque control can also be achieved by using this STATCOM control technique.

Keywords: STATCOM, PQ control theory, induction machine, PWM.

I. INTRODUCTION

To have sustainable growth and social progress, it is necessary to meet the energy need by utilizing the renewable energy resources like wind, biomass, hydro, co-generation, etc. In sustainable energy system, energy conservation and the use of renewable source are the key paradigm. The need to integrate the renewable energy like wind energy into power system is to make it possible to minimize the environmental impact on conventional plant [1]. The integration of wind energy into existing power system presents a technical challenges and that requires consideration of voltage regulation, stability, power quality problems. The power quality is an essential customer-focused measure and is greatly affected by the operation of a distribution and transmission network. The issue of power quality is of great importance to the wind turbine [2].

There has been an extensive growth and quick development in the exploitation of wind energy in recent years. The individual units can be of large capacity up to 2 MW, feeding into distribution network, particularly with customers connected in close proximity [3].

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CH.Appala Narayana, VITAM College of Engineering, Visakhapatnam.India.

D.V.N.Ananth, VITAM College of Engineering, Visakhapatnam.India.

K.D.Syam Prasad, VITAM College of Engineering, Visakhapatnam.India.

CH. Saibabu, JNTU Kakinada.

S.SaiKiran, VITAM College of Engineering, Visakhapatnam.India.

T. PapiNaidu, DADI Engineering Colleges

Today, more than 28000 wind generating turbine plants are successfully operating all over the world [6,9]. In the fixed-speed wind turbine operation, all the fluctuation in the wind speed are transmitted as fluctuations in the mechanical torque, electrical power on the grid and leads to large voltage fluctuations. During the normal operation, wind turbine produces a continuous variable output power. These power variations are mainly caused by the effect of turbulence, wind shear, and tower-shadow and of control system in the power system. There has to be a protection for such situations [4]. Thus, the network needs to manage for such fluctuations. The power quality issues can be viewed with respect to the wind generation, transmission and distribution network, such as voltage sag, swells, flickers [8], harmonics etc. However the wind generator introduces disturbances into the distribution network.

One of the simple methods of running a wind generating system is to use the induction generator connected directly to the grid system [5]. The induction generator has inherent advantages of cost effectiveness and robustness. However; induction generators require reactive power for magnetization. When the generated active power of an induction generator is varied due to wind, absorbed reactive power and terminal voltage of an induction generator can be significantly affected. A STATCOM control scheme in wind energy generation system is proposed under normal operating condition to allow the proper control over the active power production, reaching speed, torque steady state values. In the event of grid disturbances, STATCOM is used to control the machine speed not to reach below certain safe limit by injecting current based control technology has been proposed for improving the power quality which can technically manages the power level associates with the commercial wind turbines. The proposed STATCOM control scheme for grid connected wind energy generation for power quality improvement has following objectives.

- Unity power factor at the source side.
- Reactive power support only from STATCOM to wind Generator and Load.
- Simple bang-bang controller for STATCOM to achieve fast dynamic response.

Shunt Flexible AC Transmission System (FACTS) devices, such as the Static Var Compensator (SVC) and the Static Synchronous Compensator (STATCOM), have been widely used to provide high performance steady state and transient voltage control at the Point of Common Coupling (PCC) [6]. The applications of a SVC or a STATCOM to fixed-speed wind turbines equipped with induction generators have been reported in [7] for steady state voltage regulation, and in [1] for short-term transient voltage stability. The paper is organized as fallows. The Section II introduces the wind turbine model. The Section III introduces STATCOM controller and overall system design in MATLAB.

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The Section IV describes the topology for power quality improvement. The Sections V, VI, VII describes the result analysis, conclusions and references respectively.

II. WIND TURBINE MODEL

The aerodynamic model of a wind turbine can be characterized by the well-known CP-λ-β curves. CP is called power coefficient, which is a function of both tip-speed-ratio λ and the blade pitch angle β. The tip-speed-ratio λ is defined by

$$\Lambda = \omega_t R / v_w \quad (1)$$

where R is the blade length in m, ωt is the wind turbine rotor speed in rad/s, and vw is the wind speed in m/s. The CP-λ-β curves depend on the blade design and are given by the wind turbine manufacturer. Given the power coefficient CP, the mechanical power extracted by the turbine from the wind, is calculated by [1], [8]

$$P_m = \tfrac{1}{2}\rho A_r v_w^3 C_p(\lambda,\beta) \quad (2)$$

where ρ is the air density in kg/m^3; Ar = πR2 is the area in m2 swept by the rotor blades. At a specific wind speed, there is a unique value of ωt to achieve the maximum power coefficient CP and thereby extract the maximum mechanical (wind) power. If the wind speed is below the rated (maximum) value, the wind turbine operates in the variable speed mode, and the rotational speed is adjusted (by means of active power control in the DFIG) such that the maximum value of CP is achieved. In this operating mode, the wind turbine pitch control is deactivated and the pitch angle β is fixed at 0○. If the wind speed is above the rated value, the rotor speed can no longer be controlled within the limits by increasing the generated power, as this would lead to overloading of the generator and/or the converter. In this situation, the pitch control is activated to increase the wind turbine pitch angle to reduce the mechanical power extracted from wind. Figure 5 shows the structure of the pitch angle controller [1], [8]. Pt (= Ps + Pr) is the total output active power from the induction generator.

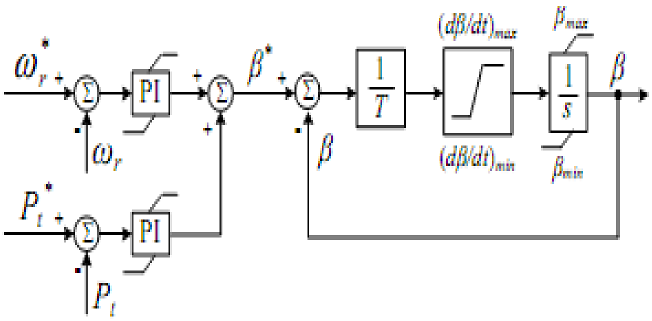

Fig. 1. Wind turbine pitch angle controller

III. STATCOM MODEL

A STATCOM [6], [12], also known as an advanced static VAR compensator, is a shunt connected FACTS device. It generates a set of balanced three-phase sinusoidal voltages at the fundamental frequency, with rapidly controllable amplitude and phase angle. A typical application of a STATCOM is for voltage support. In this paper, the STATCOM is modeled as a IGBT PWM converter with a dc-link capacitor. The objective of the STATCOM is to regulate the voltage at the PCC rapidly in the desired range and keep its dc-link voltage constant. It can enhance the capability of the wind turbine to ride through transient disturbances in the grid. The overall control scheme of the STATCOM is shown in Fig. 2.

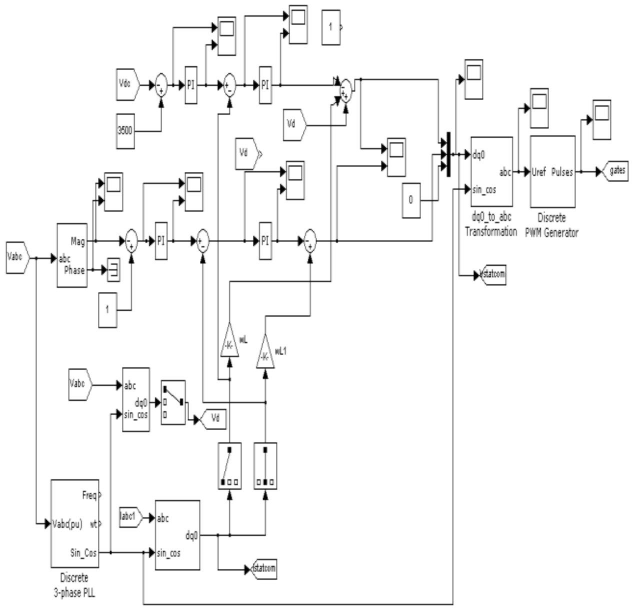

Fig. 2. Control scheme of the STATCOM.

In its most basic form, the STATCOM configuration consists of a VSC, a dc energy storage device; a coupling transformer connected in shunt with the ac system, and associated control circuits. Fig.3, shows the basic configuration of STATCOM with wind turbine driven SCIG connected directly to the grid. The VSC converts the dc voltage across the storage device into a set of three-phase ac output voltages. These voltages are in phase and coupled with the ac system through the reactance of the coupling transformer. Suitable adjustment of the phase and magnitude of the STATCOM output voltages allows effective control of active and reactive power exchanges between the STATCOM and the ac system.

The VSC connected in shunt with the ac system provides a multifunctional topology which can be used for up to three quite distinct purposes:

1) Voltage regulation and compensation of reactive power
2) Correction of power factor
3) Elimination of current harmonics.

The design approach of the control system determines the priorities and functions developed in this analysis. In this paper, the STATCOM is used to regulate voltage at the point of connection. The control is based on discrete PWM and only requires the measurement of the rms voltage at the load point, reference voltage near the grid and dc voltage near the STATCOM VSC converter.The wind energy generating system is connected with grid having the nonlinear load.

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The performance of the system is measured by switching the STATCOM at time s in the system and how the STATCOM responds to the step change command for increase in additional load at 1.0 s is shown in the simulation. When STATCOM controller is made ON, without change in any other load condition parameters, it starts to mitigate for reactive demand as well as harmonic current. The dynamic performance is also carried out by step change in a load, when applied at 1.0 s. This additional demand is fulfill by STATCOM compensator. Thus, STATCOM can regulate the available real power from source.

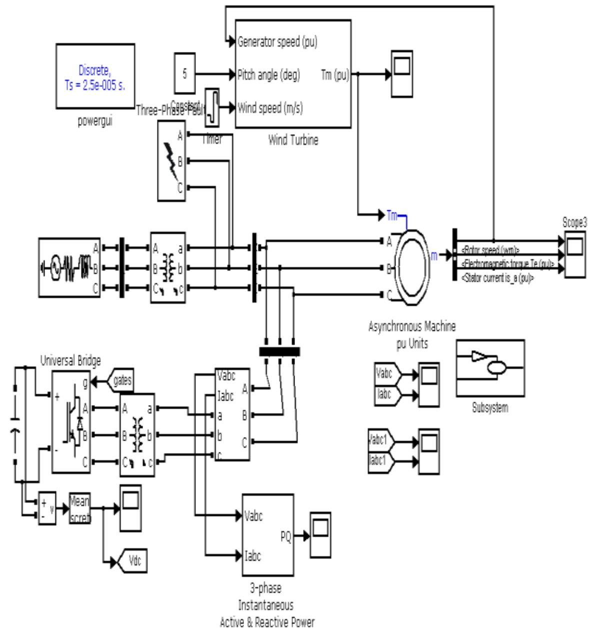

Fig 3. Overall system design for wind turbine driven SCIG and STATCOM controller

IV. UNINTERRUPTED OPERATION FEATURE OF THE WIND TURBINE DURING GRID FAULTS

The idea behind this feature is that the wind turbine does not trip when the when a severe symmetrical fault occurs near the grid or near the generator system. The wind turbine continues its operation with the induction generator (IG) with a short-circuited rotor circuit, such that the speed of the IG decreases. It may sometimes reach zero when a low impedance short circuit occurs. During such an operation condition, the self controllability of the IG is naturally lost and there is no longer any independent control of active and reactive power in the SCIG. The generator becomes a conventional induction generator, which produces an amount of active power and starts to absorb an amount of reactive power. In order to prevent the wind turbine from over-speeding or under speeding, the pitch angle controller can be activated to keep the speed around the pre-defined value.

During such circumstances, the STATCOM control system continues monitoring the generator current, the terminal voltage, the active and reactive powers and the generator rotor speed. When the fault has cleared and when the terminal voltage and the rotor current return back to their pre-defined ranges, the STATCOM starts synchronization [1]. At synchronization, the STATCOM starts switching and the external resistance is disconnected; the d-q components of the STATCOM voltage source (Fig. 2) are set to vdr = idr· Rext and vqr = iqr· Rext, which are used by the PWM module to generate the IGBT gate control signals to drive the IGBT converter. When the synchronization seems to be complete, the control system of the STATCOM switches to the regular control system as shown in Fig. 3 and the STATCOM re-starts. When the STATCOM has re-started, the SCIG again has independent active and reactive power control and the wind turbine returns to normal operation.

The advantages of this uninterrupted operation feature include: (1) the wind turbine continues supplying the active power to the power network and therefore the demand for immediate power reserves does not exist or it is reduced; (2) the wind turbine can contribute to maintaining the frequency in the power network during a transient state.

This controllability of the STATCOM, however, is limited due to the small capacity of the converter. In the case of a weak power network, there can be a risk of voltage instability initiated by the grid fault. As a result, the STATCOM will not re-start and the wind turbine will be disconnected from the network. But STATCOM is to used as dynamic reactive compensator – to provide transient voltage support to help the wind turbine IG ride through grid faults. In addition, the STATCOM can also be used for steady state voltage regulation and power factor control of the SCIG.

V. RESULT ANALYSIS

The system design is as shown in Fig 3. It is wind turbine driving induction machine as generator and STATCOM is connected near the midpoint of the system. In this analysis, there are three cases, first is without STACOM and without any disturbances in the system, and second is with without STACOM and with disturbances in the system and third is with STATCOM and a three-phase to ground fault occurring in the system. The system performances in all the cases are observed when a severe symmetrical short circuit occurs in the system.

Case 1: without STACOM and without any faults in the system

It can be observed that, the overshoots and settling time for the SCIG system is more and can be reduced by using STATCOM controller. For speed of the generator without STATCOM, the speed reaches nearly 1.5pu and settles nearly at 0.4 seconds and starting torque is 18pu and starting currents is 20A without STATCOM. But with STATCOM, the overshoot of speed is 1.05pu and settling time for speed if IG is at0.15s, electro-magnetic torque at start is 4pu and reaches steady state of -0.5pu in 0.16s. the torque is negative because, the machine is running as generator. The starting current with this controller is maximum 10.6pu. is as shown in Fig 4.

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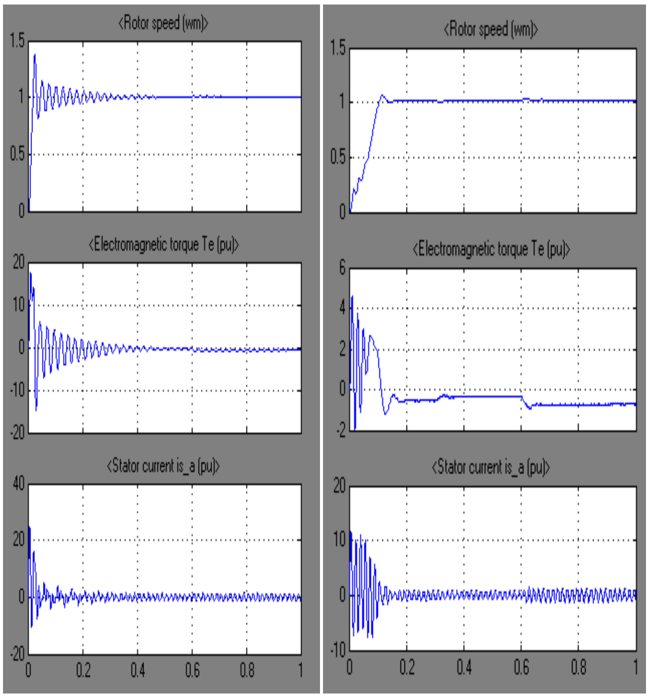


Fig 4. Without STACOM (left side) and with STACOM (right side) showing speed, torque and current waveforms in pu.

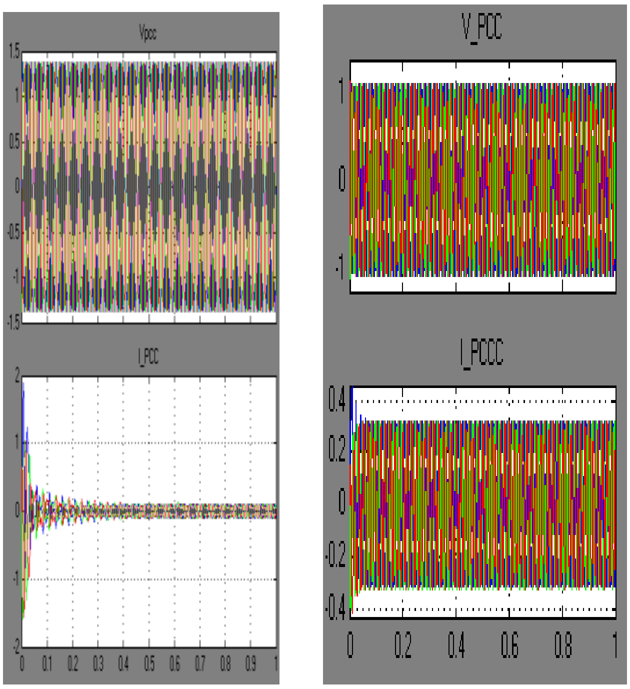


Fig 5. Without STACOM (left side) and with STACOM (right side) showing output voltage and current waveforms in pu

The Fig 5 depicts that the starting current output from stator is very high (above 1 pu) for given load. But with STATCOM, it is only 0.3pu. There is no overshoot in the current waveforms or any distortions in the current or voltage waveforms.

Case 2: without STACOM and with three phase to ground fault in the system

Although occurrence of three Ph-G faults is very low practically, such fault leads to destruction in system and system collapse. When a symmetrical fault occurs between 0.3s to 0.4s, the system results are verified without STATCOM.

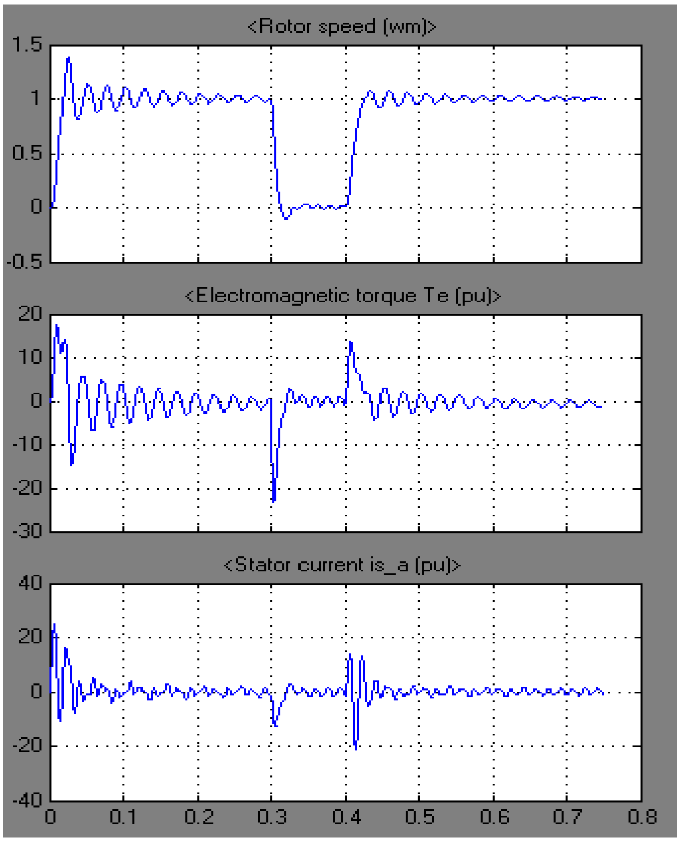


Fig 6. Without STACOM showing speed, torque and current waveforms in pu. with a 3PHG fault between 0.3 to 0.4s

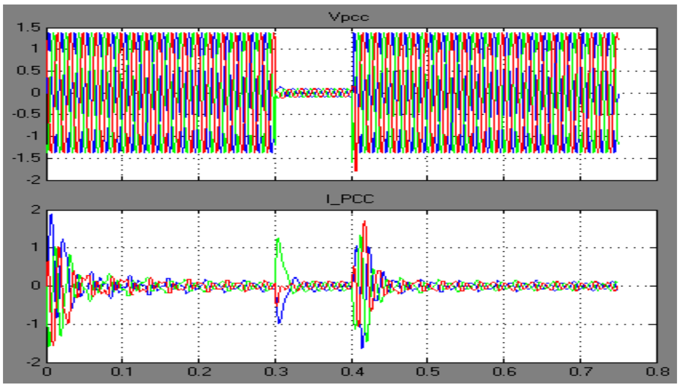


Fig7. Without STACOM showing output voltage and current waveforms in pu with a 3PHG fault between 0.5 to 0.6s

During this scenario, a three phase to ground fault with fault resistance of 0.1 ohms occurs between phases at 0.3seconds and cleared at 0.4s. The speed of the generator decreased to zero and voltage near PCC has declined to 0.1pu. The current reaches 1.8pu from 0.2pu at the time of clearing of fault. There are very high harmonics in the system and the current waveforms are not purely sinusoidal.

Case 3: with STACOM and with three phase to ground fault in the system

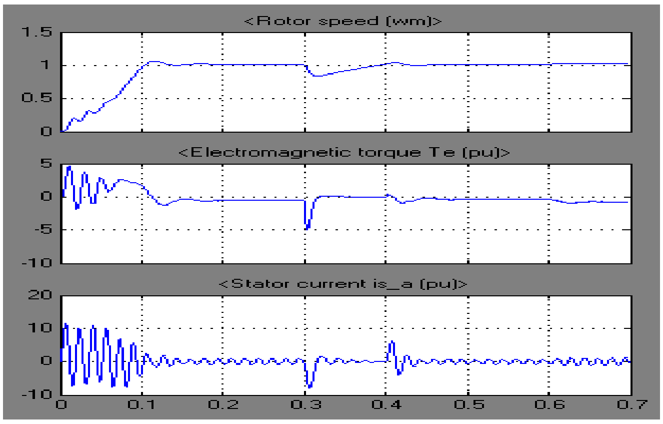


Fig 8. With STACOM showing speed, torque and current waveforms in pu. with a 3PHG fault between 0.3 to 0.4s

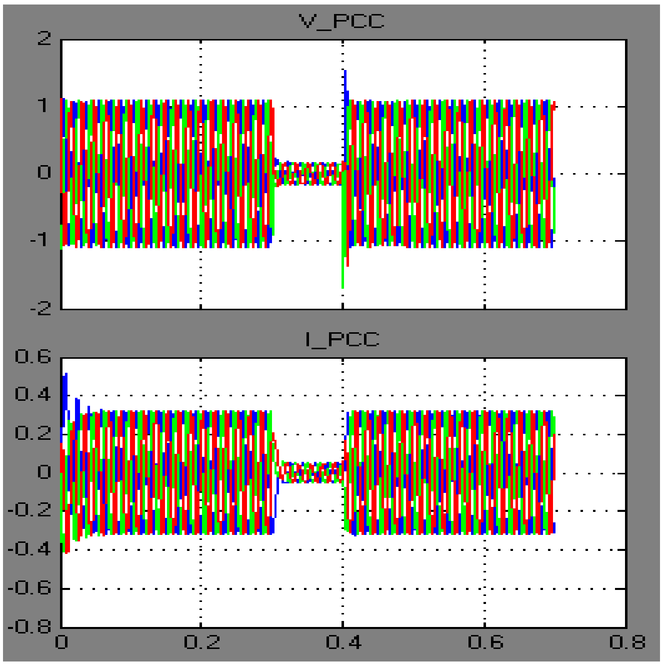
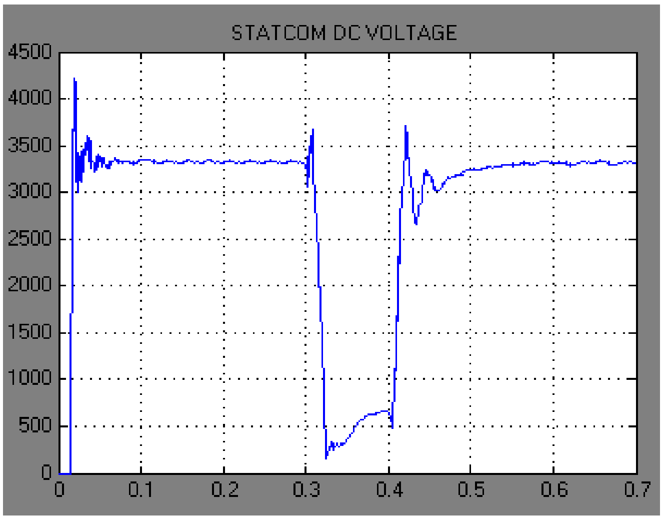


Fig9. With STACOM showing output voltage and current waveforms in pu with a 3PHG fault between 0.5 to 0.6s



Fi10.. With STACOM showing DC voltage of capacitor for VSC (STATCOM)

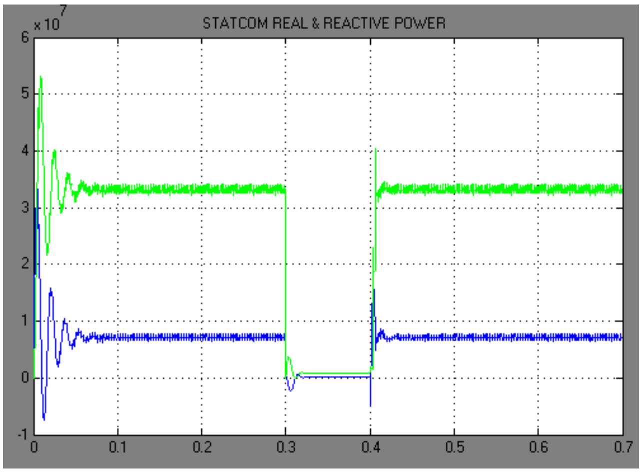


Fig11. STACOM output real (green) and reactive powers (blue).

The system with STATCOM controller, a three phase to ground fault occurs between 0.3s to 0.4s are shown in figures 8 to 11. If comparing without and with STATCOM from Fig 6 and 8, the speed decreased to zero without STATCOM, but with STATCOM, the speed nearly maintained constant. From Fig 7 and 9, severe surge currents are produced at the starting of fault and clearance of fault without STATCOM, where as there are no surge currents produced with STATCOM.

It can also be observed that the DC voltage in Fig 10. of STATCOM reaches voltage of 500V from 3250V, because of such a fault. The real and reactive power outputs of STATCOM are also shown in Fig 11.

VI. CONCLUSIONS

With a good controller for STATCOM, there can be choice for system without using vector control or direct torque control, to protect the system from surge currents and harmonics mitigation and flickering issues. It can also be observed that settling time for speed of rotor, electro magnetic torque etc can be reduced. Severe starting currents can be controlled and also severe inrush currents because of starting and/ or clearing of faults can be completely eliminated because of such powerful controller. The STATCOM based controller not only control current from stator or improves stability, it can mitigate both current and voltage harmonics occurring in the system because of natural phenomenon or due to external sources.

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AUTHORS PROFILE

CH.Appala Narayana is doing his MTECH in power systems from VITAM College of Engineering, Visakhapatnam. His interested topics are renewable resources, FACTS controller.

D.V.N. Ananth was born in Visakhapatnam, India on 20th August 1984. He received B.Tech Electrical Engineering from Raghu Engineering College, Visakhapatnam and M.Tech from Sreenidhi Institute of Science & Technology, Hyderabad, India. He is working as an Assistant Professor in VITAM College of Engineering in Electrical Department. His favorite topics include Renewable electrical systems, industrial drives, power systems, power electronics, control systems, HVDC systems and Reactive power compensation techniques.

K.D.Syam Prasad is working as Associate Professor and HOD in EEE department for VITAM College of Engineering, Visakhapatnam. He is pursuing PhD from JNTU Kakinada. His interested topics include Power Quality Management, wavelet transforms, FACTS controller and distributed systems.

CH. Saibabu is Professor from JNTU Kakinada with about 17 years of teaching experience. He has written textbooks on Power Electronics and industrial drives. He has 15 PhD scholars and guided more than 70 MTech students. On his name there are 11 international journals, 33 international conferences. He is an eminent professor in JNTU Kakinada for knowledge and student friendly nature. He is an inspiration for upcoming research scholars in EEE in coastal area of Visakhapatnam.

S.Sai Kiran completed MTech from GITAM Engineering College in 2010 and serving VITAM College of Engineering since then. His interesting topics include, Power Semi-conductor Drives, Power systems and control systems.

T.PapiNaidu is an 2nd year MTech student from DADI Engineering College in Power electronics and drives branch of engineering. Before joining here as student, he worked for TandraPaparayidu college of Enginnering near Tekkali, Visakhapatnam. He has more than 5 years of teaching experience. His favorite topics are Power Electronics, Industrial drives, Machine Design, Electrical Machines.