Improvement of Active and Reactive Power at the Wind Based Renewable Energy Sources: A case study on ADAMA wind power plant

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Abstract —
The Renewable energy sources like hydro power, solar power, wind energy which has been predictable to be a promising alternative energy supply, can bring new challenge when it is connected to the power grid. The major problems occurring at the wind power plants are, when the wind flow rate is low the out coming of power is low compared to normal condition and problems like voltage stability, Reactive power, and active power variations may occur. To overcome these problems a new emerging devices are implementing at the wind plants. So Flexible ac Transmission Systems (FACTS) device, STATCOM, UPFC is implementing at the wind generating plants to improve the problems which are occurring at wind power plants and to improve the power profile of the system. A case study has been conducted on the wind power generating station, Adama, Ethiopia. And the result has been presented clearly.

Key words: FACTS devices, STATCOM, UPFC

I. Introduction

The location of generating power form wind energy is determined by wind energy resource availability like wind flow, regularly for high voltage (HV) power transmission network and major consumption centers [1].

To have sustainable growth and social progress, we have to save the conventional sources and we have to utilize the nonconventional energy sources like wind, solar, biomass etc. It is necessary to meet the energy need by utilizing these renewable energy resources. The power of wind has been utilized from thousands of years. It may be of different forms. The first wind turbines for electricity generation had already been developed at the beginning of the twentieth century. The technology was improved step by step from the early 1970.By the end of 1990s wind energy has reemerged as one of the most important sustainable energy resources.

Wind energy is gaining increasing importance throughout the world. These fast developments of wind energy technology and of the market have large impact on a number of people and institutions who are working for instance, for scientists who research and teach future wind power and electrical engineers at universities

With the rapid improvement of wind technology, the cost of testing equipment is more. So far analyzing the whole system we have to develop a prototype, but it is also becoming high costs, so in order to analyze most of the people are recommended to the simulation studies. [2]

Power electronic devices have a revolutionary impact on the electric power systems around the world. The availability and application of thyristors has resulted in a new breed of thyristor-based fast operating devices devised for control and switching operations. Flexible AC Transmission System (FACTS) devices are new comings, which have found a wide spread application in the power industry for active and reactive power control. The Static Synchronous Compensators (STATCOM) can be used to provide reactive power to stabilize a wind farm also. There are various voltage source or current source inverter based on FACTS devices for flexible power control damping of power system and stabilization of wind generators, but in this work STATCOM based on a voltage source converter (VSC) is used.

In this paper, we will in particular look at the application of STATACOM for the purpose of transfer capability of power with high penetration of wind power. The paper investigates and demonstrates how, at effective FACTS based power flow control can be applied to relieve the transmission congestion and improve the power capability in the system with high penetration of wind power, while improving the voltage profile.

The paper is organized as follows. The Section II introduces the, issues and its consequences of wind energy system. The Section III introduces the applications of FACTS devices especially STATCOM to improve the voltage profile. The Section IV describes the proposed topology for power quality and voltage enhancement. The Section V describes simulation model and the results.

II. RECON VIEW OF WIND ENERGY:

The working principle of the wind turbine includes the following conversion processes: the rotor extracts the kinetic energy from the wind creating generates torque and the generator converts the torque into electricity and feeds it into the grid. Presently there are three main turbine types available. They are

- Squirrel-cage induction generator
- Doubly fed induction generator.
- Direct-drive synchronous generator

Especially in Ethiopia the Ashogoda is leading with this development, and Adama wind plant is also playing a key role in developing the wind energy. 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. The main scenery of generators contributes much to the transient stability of wind power generation. Wind turbine generators are generally classified into two main types, fixed speed generators and variable speed generators. Fixed speed generators mostly refer to squirrel cage induction generators.

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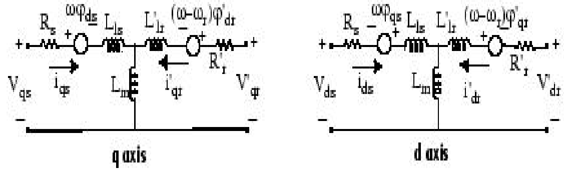
Asynchronous generator block operates in either generator or motor mode. The mode of operation is dictated by sign of the mechanical torque, If the mechanical torque is positive the machine acts as a motor, if it is negative the machine acts as a generator.



$$V_{qs}=R_s i_{qs}+\frac{d}{dt}\varphi_{qs}+\omega\varphi_{ds} \quad \text{.... (1)}$$

$$V_{ds}=R_s i_{ds}+\frac{d}{dt}\varphi_{ds}+\omega\varphi_{qs} \quad \text{.....(2)}$$

$$V^1_{qr}=R^1_r i_{qr}+\frac{d}{dt}\varphi^1_{qs}+(\omega-\omega_r)\varphi^1_{dr} \quad \text{.....(3)}$$

$$V^1_{dr}=R^1_r i_{dr}+\frac{d}{dt}\varphi^1_{ds}+(\omega-\omega_r)\varphi^1_{qr} \quad \text{..... (4)}$$

$$T_e=1.5\,P\,(\varphi_{ds}i_{qs}-\varphi^1_{qr}\,i_{ds}) \quad \text{.....(5)}$$

Asynchronous generators (SGs) have been widely used in variable-speed wind energy conversion systems. There are a number of alternative designs are there, including permanent magnet and wound rotor generators, salient and non salient pole generators, and generators with external and internal rotors. With power rating from a few kilo watts to a few megawatts, synchronous generators provide great flexibility to meet special technical requirements in realistic wind energy systems [5].Some modeling equations of the synchronous generator when they are transformed in to abc to dq reference

a. Armature equations:

$$V_d=-R_S i_d-\omega\lambda_q-(L_{ls}+L_{md})\frac{di_d}{dt}+L_{md})\frac{di_{fd}}{dt}+Lmd\,\frac{di_k}{dt} \quad \text{..(6)}$$

$$V_q=-R_S i_q-\omega\lambda_d-(L_{ls}+L_{mq})\frac{di_q}{dt}+L_{mq})\frac{di_{kq}}{dt} \quad \text{.... (7)}$$

b. Field equations

$$V_{fd}=-R_{fd}i_{fd}-L_{md}\frac{di_d}{dt}+(L_{lfd}+L_{mq})\frac{di_{fd}}{dt}+L_{md}\frac{di_{kd}}{dt} \quad \text{....(8)}$$

c. Damper winding

$$0=-R_{kd}i_{kd}-L_{md}\frac{di_d}{dt}+L_{md})\frac{di_{fd}}{dt}+(L_{md}+L_{lkd})\,\frac{di_{kd}}{dt} \quad \text{...(9)}$$

$$0=-R_{kq}i_{kq}-L_{mq}\frac{di_q}{dt}+(L_{mq}+L_{lkq})\,\frac{di_{kq}}{dt} \quad \text{...(10)}$$

The Asynchronous generator can be constructed with a large number of poles and operate at a speed that directly matches the turbine blade speed. Such a direct-drive system does not need a gearbox. This results a reduction in installation and maintenance costs and provides an advantage over induction generator (IG) based turbines where use of a gearbox is a must. The SG wind energy system is normally controlled by full capacity power converters for variable-speed operation [2], ensuring maximum wind energy conversion efficiency throughout its operating range. With full-capacity converters, the system is able to meet various grid codes [3], including leading/lagging reactive power control and fault ride through operation, without the need for additional equipment.

The main parts of the wind energy system are shown in the below figure

- Blade or rotor, which converts the energy in the wind to rotational shaft energy;
- A drive train, usually including a gearbox and a generator;
- A tower that supports the rotor and drive train; and other equipment, including controls, electrical cables, ground support

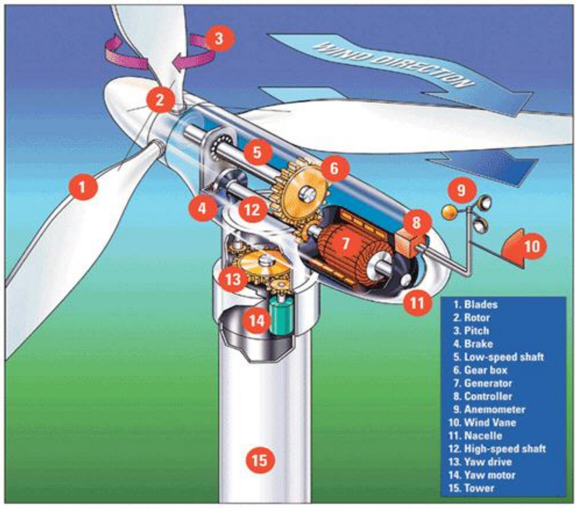


Fig.01 Representation of wind turbine with indicating the parts

III. Implementation of STATCOM Model

The concept of FACTS was first defined by Hingorani. N. G. It was in 1988 that the concept of FACTS was first introduced as "the combination of the application using high power electronic components to enhance the controllability of the power systems". Flexible AC Transmission Systems (FACTS) are devices are capable of altering voltage, phase angle and/or impedances at particular points in power system. Their operations are realized using high power electronic components, which respond quickly to control the inputs. FACTS device provide new control facilities, both in steady state power flow control and dynamic stability control. The possibility of controlling power flow in an electric power flow without generation rescheduling or topological changes can improve the performance considerably. The increased interest in these devices is essentially due to two reasons. Firstly, the recent development in high power electronics has made these devices cost effective and secondly, increased loading of power systems, combined with deregulation of power industry, motivations the use of power flow control as a very cost effective means of dispatching specified power transactions. FACTS devices are of many types based on connection series, shunt, series-series, and series-shunt. The device which we are using it is a FACTS device which is generally connected in the network in shunt type.

STATCOM is one of the most versatile FACTS devices, searching for a more effective control strategy in implementing to the renewable energy sources, is the objective of the researcher. Until now most of the investigations is done, on STATCOM implementation in the grid systems to solve the voltage flickers, power quality problems [4].

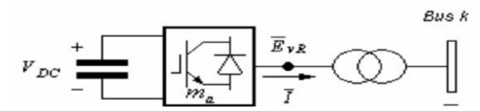


Fig.02 STATCOM's schematic representation

Based on the equivalent circuit shown in Fig. 4.2, the active and reactive power equations are

At node k

$$P_k = V_k^2 G_{kk} + V_k V_m (G_{km}\cos(\theta_k - \theta_m) + B_{km}\sin(\theta_k - \theta_m)) + V_k V_{cR}(G_{km}\cos(\theta_k - \theta_{cR}) + B_{km}\sin(\theta_k - \theta_{cR})) + V_k V_{vR}(G_{vR}\cos(\theta_k - \theta_{vR}) + B_{vR}\sin(\theta_k - \theta_{vR})) \quad \ldots (11)$$

$$Q_k = -V_k^2 B_{kk} + V_k V_m (G_{km}\sin(\theta_k - \theta_m) - B_{km}\cos(\theta_k - \theta_m)) + V_k V_{cR}(G_{km}\sin(\theta_k - \theta_{cR}) - B_{km}\cos(\theta_k - \theta_{cR})) + V_k V_{vR}(G_{vR}\sin(\theta_k - \theta_{vR}) - B_{vR}\cos(\theta_k - \theta_{vR})) \quad \ldots (12)$$

Powers at the STATCOM

$$P_{vR} = -V_{vR}^2 G_{vR} + V_{vR} V_k (G_{vR}\cos(\theta_{vR} - \theta_k) + B_{vR}\sin(\theta_{vR} - \theta_k)) \quad \ldots . (13)$$

$$Q_{vR} = V_{vR}^2 B_{vR} + V_{vR} V_k (G_{vR}\sin(\theta_{vR} - \theta_k) - B_{vR}\cos(\theta_{vR} - \theta_k)) \quad \ldots (14)$$

There are diverse publications regarding to model the STATCOM, for example, steady state studies [7], or transient stability ones [8]. There are other ones applied to voltage control problem using novel technical [9]. The focus in the present work is the analysis of the STATCOM interconnected with the wind energy system.

Here In this topology, the Facts devices are implementing at the renewable energy sources. The proposed STATCOM at the wind energy generation is majorly used to mitigate the voltage flickers and to improve the power quality and below given are the main objectives.

1. Reactive power support only from SATCOM to wind Generator and Load.
2. Voltage Flicker Mitigation.
3. Power Quality improvement.

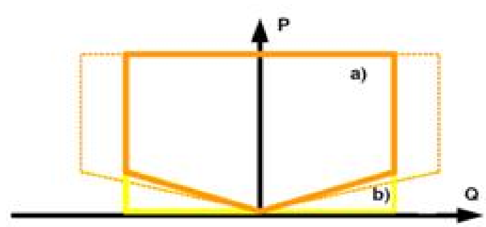


Fig.03: General capabilities of WES with FACTS capabilities a) Default Capability b) Extended capability with STATCOM

IV. IMPLEMENTATION OF UPFC MODEL

The UPFC can provide simultaneous control of transmission voltage, impedance and phase angle of transmission line. It consists of two switching converters as shown in fig1. These converters are operated from a common d.c link provided by a d.c storage capacitor. Converter 2 provides the power flow control of UPFC by injecting an ac voltage with controllable magnitude and phase angle in series with the transmission line via a series transformer. Converter one is to absorb or supply the real power demand by the converter 2 at the common dc link. It can also absorb or generate controllable reactive power and provide shunt reactive power compensation

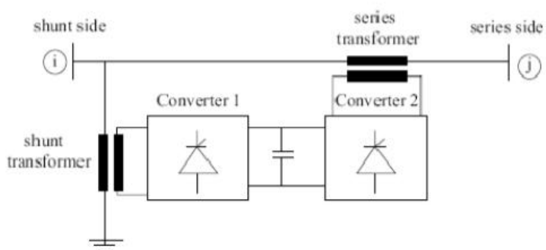


Fig.04 Implementation of the UPFC by back-to-back voltage source converters..[13]

V. PROPOSED EXPERIMENTAL MODEL:

Here the system to be studied is composed by a three wind power plants, composed of three squirrel cage induction generators and is running with a turbine. Due to the use of the asynchronous generator there is a major intake of reactive power during faults so in order to overcome this problem a capacitive bank are using at each wind turbine.[6]

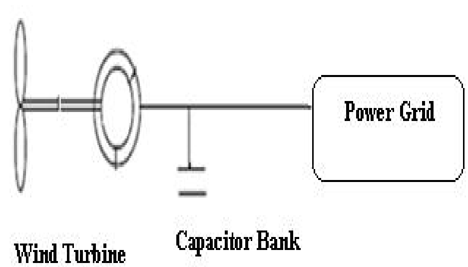


Fig.05 Representation of single wind energy plant with capacitive bank

In the below fig.6 the single wind plant is shown, it has the parts like wind turbine it is given is three different speeds and turbine will rotate the generator. Then three plants are associated together. And these plants are connected with the small grid system[10].

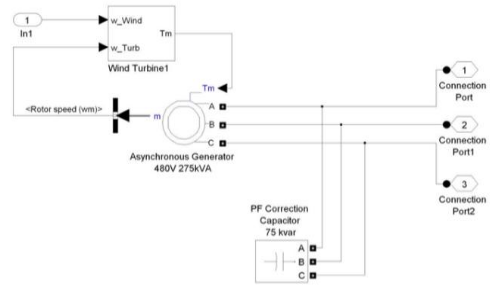


Fig.06 Simulation model of single wind turbine indicating the turbine, generator and a capacitor bank.

VI. SIMULATION MODELS

The proposed model has been simulated using the Matlab/Simulink. For simulating the model we had considered the speed to the turbine is constant, variable, and incremental speed and the synchronous generator is rotating with a speed of 1800 rpm. The proposed simulated model is shown below for single wind machine

CASE-I:

In this case all the three wind plants are interconnected and these are simulated in the Matlab environment. The interconnections of these three plants are shown in fig.no.07. Here these three plants are run normally without implementation of any external devices and these results are shown below

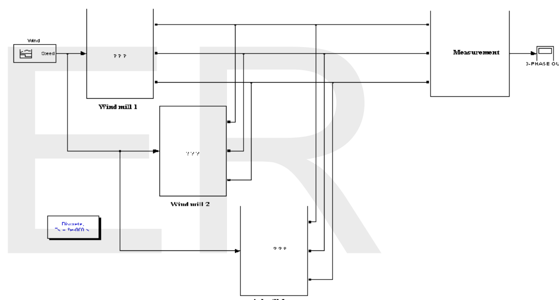


Fig.07 Simulation model of Three wind turbines without STATCOM

CASE-II:

In this case all the wind plants are interconnected and it is connected with the STATCOM and SSSC andUPFC a power electronic FACTS device and these are simulated in the Mat lab environment. The interconnections of these three plants are shown in fig.no.08. The implementation of the STATCOM and UPFC is shown in the below fig.09 and fig.10 it is composed of the active and reactive power measurement blocks, and there is a LC filter to remove the harmonics.

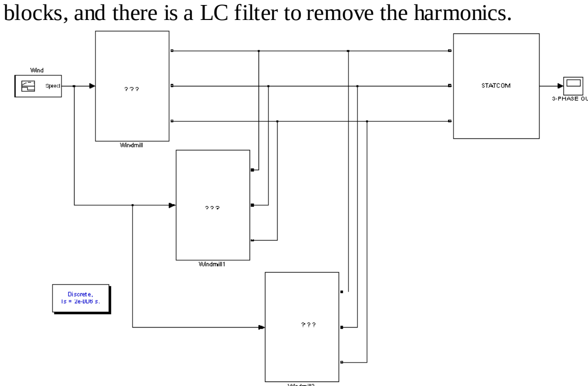


Fig.08 Simulation model of Three wind turbines with STATCOM

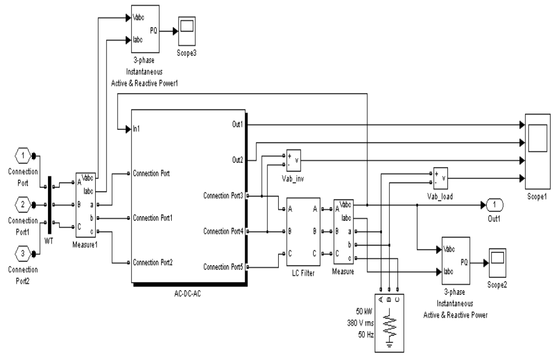


Fig.09 Simulation model of STATCOM

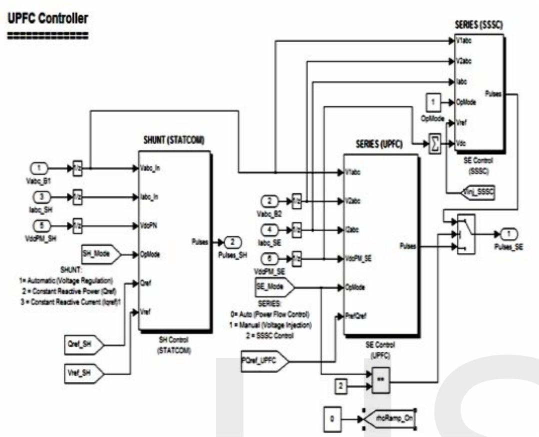


Fig.10 Simulation model of UPFC

VII. RESULTS AND DISCUSSION

By observing the results below in Fig.no.11 shows the results of three phase output of three wind plants and the Fig.no 12 shows the results of three phase output of three wind plants with the interconnection of STATCOM. On comparing these results the three phase output of the normal wind plants are having more fluctuations at the starting time of the plant due to wind variations where as in the case of STATCOM interconnected plants these variations are improved by using these FACTS devices.

The comparative graphical results of active and reactive powers of the two wind mills without STATCOM and with STATCOM is shown below in fig 13.and Fig.no14on observing these results there are many variations in the powers when the wind plants are run without STATCOM. These variations are washed-out when the system is interconnected with the STATCOM. Majorly the reactive power compensation is decreased. Fig. No 15 shows the graphical results of the STATCOM the voltage profile has been maintained at 1.0pu and by implementing the LC filters the harmonics which are present after the STATCOM are reduced.

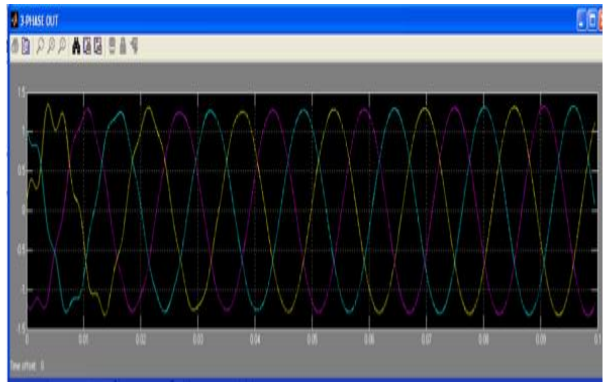


Fig. 11 Graphical results of Three-phase output of the Three wind plants without STATCOM

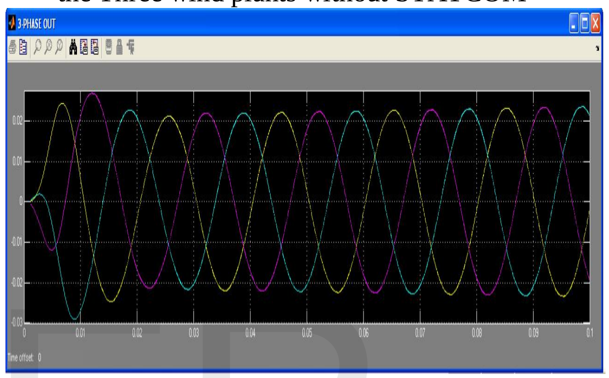


Fig.12 Graphical results of Three-phase output of the Three wind plants with STATCOM

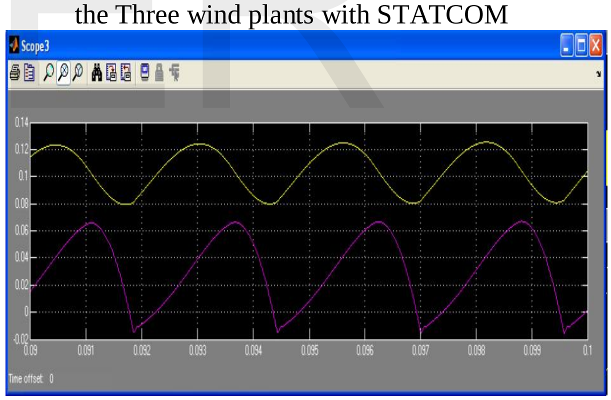


Fig.13 Graphical results of Total Active and Reactive powers of the three wind plants without STATCOM

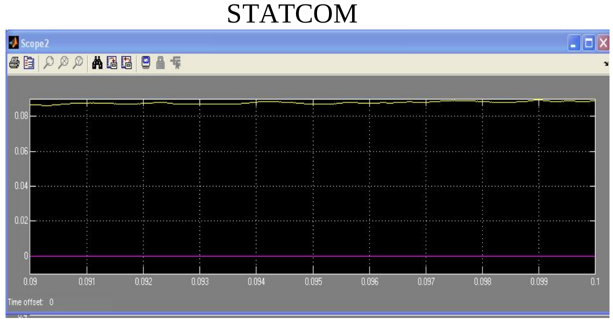


Fig.14 Graphical results of Total Active and Reactive powers of the three wind plants with STATCOM

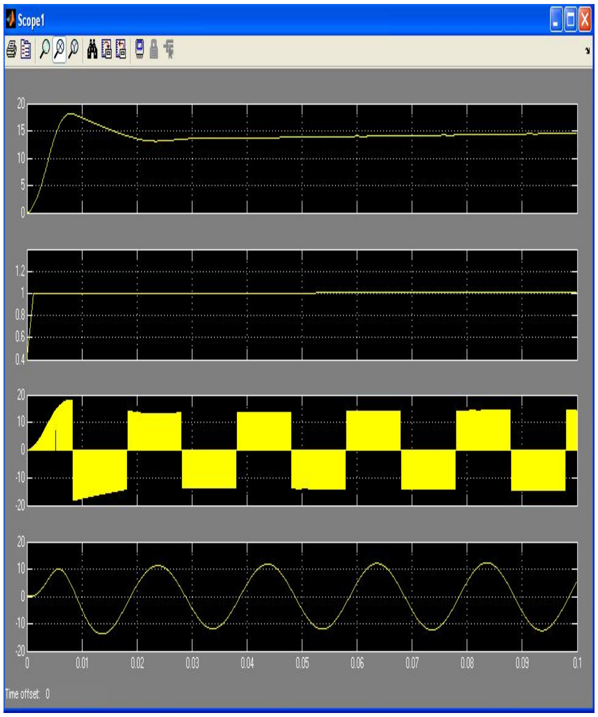


Fig.15 Graphical results of STATCOM

The same wind power plants has been considered but for the comparison of the FACTS devices like STATCOM, SSSC, UPFC single wind power plant has been taken and incorporated the FACTS devices.The comparative result of SATCOM, SSSC and UPFC are shown below in the figures.

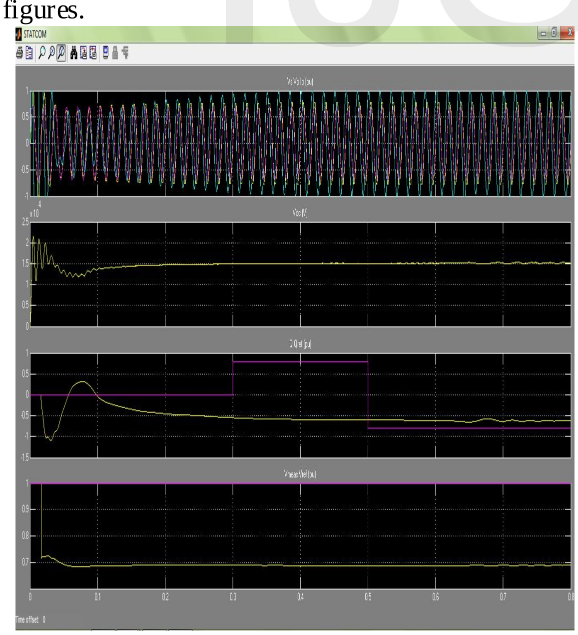


Fig. 16 Result of wind power with STATCOM device

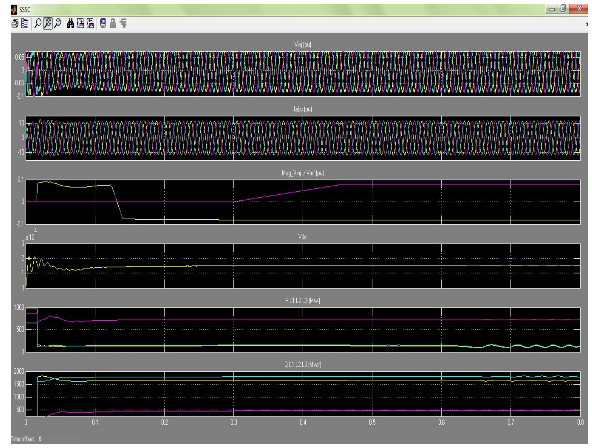


Fig.17 Result of wind power with SSSC device

From this graph the voltage, current, real power and reactive power at starting point there is some distorting but using the SSSC device the waveform becomes smooth and improved.

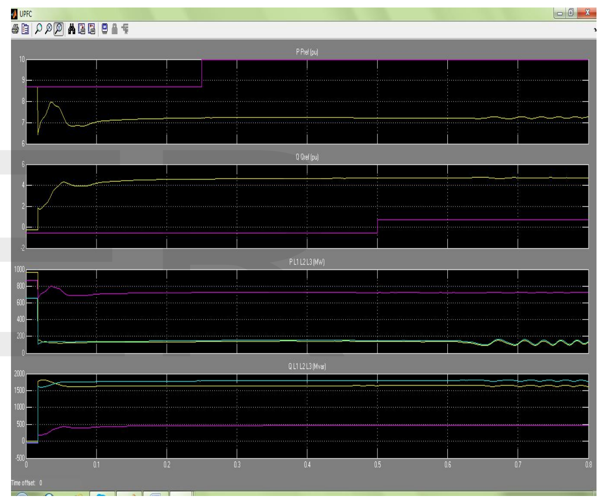


Fig. 18 Result of wind power with UPFC

VIII. CONCLUSION

This paper has exploited a detail influence of the voltage stability and the behaviors of wind plants during different wind speed conditions. The wind plants are run without the implementation of any peripheral devices in these circumstances there are variations in the system like voltage profile, active and reactive powers. These problems can be mitigated with the implementation of the STATCOM, SSSC, and UPFC near to the plants. So the FACTS devices at plants like STACOM,SSSC,UPFC, can provides evidence to the power profiles which have been improved and the voltage fluctuations have been diminished.

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