Enhancement of Power Quality in wind farm System: Comparison between STATCOM and UPFC

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Abstract—Since wind energy has got emerging trend in the power system, So it's impacts on power system are got more attentions. Voltage fluctuation of renewable sources is more significant, so it is very important to maintain power quality in the power system with existing technologies. Voltage fluctuation causes significant impacts on power system this will affect the existing protection. This paper discuss the impact on protection system with integrating the renewable energy into grid, specially with widely used Flexible Alternating Current Transmission System (FACTS) devices Two major FACTS devices ,Static Synchronous Series Compensator (STATCOM) and Unified Power Flow Controller (UPFC) is analysed and compared. After the analysis it is found that UPFC response much faster than STATCOM while maintaining power quality and power system stability. STATCOM and UPFC are used for enhancement of power quality in significant way. In this paper we will improve the power quality in wind connected power plant using STATCOM and UPFC and compare the result. UPFC response much faster than other devices while maintaining power quality and system stability. It improves the voltage stability, real power balance, reactive power compensation and damping the oscillations

Keywords—renewable energy, relay, FACTS, STATCOM, wind farm, UPFC, protection, power system.

I. INTRODUCTION

At present, renewable energy has got emerging trend specially wind energy. In 2015 wind energy is the largest source of renewable energy. In India, on March 2015 total installed capacity of wind energy was 23439 MW in different states [Tamilnadu, Karnatka, Maharashtra, Rajasthan, Andhra Pradesh, Gujarat, Madhya Pradesh, Kerla and Others] in addition[1]. Grid connected wind generation is increasing with fastest rate it is going double in almost every three year. It is having around 20-30% of all generation capacity. Wind energy is environmental friendly there is no emission of CO_2. It has no cost uncertainty from fuel supply [23]. Power grid must operate properly during any disturbances that are occurring in wind power plant. It provides best service to meet the electric market objective. Reactive power flow should be maintained during and after any disturbance while connecting it with grid. Flexible Alternating Current Transmission System (FACTS) will inject reactive current when there is voltage sag. It will inject active current just after the fault is cleared.

Many researchers have done on how to use FACTS on wind farm protection [2-10]. Dixon, et al, discussed the reactive power compensation devices that can be implemented [2]. VAR compensation is used to manage the reactive power for improved performance. Reactive power compensation has two aspects voltage support and load compensation. Voltage support is used to improve the voltage and eliminate current harmonics while load compensation increases power factor as to balance active power drawn from load. Reactive power compensation improves transmission capability of active power which makes it stable. Saberian, et al, discussed the problem that arises due to use of renewable energy [3]. Problem generated due to fluctuating nature of distributed generation that needs to be integrated with grid system. The problem is to maintain power quality of distributed generation.

Impact of various VAR on protection system is discussed in [4-6]. How to connect wind energy with grid is discussed in [7]. Among all existing method shunt FACTS devices such as Static Synchronous Compensator (STATCOM) and Unified Flow Controller (UPFC) are used as they are more reliable and efficient compared to all other devices. Yang, et al, showed how to balance reactive power and improve voltage stability [9]. Pandey, et al, provides case study on the impact of UPFC on relay protection in power grid [11].

This paper is the study of performance of STATCOM and UPFC and their impacts on relay protection system with integrating wind energy. This paper is organised as follows: Section II provides generation of wind energy. Section III provides impacts of FACTS. Section IV is about wind farm protection system. Implementation and case study for STATCOM and UPFC are presented in section V, VI, VII, VIII, IX, X, XI, XII. Conclusion is given in section XIII.

II. WIND ENERGY GENERATION

Doubly fed Induction Generator is used for simplicity in wind energy generation system. It can accept constant and variable load. It does not required separate electrical field circuit [22]. Fig. 1 gives simple sketch of wind energy generation [22].

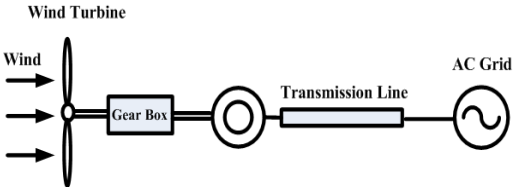

Fig. 1 Sketch of wind energy generation.

III. FLEXIBLE AC TRANSMISSION SYSTEM (FACTS)

FACTS devices are the combination of static equipment which is used to maintain reactive power supply [5]. It plays very important role in voltage regulation , power flow control, reactive power compensation, power quality improvement [12, 13]. FACTS can be classified into following categories [3]: Shunt contoller, series controller, combined series shunt controller and combined series series controller. FACTS inject reactive current for voltage sag and inject active current immediately after the fault is cleared. FACTS improves the power quality but their impacts on relay protection needs to be consider too. FACTS will produce non linearity and haromincs.

IV. WIND FARM PROTECTION SYSTEM

Now a days, most energy sectors are moving towards renewable energy because it produce less pollutiuon while it has the disadvantage of uncertainity and intermittancy properties.

A lot of research have done on wind farm and wind energy [6-8, 12, 13]. Wind farm system consist of wind tubine, induction generator, tubine/generator control, step up transformer and protection system. Circuit breaker protects against short circuit in the system while transformer is protcted with the relay.

V. STATIC SYNCHRONUS COMPENSATOR

STATCOM is most effective device for reactive power compensation. STATCOM regulate the voltage by absorbing or generating reactive power in the system. It works as voltage sourse inverter by which it can compensate active and reactive power. It can control reactive power with fast response and least interaction with power grid. STATCOM is dominant device of FACTS it regulate with reactive power compensation. Detail structure and functionality is found in [10]. Fig. 2 gives the structure of STATCOM. It is shunt connected device which controls the voltage and angle of internal voltage source [10]. A voltage source inverter convert DC input voltage into AC output to compensate the active and reactive power. Fig. 3 shows the configuration of STATCOM [17].

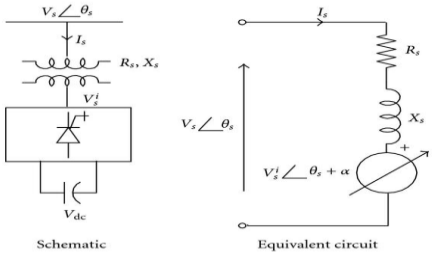

Fig. 2 Structure of STATCOM

STATCOM is Multiple Input Multiple Output system. It exhibits constant current characterstics [10]. V-I characterstics of STATCOM is given in fig. 4 equation (1)- (4) gives the mathematical expression of STATCOM.

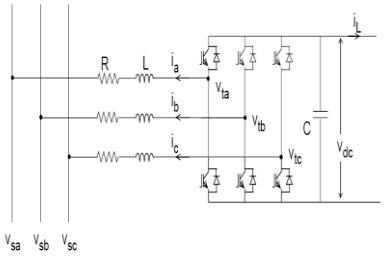

Fig. 3 Configuration of STATCOM

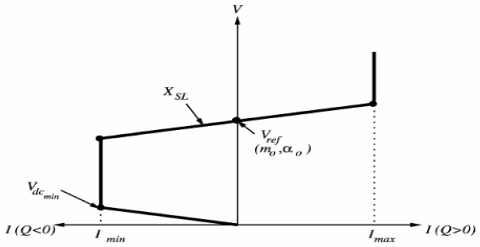

Fig. 4 V-I characterstics of STATCOM

$$\frac{di_d}{dt} = -\frac{R}{L} i_d + \omega i_q + \frac{1}{L}(V_{td} - V_{sd}) \qquad (1)$$

$$\frac{di_q}{dt} = -\omega i_d - \frac{R}{L} i_d + \frac{1}{L}(V_{tq} - V_{sq}) \qquad (2)$$

$$\frac{dV_{dc}}{dt} = -\frac{3 (V_{td} i_d + V_{tq} i_q)}{2CV_{dc}} - \frac{i_L}{C} \qquad (3)$$

$$Q = \frac{3}{2}(V_{sq} i_{sq} - V_{sd} i_{sd}) \qquad (4)$$

Where subcripts d, q are variable in the rotating coordinate and ω is the angular frequency.

VI. IMPACTS OF STATCOM ON RELAY PROTECTION SYSTEM

Simulated model of Induction Generator wind farm with grid connected system under three phase short circuit fault by using MATLAB/SIMULINK is studied by Gautam, et al, [11]. In order to study the impacts of STATCOM on protection system first STATCOM is disabled mannualy. Due to lack of reactive power support the grid voltage dropped below 0.9 pu which results in overloaded of wind turbine.

Here in this case study 9MW wind farm has been taken and it is to be implimented with a grid of 25KV system

STATCOM and UPFC are usrd for the analysis. Fig.5 gives the detail model of analysis.

From the study it can be seen that, by using STATCOM steady state voltage can be obtained and relay function well with designed tripping time.

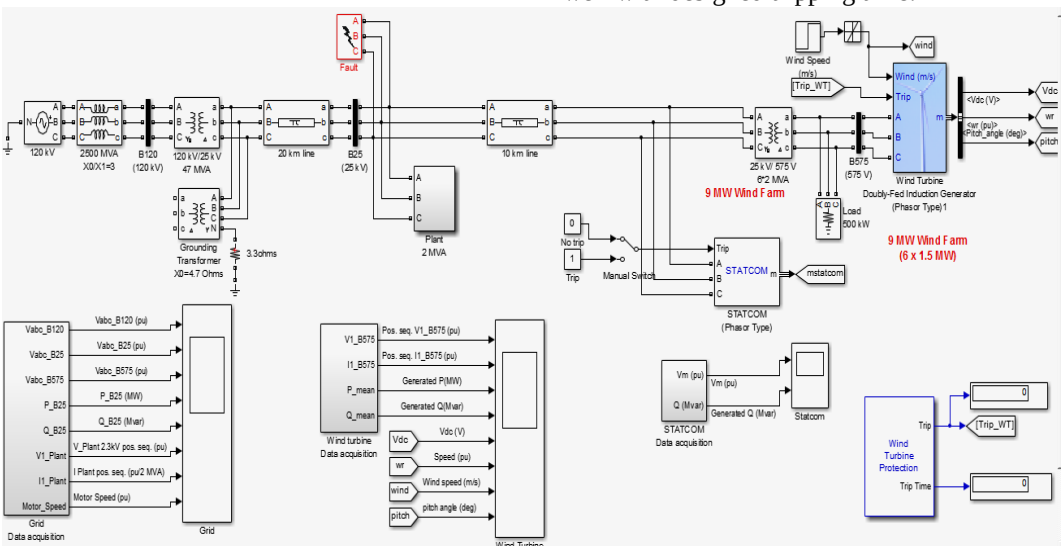

Fig.5 MATLAB/SIMULINK model of wind farm system with STATCOM

VII. SIMULINK RESULT WITH STATCOM

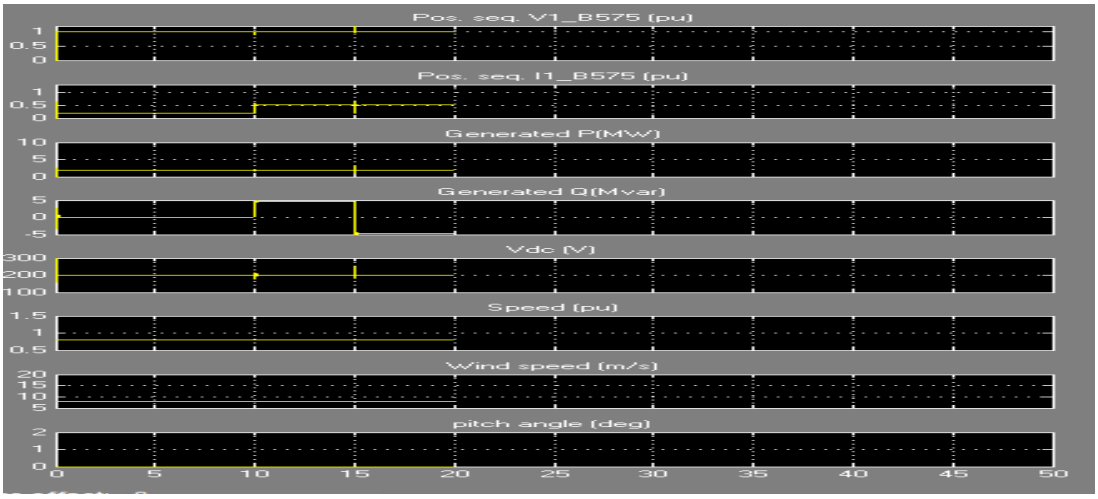

Fig.6 SIMULINK result of grid

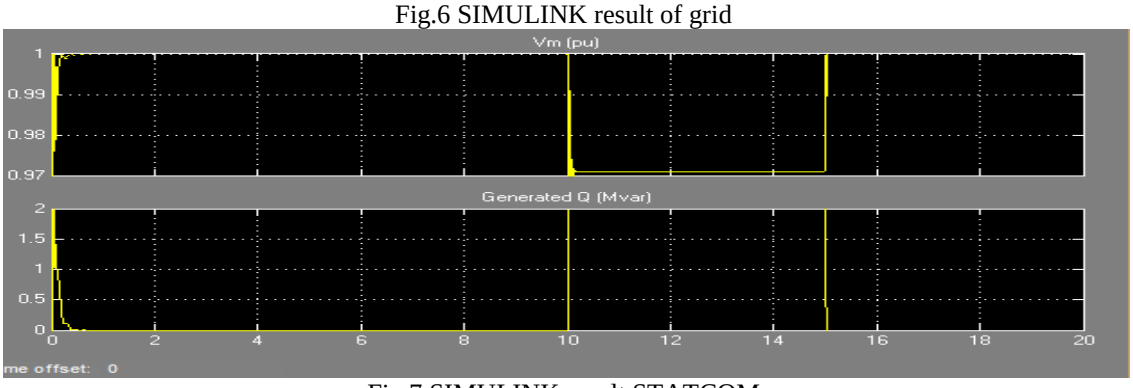

Fig.7 SIMULINK result STATCOM

Fig.6,7 gives the result of system. By this result it can be concluded that the system responces well with STATCOM during fault and integration with grid. Here in this figure when the fault occurs and voltage drop decreases immediately STATCOM inject reactive power by which the output voltage is maintained and system power quality is improved.

VIII. UNIFIED POWER FLOW CONTROLLER (UPFC)

UPFC is most complex and versatile device of FACTS. It is the combination of STATCOM and SSSC [11, 16]. In [11] it is discussed how to implement UPFC in transmission system. Fig. 6 shows complex structure of UPFC it's components are Shunt DC storage capacitor

and power system through coupling transformer. It has two voltage source ontroller, Series controller, Common inverter (VSI) sharing a common DC storage capacitor. VSI is connected in shunt to the shunt transformer while other is connected in series.

Series inverter inject a symmetrical 3-Φ voltage system of controllable magnitude and phase angle to control active and reactive power flow control. This inverter exchange active and reactive power control with transmison line. With the presence of two inverter UPFC not only supply reactive power but also active power. Fig.9 gives the structure of UPFC and Fig. 10 gives the model of UPFC.

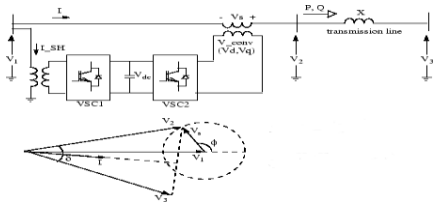

Fig. 8 Structure of UPFC

IX. MATLAB SIMULINK MODEL WITH UPFC

MATLAB/SIMULINK Modeling of Wind Connected Power Plant with UPFC is shown in Fig.9 Here We connect a UPFC to the PCC bus to increase the WTG damping and to provide support to the system during fault conditions. In the above modelling in place of STATCOM connect UPFC. The model of the power system scheme for case study is illustrated in Fig. 9, including the controllers with the control strategy, is implemented using MATLAB/SIMULINK software.

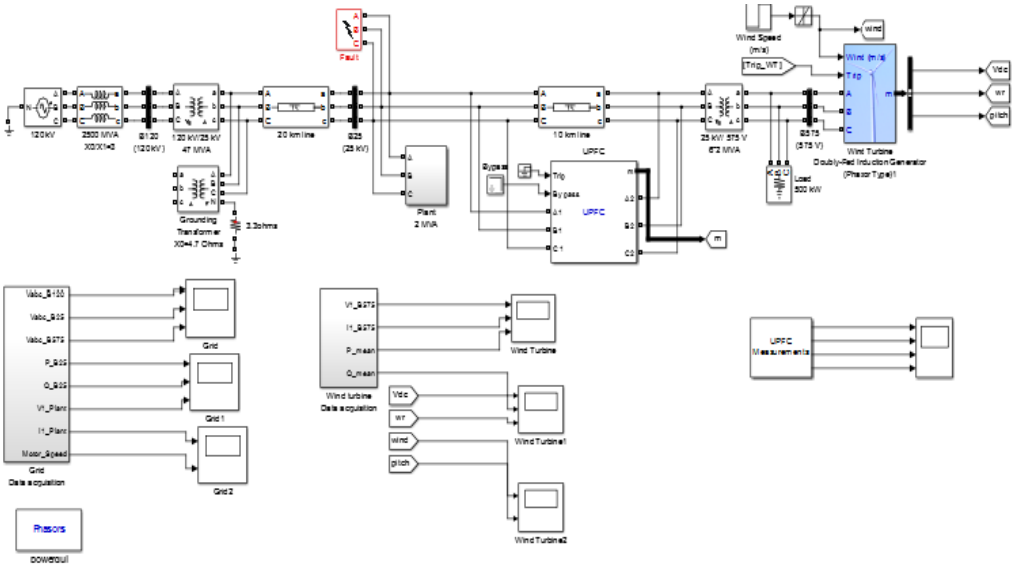

Fig. 9 MATLAB Modeling of Wind Connected Power Plant with UPFC.

X. MATLAB MODELING RESULT WITH UPFC

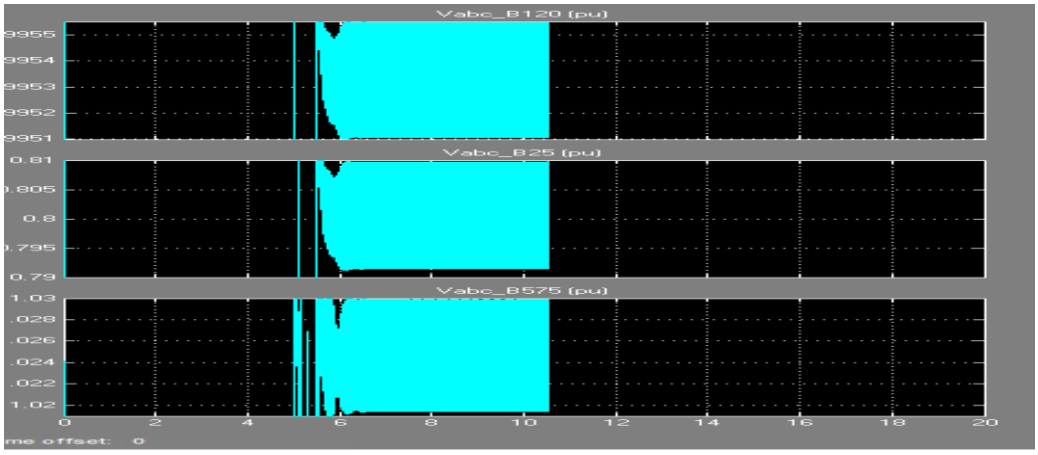

Fig. 10 Voltages of Bus System.

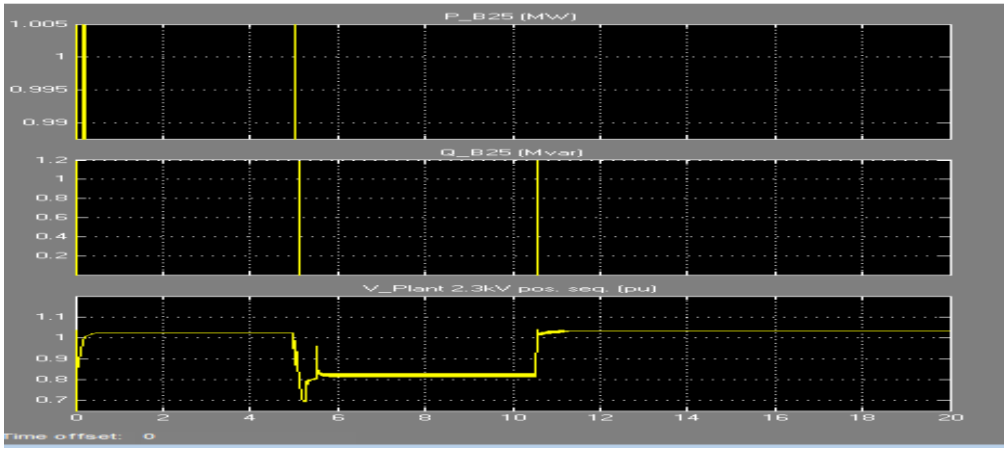

Fig.11 Active and Reactive Power of Bus System

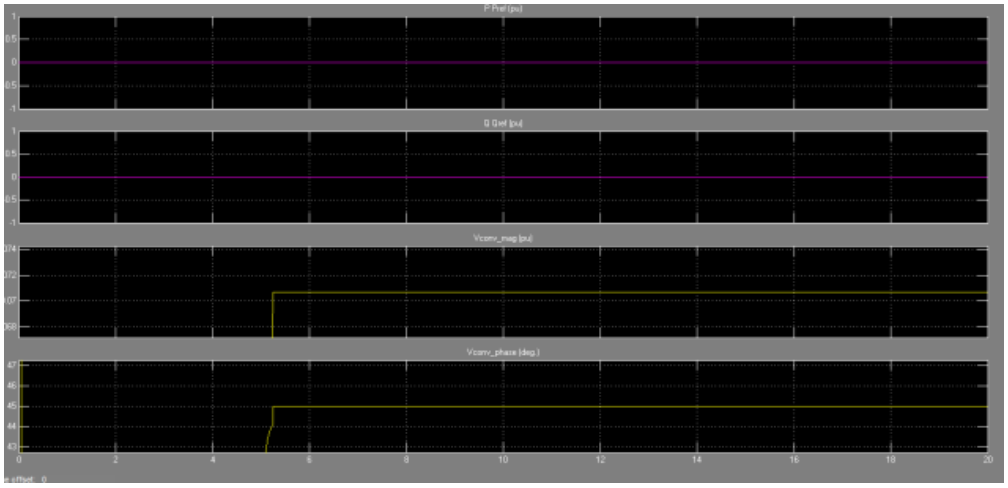

Fig.12 Result of UPFC Control

XI. IMPACTS OF UPFC ON RELAY PROTECTION SYSTEM

Operation of relay depends on setting by calculating the measurements such as magnitude of voltage. UPFC will inject or absorb reactive power to support the voltage in power system which affects the relay operation. This same test with induction generator based wind farm under 3-Φ short circuit fault. Impacts of UPFC on relay behavior are studied by changing the STATCOM with UPFC.

Similar with STATCOM first disable UPFC and then study the simulation results of voltage measurements from grid and power generation. Voltage fluctuates with disabled UPFC. It is observed that voltage during fault is stable and close to 1.0pu due to reactive current compensation from UPFC. Simulated result is shown in fig. 10-12. The relay trips at t = 5sec by the under current protection from the turbine. By comparing the results of UPFC and STATCOM it is found that UPFC is more sensitive to relay setting and fault and UPFC more accurately maintain the voltage level after disturbance.

Fig.10 shows that with UPFC the grid voltages are in continuous mode and performs well without interruption. By the help of Fig. 11 it can be seen that when the fault occurs voltages drops down system will generate the reactive power by which the voltage of the system is improved. Fig 12 shows how the system improves its voltage and power with UPFC.

XII. CONCLUSION

UPFC and STATCOM are very important equipment for reactive power compensation. At present the renewable energy is the active topic of research. The impact of UPFC and STATCOM on wind farm protection improves the stability of operation of power system and decreases the risk of misshapen and breakdown.

This paper presents the comparison of STATCOM and UPFC in integration of wind farm into power grid. After the study we can conclude that using UPFC provides more stable voltage during fault in comparison to STATCOM. It has short tripping time for protection relay; it means UPFC has less impact on relay. By this way UPFC is considered more efficient because it combines the feature of STATCOM and SSSC.

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