Scientific Journal of Impact Factor (SJIF): 4.72
e-ISSN (O): 2348-4470
p-ISSN (P): 2348-6406

International Journal of Advance Engineering and Research Development

Volume 4, Issue 6, June -2017

Dynamic Modelling, Analysis and Simulation of Distributed Generation System with FACTS Devices – SSSC & UPFC

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Abstract — *Paper demonstrated a modelling & simulation for optimal allocation & Coordination of Distributed generation with FACTS devices for a given simulation model of distributed network. The proposed approach is based on the distributed power generation to be integrated to network to minimize power losses, improve voltage stability & in practical expertise rules to control the reactive power of FACTS devices (SSSC, UPFC) designated to improve the system security. Both SSSC and UPFC are the members of FACTS family. This proposed approach is implemented with Mat lab program & applied to small case study of 9MW DFIG based distributed generation wind farm system. The results obtained confirm the effectiveness of FACTS devices to improve the power quality, voltage stability and thus reduces the power losses of distributed generation system.*

Keywords- *Distributed generation (DG), FACTS, SVC, STATCOM, Power Quality*.

I. INTRODUCTION

Small localized power sources, commonly known as “Distributed Generation” (DG), have become a popular alternative to bulk electric power generation [1]. In the present scenario, distributed generation plays a very special role in power system. It has received significant attention as a means to improve the performance of the electrical power system, provide low cost energy, and increase overall energy efficiency. DGs are located near the load. By locating near the load, transmission and distribution costs are decreased and delivery problems mitigated. DGs application can relieve transmission and distribution assets, reduce constraints, and improve reliability and power quality [2]. Power quality problems become significant, when the distributed generation systems are operated in parallel with utility power systems, especially with reverse power flow.

There are many types of distributed generation (DG) technology such as photovoltaic, wind, geothermal, Micro turbines, fuel cells etc. Among these, this paper highlights the wind turbine based distributed generation system. The typical capacity of wind technology ranges between 10VA to 500KVA. In this paper we observed the 9MW DFIG based wind farm distributed system. This paper focuses on modelling, simulation of distributed generation system and analyses the different problems associated with (DG) using the FACTS devices like SSSC and UPFC.

II. TYPES OF DISTRIBUTED GENERATION

Distributed Generators can be divided into three basic classes: induction, synchronous and electronic power inverters. Induction generators require external excitation (VARs) and start up much like a regular induction motor. They are less costly than synchronous machines and are typically less than 500 KVA. Induction machines are most commonly used in wind power applications. Alternatively, synchronous generators require a DC excitation field and need to synchronize with the utility before connection. Synchronous machines are most commonly used with internal combustion machines, gas turbines, and small hydro dams. Finally, asynchronous generators are transistor switched systems such as inverters. Asynchronous generators are most commonly used with micro turbines, photovoltaic, and fuel cells.

III. ADVANTAGES OF DISTRIBUTED GENERATIONS

- Flexibility - DG resources can be located at numerous locations within a utility's service area. This aspect of DG equipment provides a utility tremendous flexibility to match generation resources to system needs.
- Improved Reliability - DG facilities can improve grid reliability by placing additional generation capacity closer to the load, thereby minimizing impacts from transmission and distribution (T&D) system disturbances, and reducing peak-period congestion on the local grid. Furthermore, multiple units at a site can increase reliability by dispersing the capacity across several units instead of a single large central plant.
- Improved Security - The utility can be served by a local delivery point. This significantly decreases the vulnerability to interrupted service from imported electricity supplies due to natural disasters, supplier deficiencies or interruptions, or acts of terrorism.

- Reduced Loading of T&D Equipment - By locating generating units on the low-voltage bus of existing distribution substations, DG will reduce loadings on substation power transformers during peak hours, thereby extending the useful life of this equipment and deferring planned substation upgrades
- Reduces the necessity to build new transmission and distribution lines or upgrade existing ones.
- Reduce transmission and distribution line losses [3]
- Improve power quality and voltage profile of the system.[3]

IV. TECHNICAL CHALLENGES RELATED TO DG

Distributed Generation (DG) is not without problems. It faces a series of integration challenges. Depending on the amount of DG connected and the strength of the utility power system, the issues outlines in Table 1 can become substantial problems. The challenges with DG listed in Table 1.

Sr.No.	Technical Challenges
1.	Voltage Flicker
2.	DG shaft over- torque during faults
3.	Harmonic Control
4.	Groundling
5.	Transient Stability
6.	Sensitivity of Existing Protection Schemes
7.	Coordination of Multiple Generators
8.	Islanding Control

Table-1. Different Technical challenges for distributed generations.

V. SSSC CONFIGURATION

Static Series Synchronous Compensator (SSSC), one of the key FACTS devices, consists of a voltage sourced converter and a transformer connected in series with a transmission line. The SSSC injects a voltage of variable magnitude in quadrature with the line current, thereby emulating an inductive or capacitive reactance. This emulated variable reactance in series with the line can then influence the transmitted electric power. A Static Series Synchronous Compensator (SSSC) may also be called a series power flow controller (SPFC). The SSSC increases the maximum power transfer by a fraction of the power transmitted, nearly independent of δ.

$$P_q = \frac{V^2}{X_{sc}} Sin\delta + \frac{V}{X_{sc}} V_q Cos(\frac{\delta}{2})$$

While a capacitor can only increase the transmitted power, the SSSC can decrease it by simply reversing the polarity of the injected voltage. The reversed voltage adds directly to the reactive power drop in the line and the reactive line impedance is increased. If this reversed polarity voltage is larger than the voltage impressed across the line by sending and receiving end systems, the power flow will reverse.

$$|V_q| = |V_s - V_r| + IX_l$$

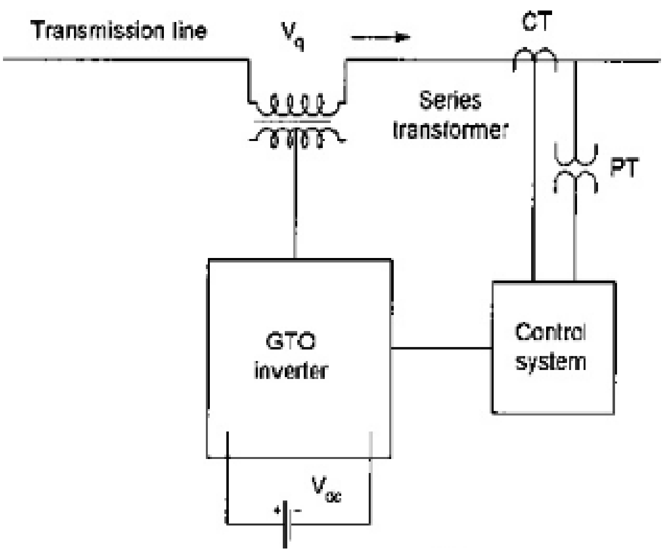


Fig.1 Static Series Synchronous Compensator Configuration

VI. UPFC CONFIGURATION

The UPFC is the most versatile FACTS controller developed so far, with all encompassing capabilities of voltage regulation, series compensation, and phase shifting. It comprises of two voltage source converters coupled through a common DC link. The single line diagram is shown in Fig.2.

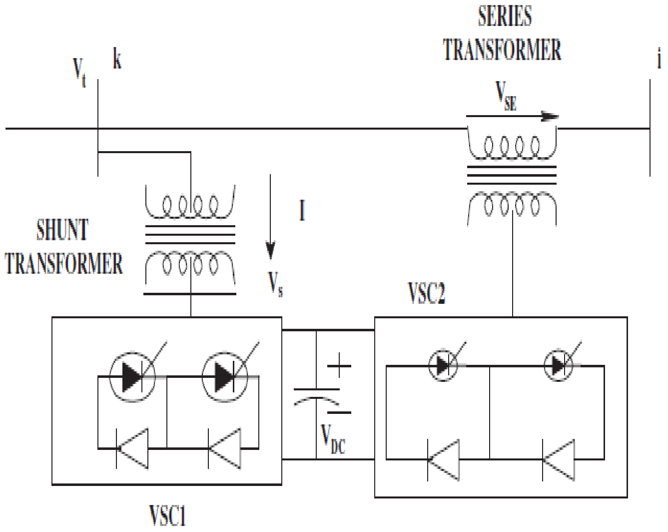


Fig. 2 Single line diagram of UPFC

The active and reactive power flow control loop of the UPFC is shown in Figs. 3 and 4. The stabilizing signal for the unified power flow controller is derived from a power oscillation-damping block, which uses active power flow (P_{flow}) as the input signal. Power flow Ref is the reference value of active power flow in the line on which UPFC is connected. This value is obtained after running a power flow in the line on which UPFC is to be connected. V_{seq} is the component of series injected voltage in quadrature with the line current. Q_{ref} is the reference setting for reactive power flow in the UPFC connected line and Q_{flow} is the actual reactive power flow in the line and V_{sep} is the component of AC voltage injected in phase with the line current.

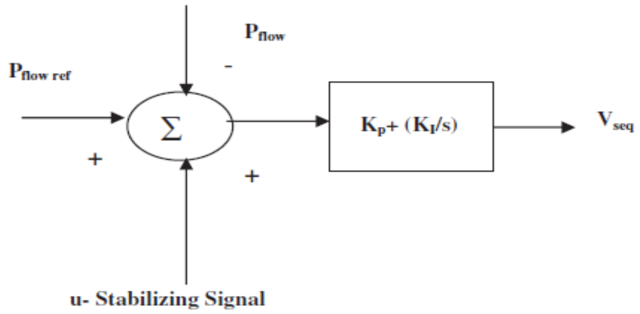


Fig. 3 Active Power Flow Loop of UPFC

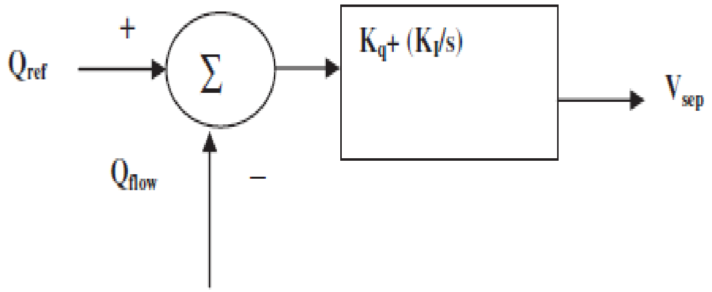


Fig. 4 Active Power Flow Loop of UPFC

VII. MODELLING THE SYSTEM

This case study shows a 9-MW wind farm based distributed generation system consisting of six 1.5 MW wind turbines linked with 25-kV distribution system exports power to a 120-kV grid through a 30-km, 25-kV feeder. A 2300V, 2-MVA plant consisting of a motor load (1.68 MW induction motor at 0.93 PF) and of a 200-kW resistive load is coupled on the same feeder at bus B25. Both the wind turbine and the motor load have a protection system monitoring different parameters like voltage, current and machine speed. The DC link voltage of the DFIG is also monitored. Wind turbines use a doubly-fed induction generator (DFIG) consisting of a wound rotor induction generator and an AC/DC/AC IGBT-based PWM converter. The DFIG technology allows extracting maximum energy from the wind for low wind speeds by optimizing the turbine speed, while minimizing mechanical stresses on the turbine during gusts of wind. The optimum turbine speed producing maximum mechanical energy for a given wind speed is proportional to the wind speed. For wind speeds lower than 10 m/s the rotor is running at sub-synchronous speed. At high wind speed it is running at hyper synchronous speed. Advantage of the DFIG technology is the capability for power electronic converters to generate or absorb reactive power, thus eliminating the need for installing capacitor banks as in the case of squirrel cage induction generator.

In this case study first we simulated the DFIG based wind farm system with fault with FACT device UPFC and then we simulated the DFIG based wind farm system with fault and with FACT device SSSC and showed that the improvement and impact of FACT devices on the Load Bus. Figures 5 and 6 show simulations of system with and without FACT device UPFC and SSSC.

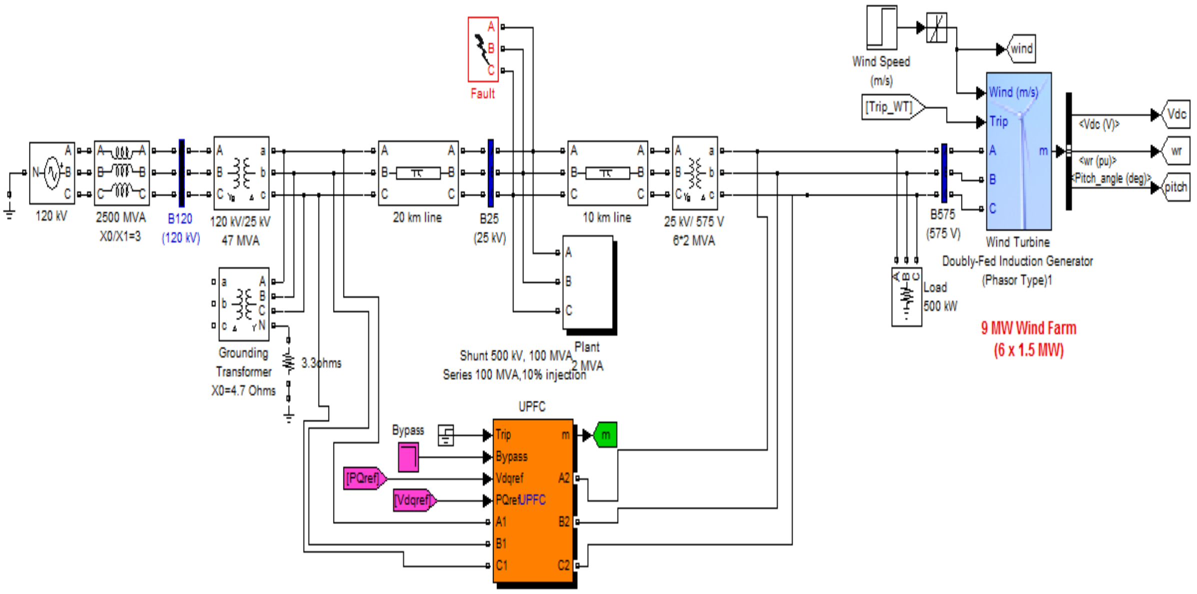


Fig.5 DFIG wind farm system with UPFC

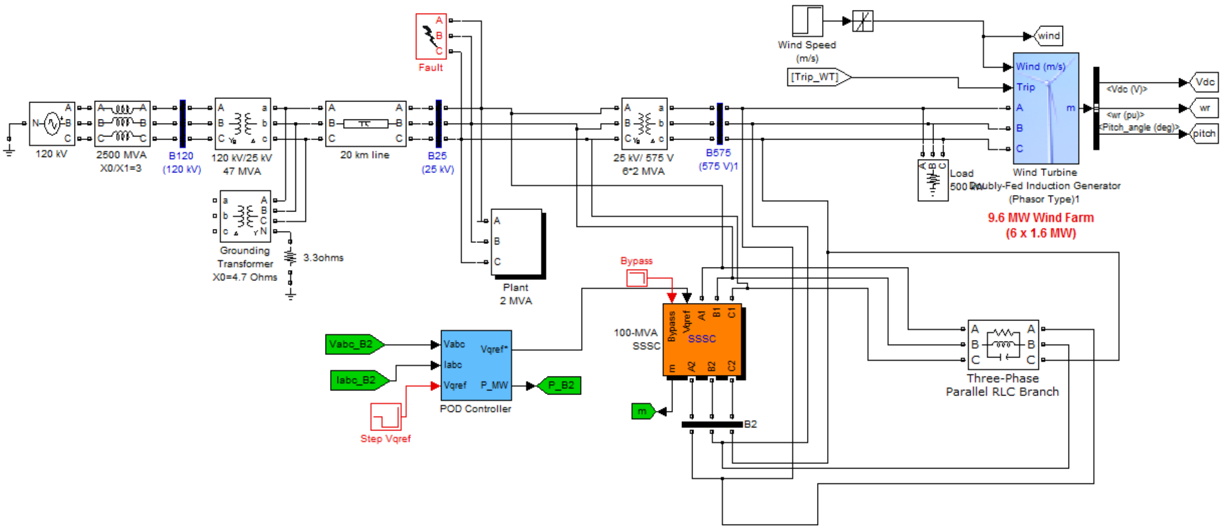


Fig. 6 DFIG wind farm system with SSSC

VIII. EXPERIMENTAL RESULTS

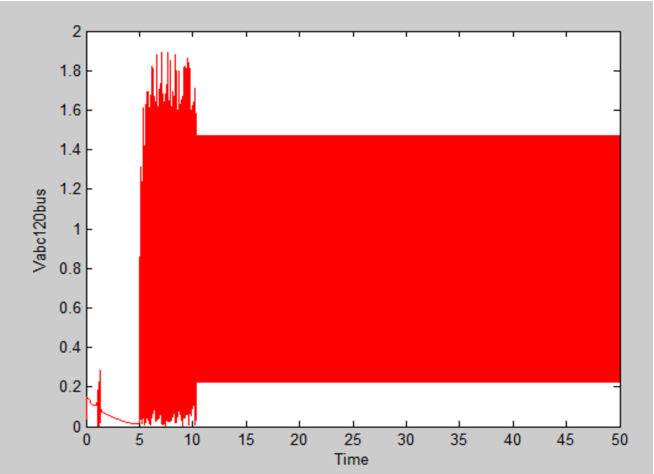


Fig.7 Vabc120Bus with UPFC

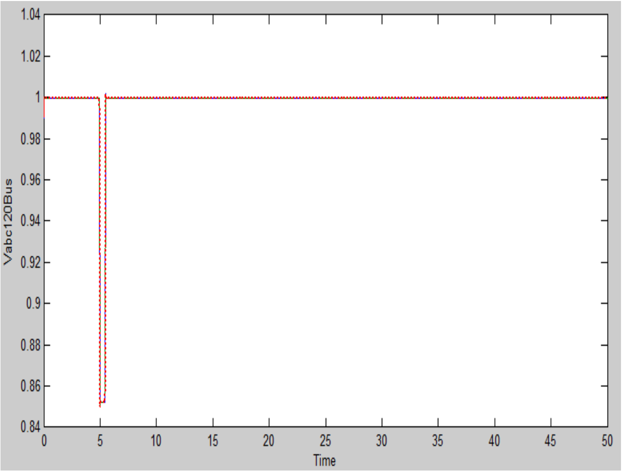


Fig. 8 Vabc120Bus with SSSC

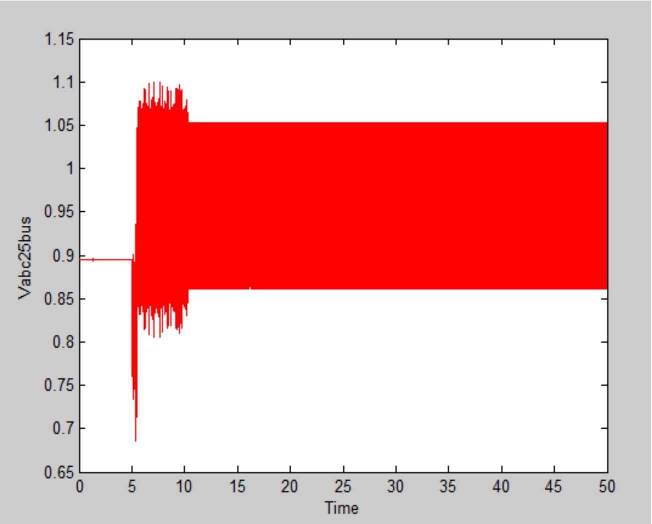


Fig. 9 Vabc25Bus with UPFC

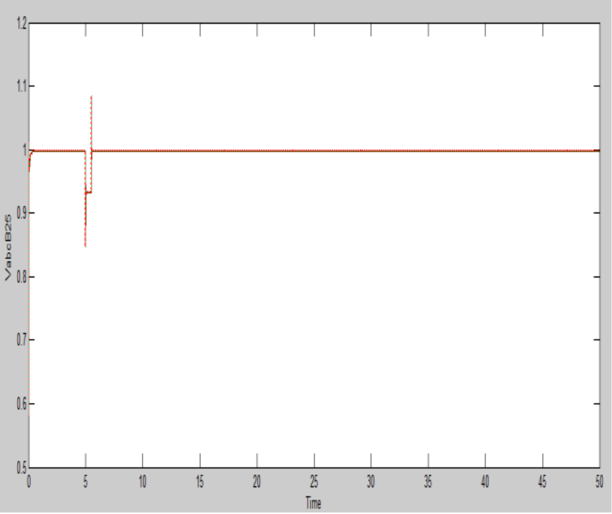
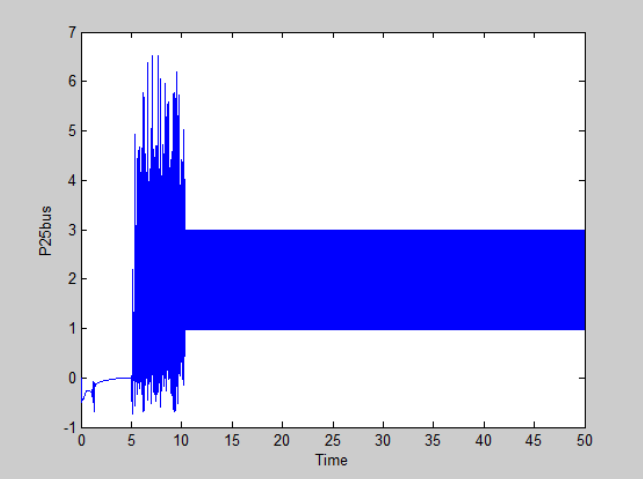


Fig. 10 Vabc25Bus with SSSC



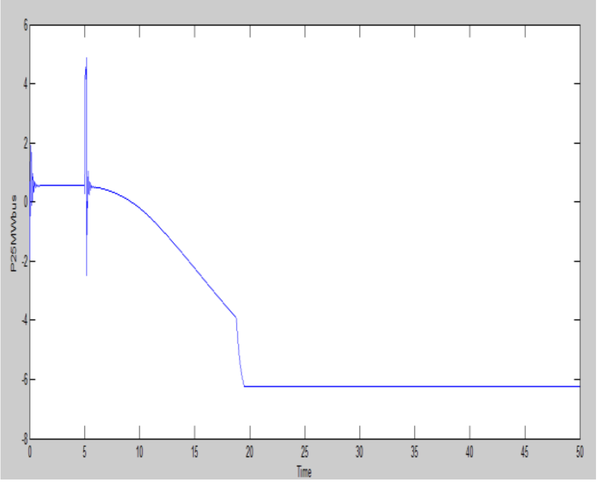


Fig. 11 P25Bus with UPFC

Fig. 12 P25Bus without SSSC

IX. CONCLUSION

Based on the simulation model of wind farm based distributed system, the paper researches on dynamic modeling and analysis of power quality and voltage stability of distribution system, as well as control strategy for grid-connected network. Based on the model in Matlab/simulink, the output control strategy is applied to analyze the load fluctuations of DG system. We simulated the distributed generation based wind farm system with FACTS device & observed coordination and the effectiveness of FACTS devices and simulated result shows that the UPFC is better effective than SSSC for power quality, voltage stability improvement of distribution system.

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