Dynamic Performance Analysis of IG based Wind Farm with STATCOM and SVC in MATLAB / SIMULINK

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ABSTRACT

Voltage Stability is a key factor for the stable operation of grid connected wind farm during fault through and grid disturbances. This paper investigates the implementation and comparison of FACTS devices like STATCOM and SVC for the voltage stability issue for IG-based wind farm connected to a grid and load. The steady state behaviour of an interconnected IG based wind farm with STATCOM and SVC is studied and compared for performance evaluation of the two FACTs devices. The power system model is simulated in MATLAB / SIMULINK and the results show that the STATCOM is better than SVC for the stable operation of wind turbine generator system to remain in service during grid faults.

Keywords

Dynamic Performance, Induction Generator, FACTs, Power System Stability, Matlab/Simulink, Transient Stability,Wind Power Plant

1. INTRODUCTION

In the last few years, there is a strong trend towards decentralized production and supply, leading to a solution where a growing number of small and medium size producers are connected to energy networks[17]. But at the same time, the power quality of the generation must be ensured and this means that the electrical parameters of the distribution network have to be maintained within their upper and lower limits. Therefore, new problems related to the management and operation of energy transfer and distribution and efficient distribution of renewable energy in the grids are actually arising[18]. Hence, it is reasonable to think that dispersed generation should start to take part in the control of electric variables, and in particular, in reactive power control which is directly related to the voltage level control of distribution networks [16].There is an increasing concern over the environmental impact and sustainability of traditional fossil-fuelled power plants. Wind energy is one of the most important and promising renewable energy resources in the world, leading to a growing penetration of the wind energy in electrical system[19]. As a consequence, the number of small size wind farms used as DG sources located within the distribution system is rapidly increasing in recent years[1]. Installing wind farm in the distribution system can defer the investments for the distribution system expansion, but at the same time, the power quality of the distribution network has to be ensured. Hence, wind farms are more and more required to take part in the control of electric variables and in particular in reactive power control [17]. The variable-speed wind turbine equipped with Induction generator (IG) is widely used generator in wind farms. The Induction generator is able to obtain the maximum active power from wind speed and the generated reactive power can be controlled in an independent way[20]. Utilizing IG reactive power control capability, wind farm made up with IG can be used as the continuous reactive power source to support system voltage control without causing any interference in their active power generation process[2]. Wind farm reactive power control can reduce power losses and improve the voltage profile at the user terminal by providing reactive power compensation in distribution systems. The benefits of compensation depend greatly on the IG wind turbine reactive power output capability. The idea is to find the optimal wind farm reactive power output to minimize losses and improve voltage profiles in the distribution system[18].A wind farm comprising IG wind turbines is proposed as a continuous reactive power source to support system voltage control due to reactive power control capability of IG[5]. Wind farms are located in geographical areas which have continuous, steady, favourable wind in the speed range between 6m/s to 30 m/s. Annual average wind speed of 10m/s is considered to be very suitable, A wind farm has several wind turbine generator units[6]. A typical wind farm may have 5 to 50 wind turbine generator units of small or medium size. Large wind turbine generator units are generally built as single units (without wind-farm) [20].

The electrical generators with the wind turbine units are of two types[19]

1. 50 Hz a.c. synchronous generators with constant speed connected to the grid.
2. Variable frequency a.c induction generator with variable speed.

Following options are available for wind electric energy conversion plants.

1. Stand alone generators with battery storage support.
2. Wind energy conversion plants in parallel with the electrical grid as energy displacement plants. Battery storage is not necessary in these energy conversion plants.
3. Wind-diesel hybrid for remote stand alone systems.

2. OUTLINE OF FACTS DEVICES

2.1 SVC V-I Characteristics

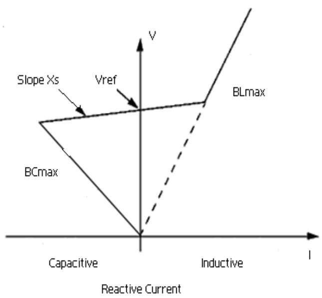

Fig 1: The V-I Characteristics of SVC

2.2 Transient Stability with SVC

The SVC can be operated in two different modes[22]:

- In voltage regulation mode.
- In var control mode (the SVC susceptance is kept constant).

When the SVC is operated in voltage regulation mode, it implements the V-I characteristic shown in Fig. 1.

As long as the SVC susceptance B stays within the maximum and minimum susceptance values imposed by the total reactive power of capacitor banks (B_{cmax}) and reactor banks (B_{lmax}), the voltage is regulated at the reference voltage Vref[26]. However a voltage droop is normally used usually between 1% and 4% at maximum reactive power output).

The V-I characteristic is described by the following three equations

$V=V_{ref} + X_s.I$ SVC is in regulation range ($-B_{max}< B <B_{Lmax}$) (1)

$V= -I / Bc_{max}$ SVC is fullycapacitive ($B=B_{cmax}$) (2)

$V=I / Bl_{max}$ SVC is fully inductive ($B=B_{Lmax}$) (3)

Where,

V = Positive sequence voltage (p.u.)

I = Reactive current (p.u./P_{base}) (I > 0 indicates an inductive current)

X_S = Slope or droop reactance (p.u./P_{base})

B_{Cmax} = Maximum capacitive susceptance (p.u./P_{base}) with all TSCs in service, no TSR or TCR

B_{Lmax} = Maximum inductive susceptance (p.u./P_{base}) with all

TSRs in service or TCRs at full conduction, no TSC

P_{base} = Three-phase base power

2.3 Static Synchronous Compensator (STATCOM)

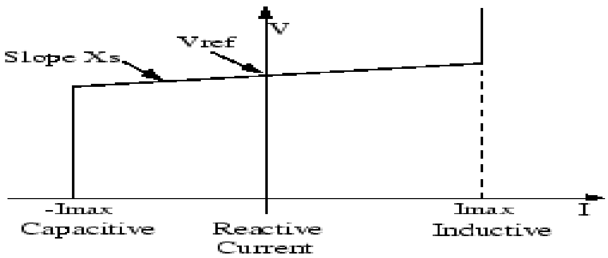

Fig 2: V-I Characteristics of STATCOM

As long as the reactive current stays within the minimum and minimum current values (-Imax, Imax) imposed by the converter rating, the voltage is regulated at the reference voltage Vref. However, a voltage droop is normally used (usually between 1% and 4% at maximum reactive power output), and the V-I characteristic has the slope indicated in the figure. In the voltage regulation mode, the V-I characteristic is described by the following equation:

$V=V_{ref} + X_s I$ (4)

Where

V : Positive Sequence Voltage (pu)

I : Reactive Current (I>0 indicates an Inductive Current)

Xs: Slope or Droop Reactance

3. SIMULATION

The investigated power system network is modeled and simulated in MATLAB / SIMULINK as shown in Fig. 3 and Fig. 4 to study the steady state behavior with SVC and STATCOM . The fault is initiated between 10 and 10.1 sec from starting of the simulation. The purpose of running simulation in this mode is to verify the dynamic reactive power compensation capability of SVC and STATCOM during the event of fault, while integrating wind power in a distribution network. 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 20 MW and another load of 4 MW 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 4 MW load point. Dynamic compensation of reactive power is provided by a SVC or STATCOM located at the point of wind farm connection. 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. Test system is simulated in MATLAB/Simulink. Fig.3 and 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.

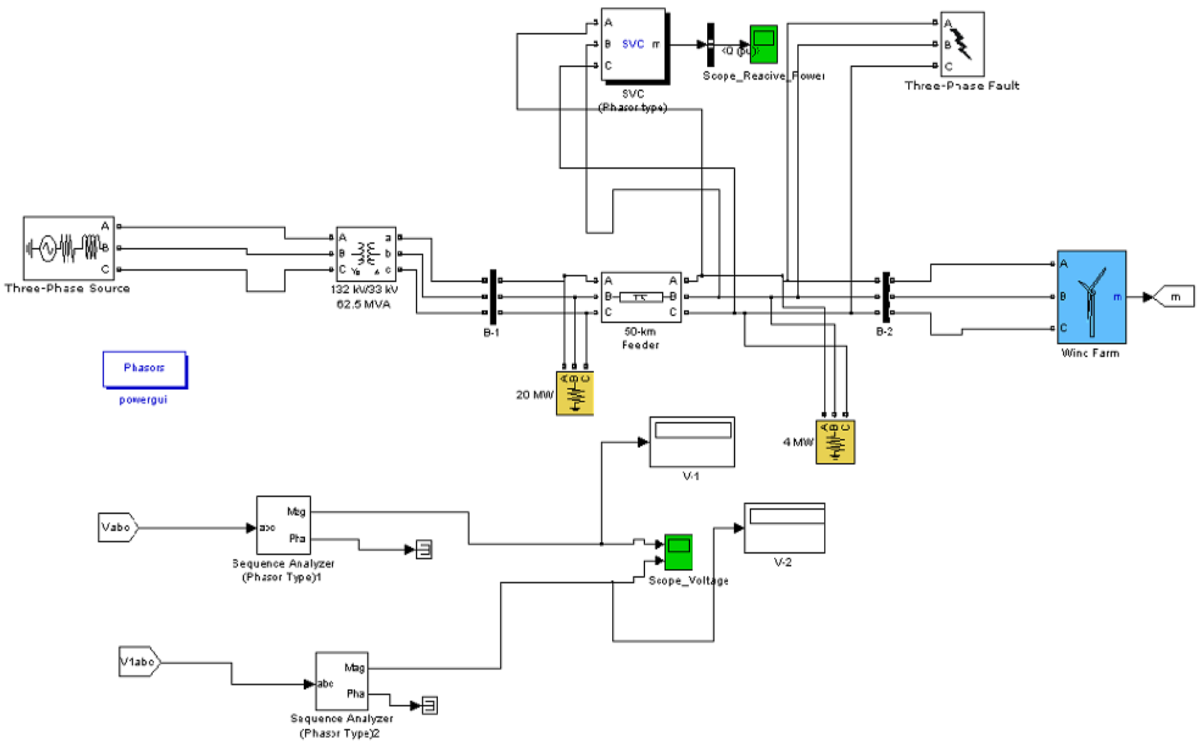

Fig. 3:Simulink Model of IG with SVC

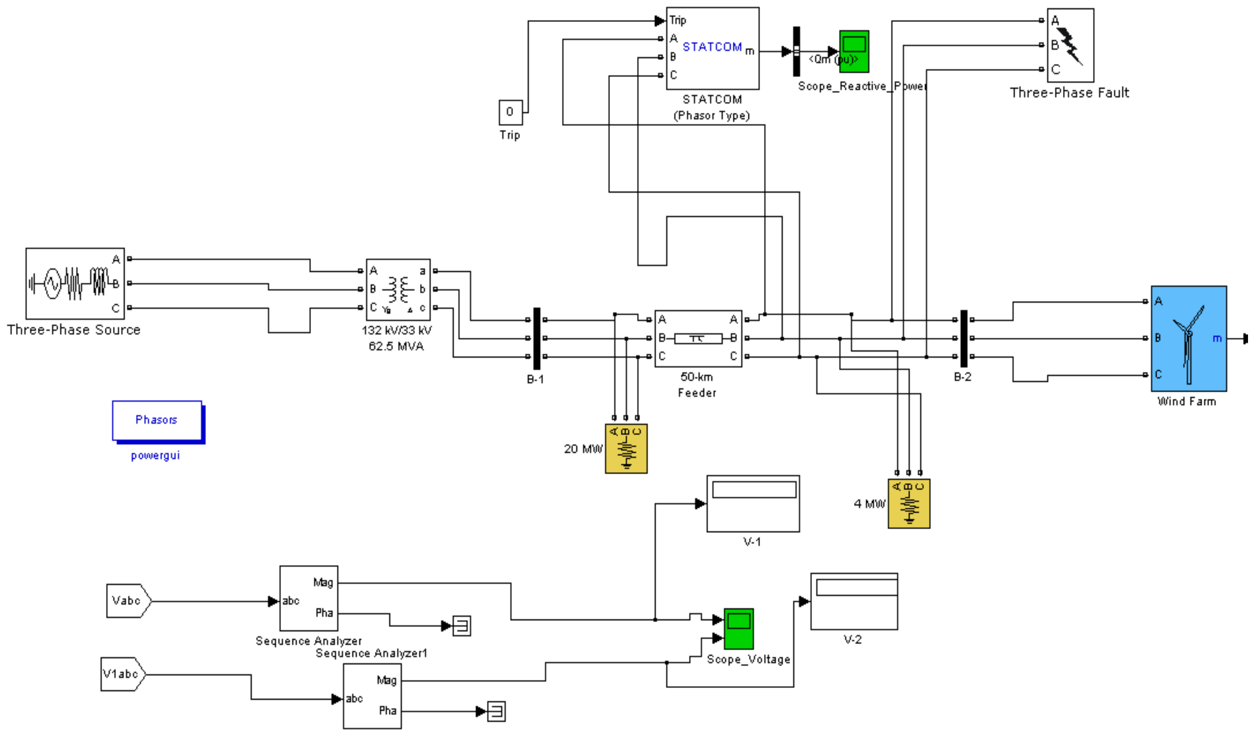

Fig.4: Simulink Model of IG with STATCOM

6. SIMULATION RESULTS AND DISCUSSIONS

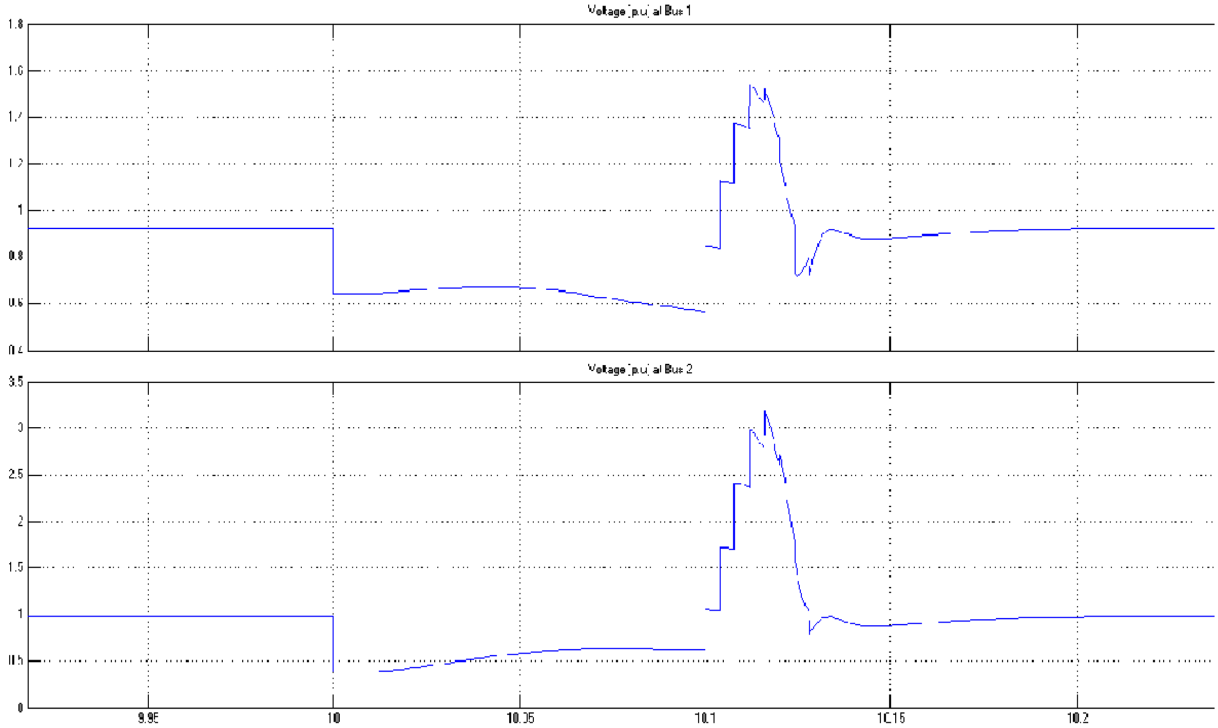

Fig.5 : Voltages at 33 kV Bus – 1 and Bus – 2 during SVC

Fig. 5 shows the voltages at 33 kV Bus – 1 and Bus – 2 during the operation of SVC located at the point of wind farm connection.

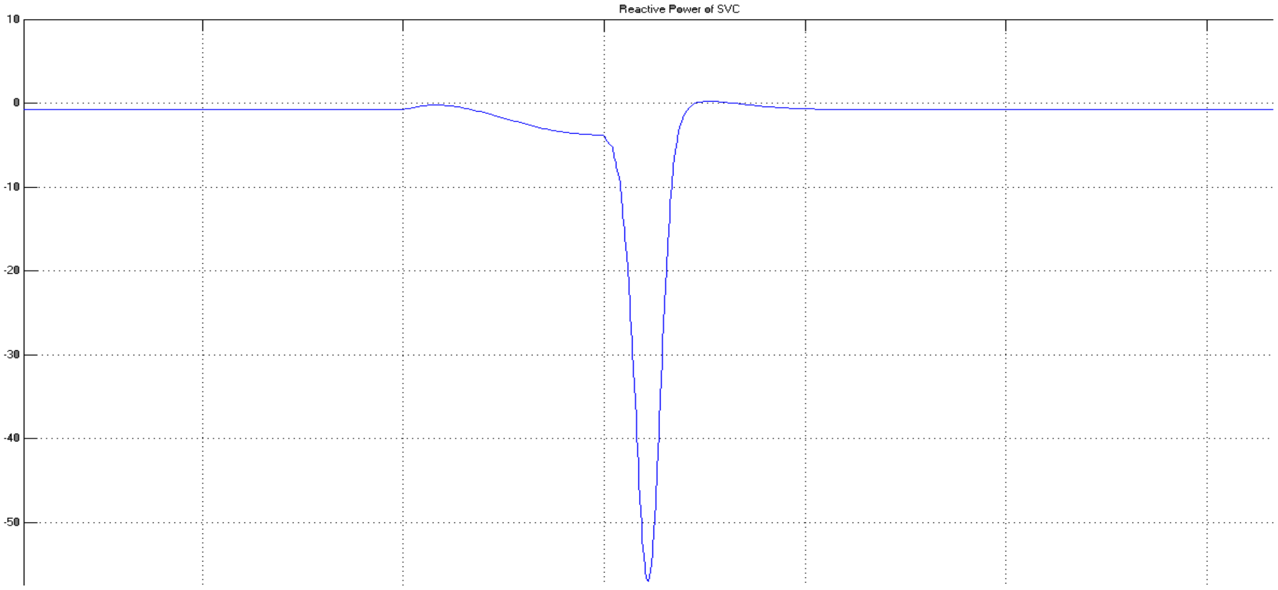

Fig.6: Reactive Power of SVC

Fig.6 shows the reactive power supplied by SVC to the network.

Table 1. Values of voltage at bus 1 and 2 and reactive power by SVC between 1 to 20 s.

Time (s)	**V1 (p.u.)**	**V2 (p.u.)**	**Reactive Power by SVC (MVAR)**
1	.9265	.9663	-1.501
2	.9379	.9752	-.8471
3	.9378	.9737	-.8373
4	.9373	.9732	-.8702
5	.9377	.9728	-.8815
6	.9213	.9769	-.7522
7	.9213	.9769	-.7522
8	.9213	.9769	-.7522
9	.9213	.9769	-.7522
10	.9213	.9769	-.7522
10.125	.8491	1.0	-3.861
10.150	.8491	1.0	-3.861
10.199	.8491	1.0	-3.861
10.2	.9196	.9727	-.6692
10.3	.9213	.9769	-.7522
10.5	.9213	.9769	-.7522
11	.9213	.9769	-.7522
12	.9213	.9769	-.7522
13	.9213	.9769	-.7522
14	.9213	.9769	-.7522
15	.9213	.9769	-.7522
16	.9213	.9769	-.7522
17	.9213	.9769	-.7522
18	.9213	.9769	-.7522
19	.9213	.9768	-.7524
20	.9209	.9759	-.7498

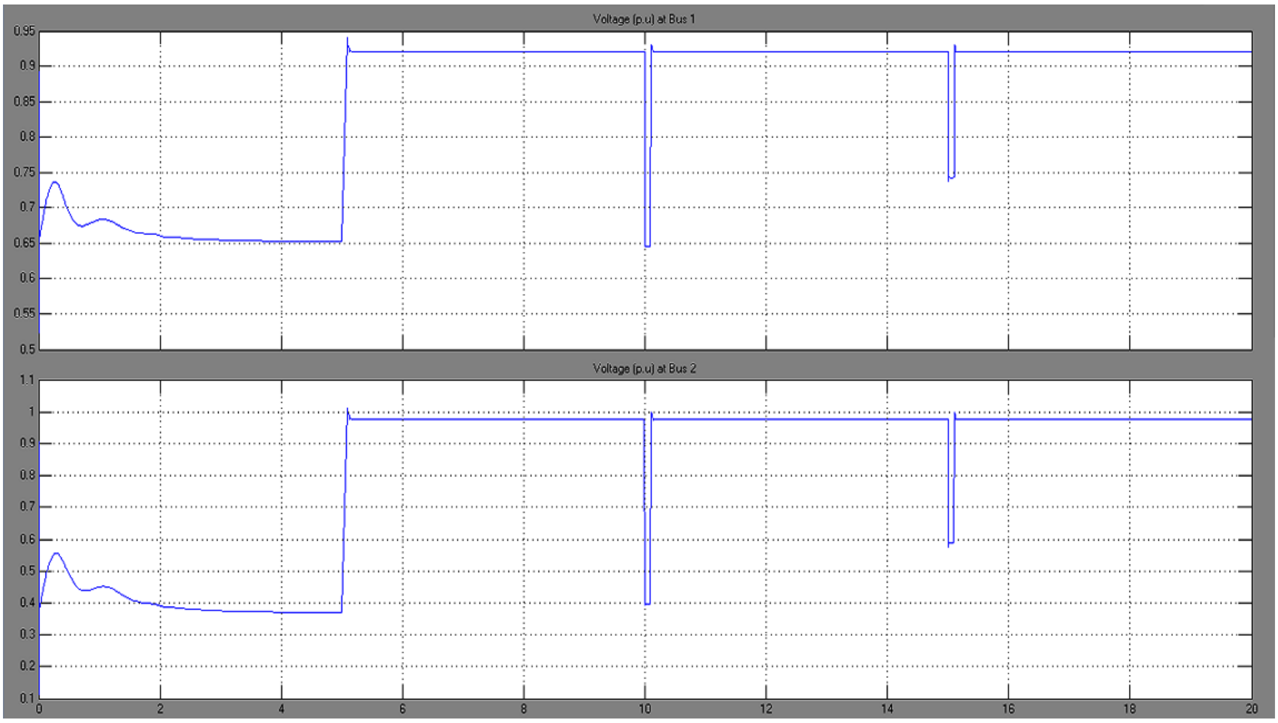

Fig.7: Voltages at 33 kV Bus – 1 and Bus – 2 during STATCOM

Fig. 7 and Fig. 8 shows the voltages at 33 kV Bus – 1 and Bus – 2 during the operation of STATCOM located at the point of wind farm connection.

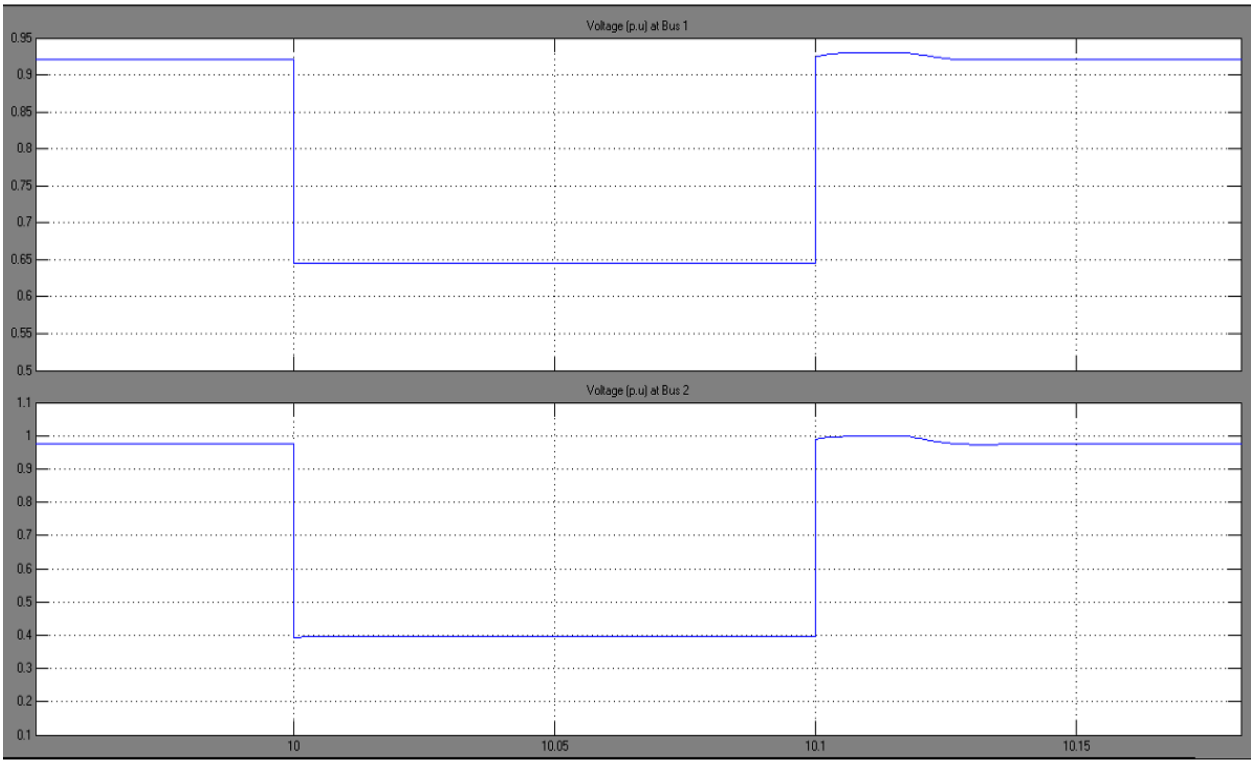

Fig. 8: Voltages at 33 kV Bus – 1 and Bus – 2 between 10 and 10.1 s during STATCOM

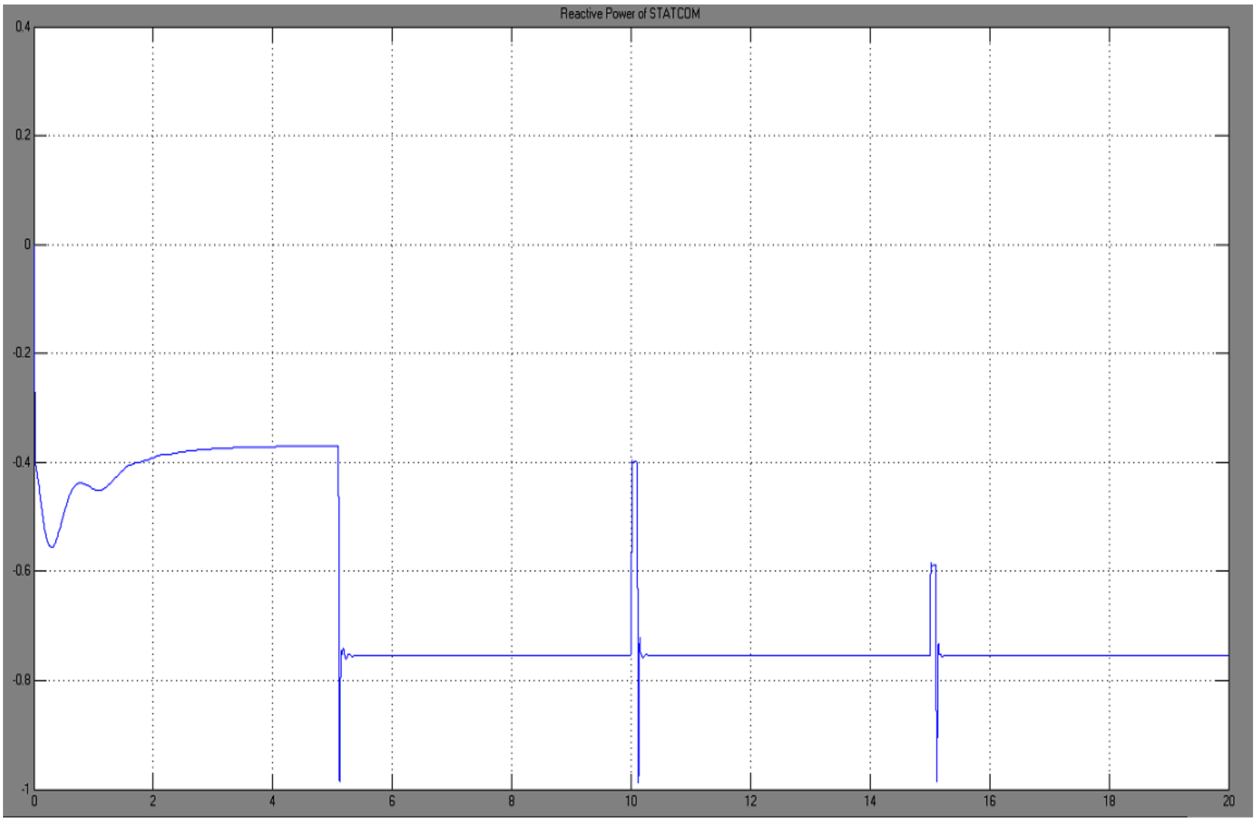

Fig. 9: Reactive Power of STATCOM

Fig.9 and Fig.10 shows the Reactive Power supplied by STATCOM to the network.

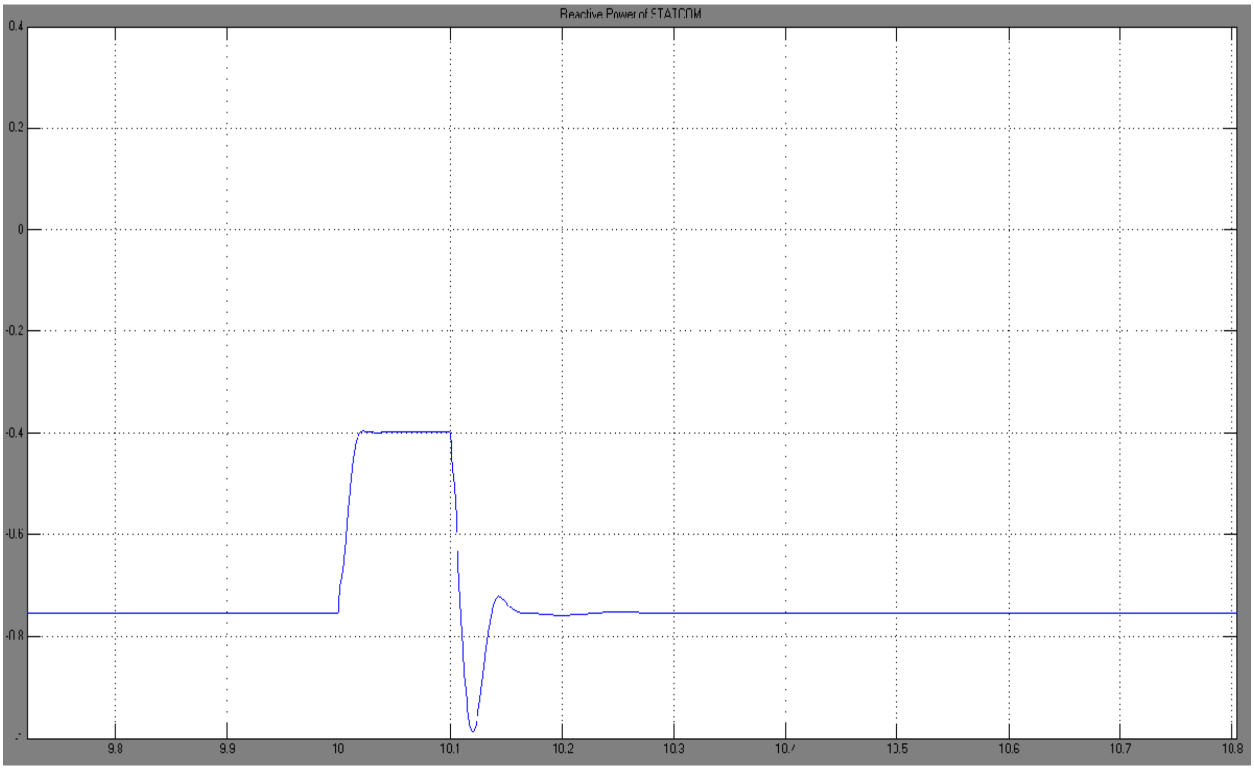

Fig. 10: Reactive Power of STATCOM between 10 and 10.1 s

Table 2: Voltage at bus 1 and 2 and Reactive Power by STATCOM between 1to 20 s.

Time (s)	V1 (p.u.)	V2 (p.u.)	Reactive Power by STATCOM (MVAR)
1	.6369	.3376	6.909e-010
2	.6369	.3376	6.909e-010
3	.6347	.3324	3.62e-012
4	.6342	.3311	-2.837e-013
5	.6338	.3304	5.364e--013
6	.8927	.9067	-3.431e-009
7	.8927	.9067	-.5.042e-009
8	.8927	.9067	-6.816e-009
9	.8927	.9067	-1.347e-009
10	.8927	.9067	-3.018e-010
10.1	.6361	.365	9.228e-010
10.109	.8927	.9067	1.3e-010
10.112	.8927	.9067	1.3e-010
10.125	.8927	.9067	1.3e-010
10.150	.8927	.9067	1.3e-010
10.199	.8927	.9067	1.3e-010
10.2	.8927	.9067	1.276e-011
10.3	.8927	.9067	-1.154e-008
10.5	.8927	.9067	1.039e-012
11	.8927	.9067	2.792e-008
12	.8927	.9067	7.409e-008
13	.8927	.9067	4.543e-008
14	.8927	.9067	-5.131e-008
15	.8927	.9067	4e-010
16	.8927	.9067	1.644e-009
17	.8927	.9067	2.029e-010
18	.8927	.9067	2.202e-009
19	.8927	.9067	4.351e-009
20	.8927	.9067	3.71e-009

7. CONCLUSION

Hence Both the system, IG with STATCOM and other IG with SVC is operated with same load. The system is tested under the voltage regulation mode of STATCOM and SVC to analyze and compare the behavior of both the system on the basis of voltage and reactive power flow . However analyzing the reactive power flow for stabilizing the system voltage then it is quite clear then settling time and reactive power for the stable operation of the system is also quite low in the case of STATCOM. As 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 decrease (constant current). This ability to provide more capacitive power during a fault is one important advantage of the STATCOM over the SVC. In addition, the STATCOM will normally exhibits a faster response than the SVC because with the voltage-sourced converter, the STATCOM has no delay associated with the thyristor firing (in the order of 4 ms for a SVC). So STATCOM provides fast acting dynamic reactive compensation for voltage support during contingency events which would otherwise depress the voltage for a significant length of time. So in this paper it is successfully demonstrated that how STATCOM has successfully been applied to IG based wind farm connected to grid and load for effectively regulating system voltage.

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