Dynamic Compensation of Reactive Power for Integration of Wind Power in a Weak Distribution Network

S. M. Shinde, K. D. Patil, and W. Z. Gandhare

Abstract — As a promising renewable alternative, the wind power is highly expected to contribute a significant part of generation in power systems in the future, but this also bring new integration related power quality issues, which mainly consist of voltage regulation and reactive power compensation. Wind power, as a rule, does not contribute to voltage regulation in the system. Induction machines are mostly used as generators in wind power based generations. Induction generators draw reactive power from the system to which they are connected. Therefore, the integration of wind power to power system networks; especially a weak distribution networks is one of the main concerns of the power system engineers. Voltage control and reactive power compensation in a weak distribution networks for integration of wind power represent main concern of this paper. The problem is viewed from MATLAB/Simulink simulation of weak distribution network and wind power integration in this network. Without reactive power compensation, the integration of wind power in a network causes voltage collapse in the system and under-voltage tripping of wind power generators. For dynamic reactive power compensation, when, STATCOM (Static Synchronous Compensator) is a used at a point of interconnection of wind farm and the network; the system absorbs the generated wind power while maintaining its voltage level.

Index Terms — Induction generators, Non-linear dynamic simulation, Reactive power compensation, STATCOM, Voltage regulation.

1 Introduction

OVER recent years there has been a continuous increase in installed wind power generation capacity throughout the world. In fact, the grid connected wind capacity is undergoing the fastest rate of growth of any form of electricity generation. Fig.1 shows the global annual installed capacity growth from 1996 to 2008 [1]. Fig.2 shows year wise installed capacity (MW) in INDIA. At the end of 2008, the total wind power installed capacity in India has gone to 8697.925 MW. The Indian Wind Turbine Manufacturers Association (IWTMA) estimates the potential to be of the order of 65,000 MW [2]. Recently, Government of India has de-regularized the power sector. Ministry of New and Renewable Energy (MNRE) has issued guidelines to all state governments to create an attractive environment for the export, purchase, wheeling and banking of electricity generated by wind power projects. Hence, sustainable growth of wind power generation is expected in the years to come.

This growth of wind power generation is likely to influence the operation and planning of the existing power system networks. Because integration of wind power in a power systems presents problem of voltage regulation and reactive power compensation [3].

The wind turbines are composed of an aerodynamic rotor, a mechanical transmission system, squirrel cage induction generator, a control system, limited reactive power compensation and a step-up transformer. The conventional wind turbine is even at the present time, the most common type of wind turbine installed.

Therefore, this paper deals about such conventional squirrel cage induction generator system.

An important operating characteristic of the squirrel cage induction generator is that this type of

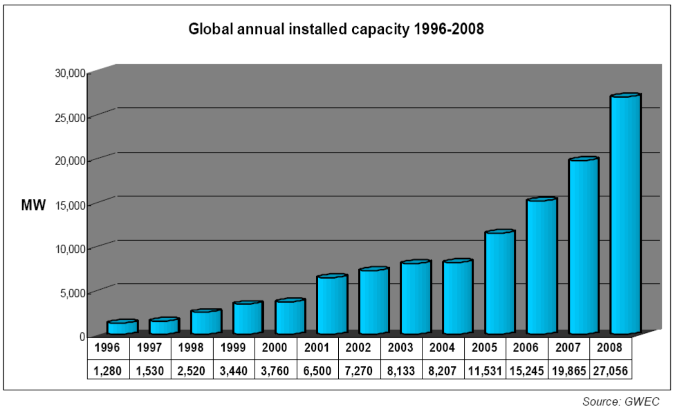

Fig. 1. Global annual installed capacity growth from 1996 to 2008

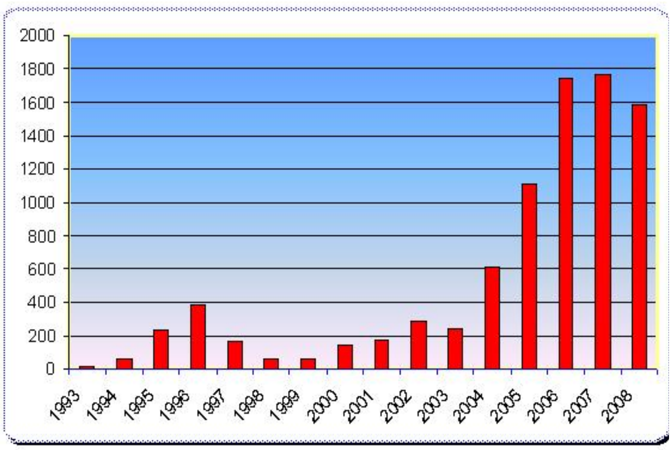

Fig. 2. Yearwise installed capacity (MW) in India

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Manuscript received: 21st February 2009

generator always consumes reactive power, which is undesirable for the transmission system. Particularly in the case of large turbines and weak distribution system.

Another characteristic of the squirrel cage induction generators is that, in general, this type of generator tends to slow down voltage restoration after a voltage collapse and this can lead to voltage and rotor speed instability. When the voltage restores, the generator will consume reactive power, impeding the voltage restoration. When the voltage does not return quickly enough, the generator continues to accelerate and consumes even larger amount of reactive power [4]. This process eventually leads to voltage and rotor speed instability if the wind turbine is connected to a weak system. To prevent these types of instabilities; conventionally, shunt capacitor banks are connected at the generator terminals to compensate its reactive power consumption.

To minimize the reactive power exchange between wind farms and distribution network, dynamic compensation of reactive power can be employed [5]. Power electronics based FACTS devices such as SVC and STATCOM are useful for dynamic compensation of reactive power. The STATCOM performs the same function as the SVC. However at voltages lower than the normal voltage regulation range, the STATCOM can generate more reactive power than the SVC. This is due to the fact that the maximum capacitive power generated by a SVC is proportional to the square of the system voltage (constant susceptance) while the maximum capacitive power generated by a STATCOM decreases linearly with voltage (constant current). This ability to provide more capacitive reactive power during voltage collapse is one important advantage of the STATCOM over the SVC. In addition, the STATCOM will normally exhibit a faster response than the SVC because with the VSC, the STATCOM has no delay associated with the thyristor firing [6].

In his paper the reactive power compensation capability of STATCOM for wind power integration into a weak distribution network is evaluated. The study is based on the three phase non-linear dynamic simulation, utilizing the Simpowersystem blockset for the use with MATLAB/Simulink [6].

2 Test System

The single line diagram of a test system employed in this study is shown in Fig.3. The network consists of a 132 kV, 50 Hz, grid supply point, feeding a 33 kV distribution system through 132/33 kV, 62.5 MVA step down transformer. There are two loads in the system; one load of 50 MW, 0.9 pf (lag) and another load of 6 MW, 0.9 pf (lag) at 50 kM from the transformer. The 33 kV, 50 kM long line is modeled as line. A 9 MW wind farm consisting of six 1.5 MW wind turbines is to be connected to the 33 kV distribution network at 6 MW load point. The total MVA loading on the system is 62.22 MVA; considering the T & D losses in the system it is over loaded; thus, truly, representing weak distribution network. Dynamic compensation of reactive power is provided by a STATCOM located at the point of wind farm connection.

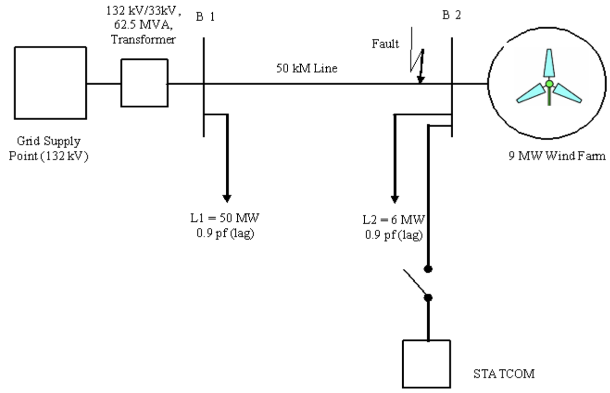

Fig. 3. Single line diagram of a test system

The 9 MW wind farm have conventional wind turbine systems consisting of squirrel-cage induction generators and variable pitch wind turbines. In order to limit the generator output power at its nominal value, the pitch angle is controlled for winds exceeding the nominal speed of 9 m/s [4]. Each wind turbine has a protection system monitoring voltage, current and machine speed.

3 Simulation of Test System

Distribution systems are inherently unbalanced in most of the cases due to the asymmetrical line spacing and imbalance of consumer load. In view of this, single phase models can not be used for accurate studies on the operation of distribution systems [4]. Therefore in this work all network components are represented by the three phase models.

Test system is simulated in MATLAB/Simulink. Fig.4. shows the Simulink model of the test system. Phasor simulation is used to simulate the test system; so as to make it valid for intended purpose. Variable-step ode23tb solver is used for simulation. The simulation time is 20 sec.

The simulation is run in four different modes, as follows –

i. Without wind farm and STATCOM,
ii. With wind farm and without STATCOM,
iii. With wind farm and STATCOM (without fault),
iv. With wind farm and STATCOM (with fault).

In each case the pu voltage, active and reactive power at 33 kV bus - 1 and bus – 2, active and reactive power at load -1 and load - 2 and active and reactive at the wind farm are measured. When the STATCOM is connected to the system reactive power supplied by the STATCOM is also measured. For all the measurements, base power taken as 50 MVA and base voltage is 33 kV. Suitable sign convention is followed for measurement and subsequent analysis of active and reactive power at the buses as well as at the load points. The same quantities at different locations are muxed to multiplex the signals [7] for respective measurement.

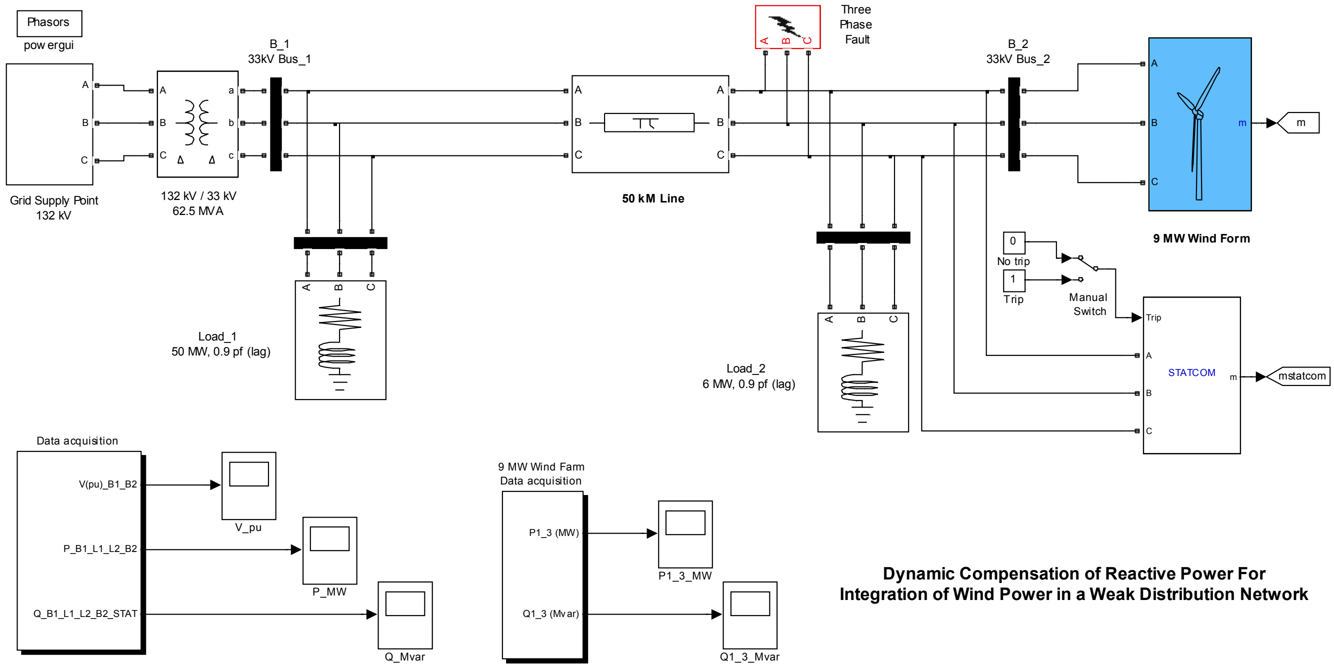

Fig. 4. The Simulink model of the test system

4 SIMULATION RESULTS

4.1 Without wind farm and STATCOM

In this mode the wind farm and STATCOM were skipped while running the simulation. Only the distribution system and two loads were kept in the model. The purpose of running the simulation in this mode is to ascertain that, the test system is a weak system. Thus, in this mode only voltages at 33 kV Bus – 1 and Bus – 2 are measured.

Fig. 5 shows the voltages at 33 kV Bus – 1 and Bus – 2. From this Fig. it seen that the voltage at 33 kV Bus – 1 is below 0.94 pu. Where as the voltage at 33 kV

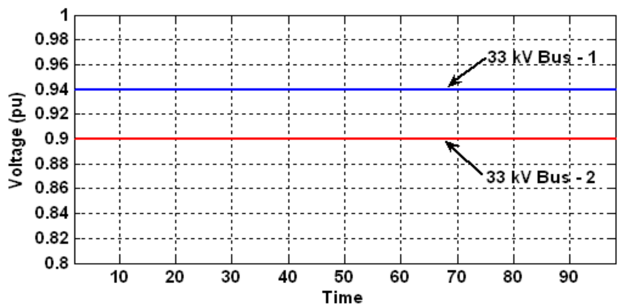

Fig. 5. Voltages at 33 kV Bus – 1 and Bus – 2

Bus – 2 is 0.9 pu. As these voltages are below 0.95 pu the distribution network taken for this study is really weak.

4.2 With wind farm and without STATCOM

In this mode of simulation the wind farm is connected to the weak distribution network in above mode. The purpose of running simulation in this mode is to try integration of 9 MW wind power in weak distribution network, without dynamic compensation of reactive power *i.e.* without using the STATCOM.

Fig.6 shows active power supplied by wind turbine generators to the distribution network. From Fig. it seen that the wind turbine generators are tripped one by one. First set number-2, then set number-3 and finally set number-1 is tripped.

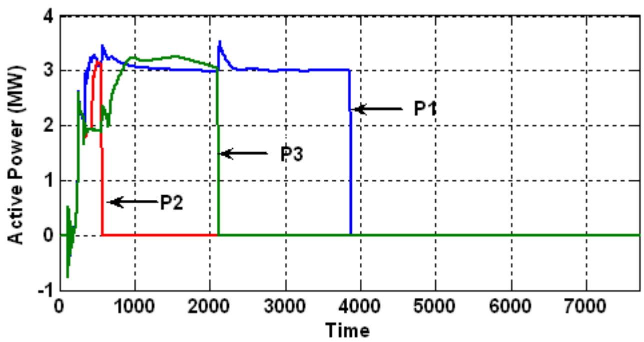

Fig. 6. Active power supplied by wind turbine generators

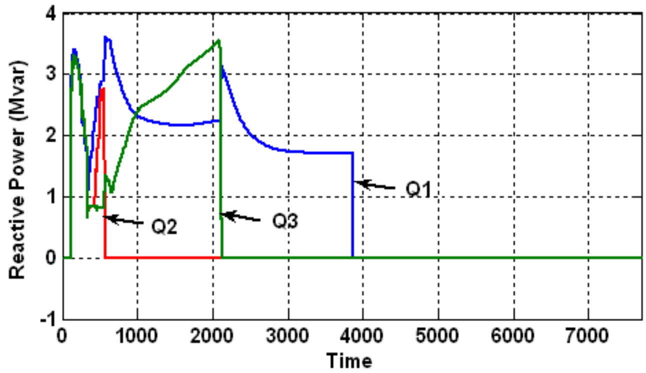

Fig. 7. Reactive power drawn by induction generators

The cascade tripping of wind power generators is due under voltage at 33 kV Bus – 2. This shows that as such, the wind power can not be integrated in a weak distribution network. This is due to fact that, weak network is not capable of supplying reactive power demanded by induction generators [8]. Fig.7 shows the reactive power drawn by induction generators from the network before tripping.

The active power at various points in the network is shown in Fig.8. From this Fig. it is seen that, before the tripping the wind turbines have supplied active power to the network.

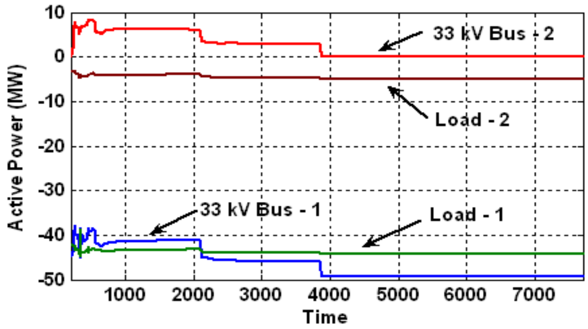

Fig. 8. Active power at various points in the network

The reactive power at various points in the network is shown Fig.9. From this figure it is seen that, before tripping the wind turbine generators have drawn reactive power from the network. As a result the voltage at 33 kV Bus – 2 as well as Bus – 1 is decreasing, thereby causing under voltage tripping of wind turbine generators. Fig.10 shows the voltages at 33 kV Bus – 1 and 33 kV Bus – 2.

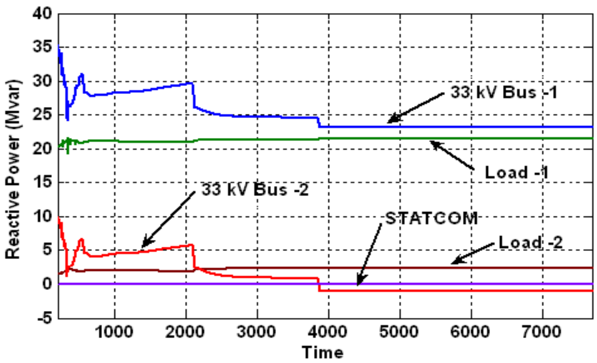

Fig. 9. Reactive power at various points in the network

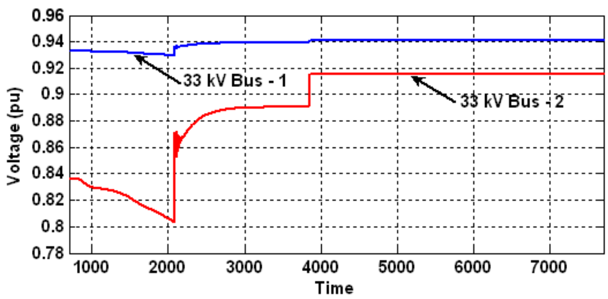

Fig. 10. Voltages at 33 kV Bus -1 and Bus – 2

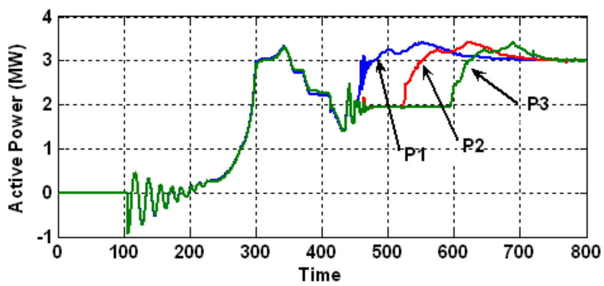

Fig. 11. Active power supplied by wind turbine generators

4.3 With wind farm and STATCOM (without fault)

In this mode of simulation the wind farm with dynamic compensation by STATCOM is connected to the weak distribution network in above mode. The purpose of running simulation in this mode is to integrate 9 MW wind power in weak distribution network, with dynamic compensation of reactive power using the STATCOM.

Fig.11 shows active power supplied by wind turbine generators to the distribution network. From Fig. it seen that, in this case the wind turbine generators are not tripped. But they are supplying (3 x 3) MW power to the distribution network.

Fig.12 shows the reactive power drawn by induction generators from the network. From Fig. it is seen that initially wind turbine generators draw more reactive

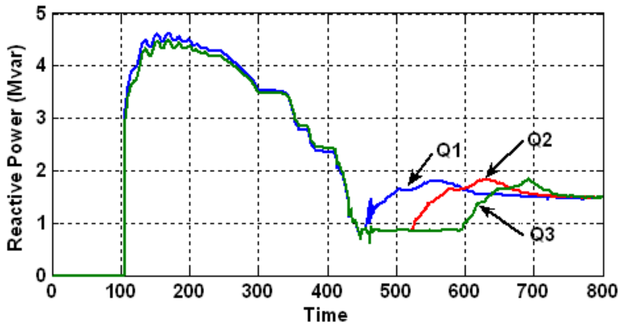

Fig. 12. Reactive power drawn by induction generators

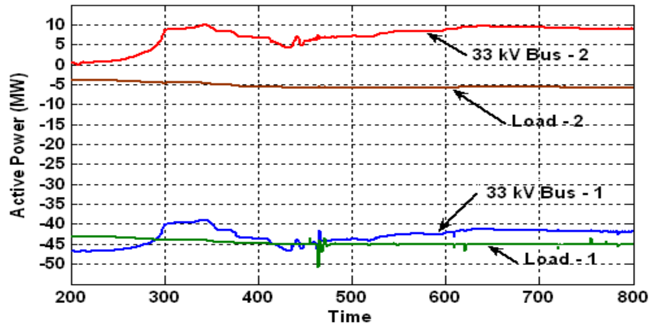

Fig. 13. Active power at various points in the network

power, but later on the reactive power demand is stabilized at (1.5 x 3) Mvar.

The active power at various points in the network is shown in Fig.13.

The reactive power at various points in the network is shown in Fig.14. From Fig. it is seen that, the STATCOM is supplying 3 Mvar reactive power to the network. This is to meet the reactive power demand of the wind turbine generators, while maintaining the system voltage.

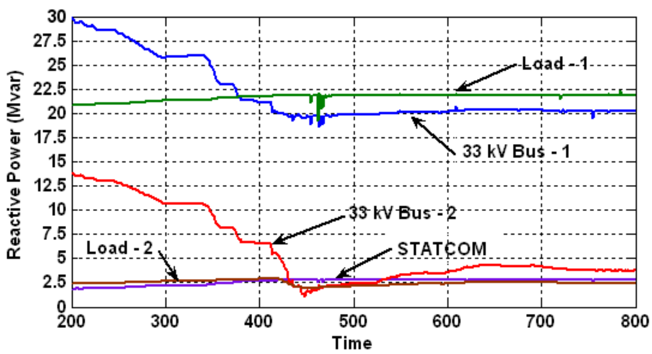

Fig. 14. Reactive power at various points in the network

Fig.15 shows the voltages at 33 kV Bus – 1 and 33 kV Bus – 2. From Fig. it is seen that initially the voltage at Bus – 2 is less than that at Bus – 1, but due to reactive power injection by STATCOM the voltage at Bus – 2 goes beyond voltage at Bus – 1.

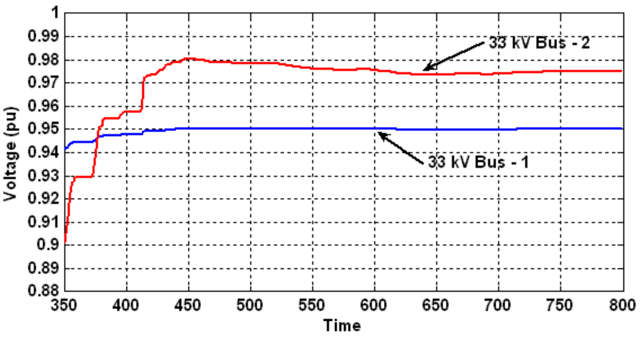

Fig. 15 Voltages at 33 kV Bus -1 and Bus – 2

4.4 With wind farm and STATCOM (with fault)

This mode is same as above mode of simulation, but in this case a three phase fault for 2 cycles i.e. 0.04 sec is made at 33 kV Bus – 2. The fault is initiated after 5 sec from starting of the simulation. The purpose of running simulation in this mode is to verify the dynamic reactive power compensation capability of STATCOM during the event of fault, while integrating wind power in a weak distribution network.

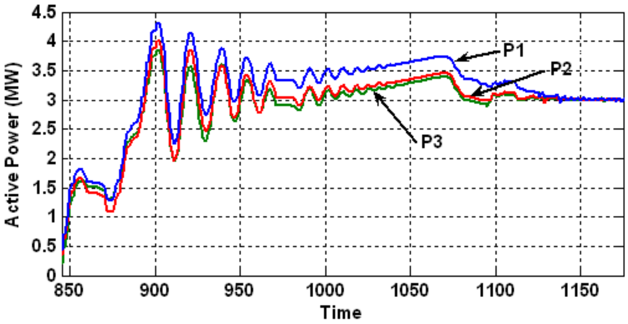

Fig. 16. Active power supplied by wind generators

Fig.16 shows active power supplied by wind turbine generators to the distribution network. From fig. it seen that, in this case also the wind turbine generators are not tripped. But they are supplying (3 x 3) MW power to the distribution network.

Fig.17 shows the reactive power drawn by induction generators from the network.

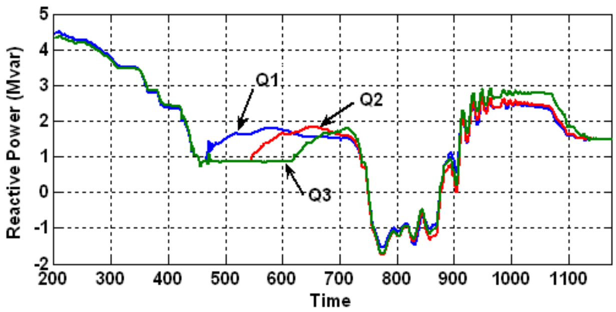

Fig. 17. Reactive power drawn by induction generators

The active power at various points in the network is shown in Fig.18.

The reactive power at various points in the network is shown in Fig.19. From Fig. it is seen that, the STATCOM is supplying reactive power to the network even in the event of short duration fault at its point of interconnection.

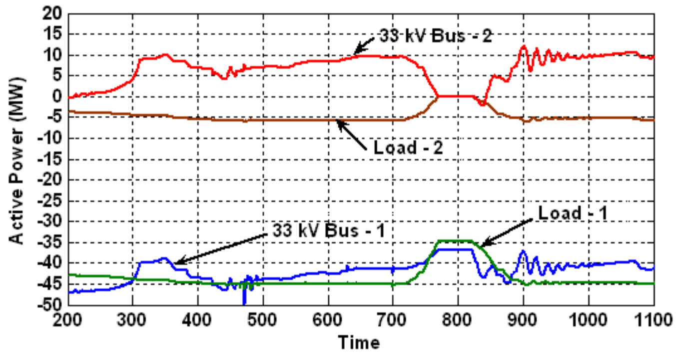

Fig. 18. Active power at various points in the network

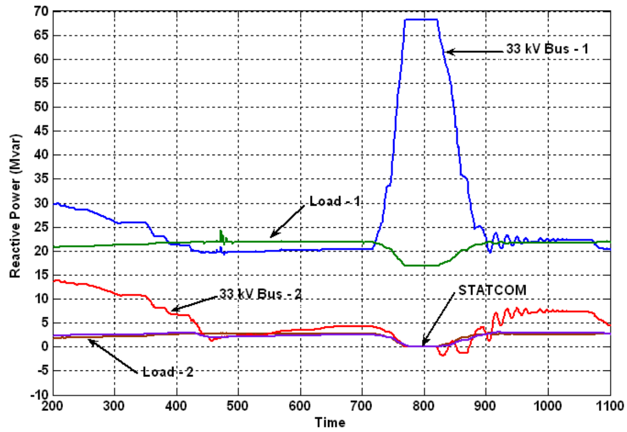

Fig. 19. Reactive power at various points in the network

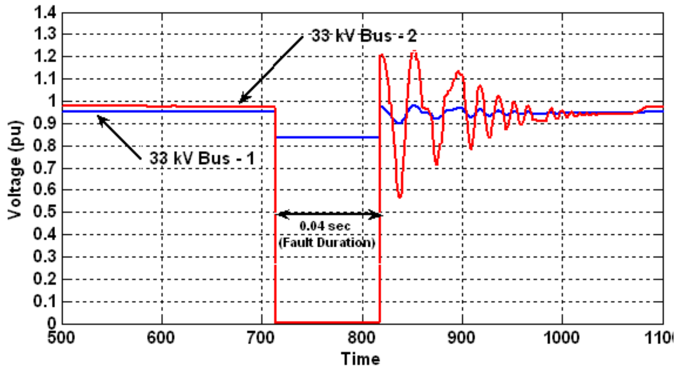

Fig. 20. Voltages at 33 kV Bus -1 and Bus – 2

Fig.20. shows the voltages at 33 kV Bus – 1 and 33 kV Bus – 2. From Fig. it is seen that the voltage recovery after the fault is accelerated due to STATCOM and the system voltage restores before the initiation of protection systems. Thus the wind turbine generators do not trip even in the event of short duration fault.

5 Conclusions

This paper presented an evaluation study about the dynamic power compensation capability of STATCOM for the integration of wind power in a weak distribution network. The dynamic power compensation capability of STATCOM is also evaluated during an external three phase fault. The study reveals that, reactive power compensation by STATCOM makes it possible the integration of wind farm in a weak distribution network. STATCOM prevents large deviations of bus voltage due to reactive power drawn by wind turbine generators and also after fault the rapid recovery of voltage is resulted.

ACKNOWLEDGEMENT

This work was performed at The Government College of Engineering, Aurangabad (India). Author gratefully acknowledges the kind permission, advices and contributions of Prof. Dr. W. Z. Gandhare (Principal) and Prof. Ms. Archana Thosar (Assistant Professor and Head of the Electrical Engineering Department).

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