Dynamic Voltage Stability of Power Systems

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Abstract - **Voltage stability is one of the most important problems faced in power systems. Recently, a lot of studiousness has been paid to the subject of dynamic voltage stability. It is well known that induction motor loads have a particularly significant impact in the voltage stability. This paper investigates the effect of the increasing load on the bus, and studies the effect of Flexible Alternating Current Transmission Systems (FACTS), whether Static Var Compensator (SVC) or Static Synchronous Compensator (STATCOM) on dynamic voltage stability of a power system. The Critical fault Clearing Time [CFCT] of the system due to startup of induction motor, to prevent voltage instability has been analyzed. Comparative performance assessment for SVC and STATCOM has been examined. A Power System Analysis Toolbox (PSAT) using MATLAB Program is used to calculate voltages with Time and Critical Fault Clearing Time at each bus for IEEE 9 bus systems.**

***Keywords* - Dynamic Voltage Stability, SVC, STATCOM, CFCT**

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I. INTRODUCTION

One of the main criteria, deciding the power system operation and control is its voltage stability. Voltage Stability of the power system is the ability of the system to retain system voltages within acceptable limits when subjected to disturbance [1, 2]. But disturbances always occur either as a result of the addition or removal of a sudden load, lightning; short circuit of lines etc. The voltage instability is characterized by a progressive fall in voltage magnitude at a particular area or at a particular location, and may finally spread in the entire network causing blackout system or voltage collapse. We can thus define the power system voltage instability as the inability of the power system to meet a certain load demand of reactive power. Voltage instability being primarily a steady state phenomenon, transient voltage instability. It is characterized by a sharp and sudden fall in system voltage and is possibly governed by the situation of the load bus when the system experiences voltage swings, and by the dynamics of induction motor loads. A large induction motor is one of the most common loads constituent that shows a fast increase of reactive power demand owing to voltage drops even of relatively small values. This fast increase of reactive power demand results in further deterioration in voltage indicating complete voltage collapse, if appropriate action is not taken immediately. The role of induction motors has also been highlighted, that for the induction motor predominant load buses, the critical clearing time is important to ensure the stability of the operating voltage. The System state does not enter the 'impasse' surface; it is possible to regain the bus voltage following the fault clearing. Once the system voltage enters into that zone, any endeavor to restore the normalcy of bus voltage does not serve the purpose of maintaining voltage stability. Hence clear that the voltage collapse depends not only on the system reactive power limitation and, load behavior but also on the critical clearing time for the system to restore voltage stable state. The progression in semi-conductor electronics has helped in the expansion of new control technologies for stability enhancement, which contains the use of Flexible Alternating Current Transmission Systems (FACTS) controllers. Changing electric power systems create a growing need for reliability, flexibility, accuracy and fast response in the fields of electric power generation, transmission, distribution and consumption. FACTS are new devices emerging from recent innovative techniques that are capable of altering voltage, phase angle and/or impedance at particular points in power systems. Their fast response offers a great potential for power system stability enhancement apart from steady state flow control. Static Var Compensator (SVC) and Static Synchronous Compensator(STATCOM) provides the fast acting dynamic reactive compensation for voltage support during contingency events which would otherwise depress the voltage to a significant length of time. Also, Static Var Compensator SVC and STATCOM dampen power swings and reduce system losses by optimized the reactive power control. Power System Analysis Toolbox (PSAT) by using Matlab Program have been used in this paper to conduct simulations on voltage regulation at the point of connection of SVC and STATCOM to the system. However, this paper aims to enhance voltage stability using SVC and STATCOM at the event of occurrence of voltage instability [3]-[9].

II. STATIC VAR COMPENSATOR (SVC)

Static VAR systems are applied by utilities in transmission applications for several purposes. The primary purpose is usually for rapid control of voltage at weak points in a network. Installations may be at the midpoint of transmission interconnections or at the line ends. Static VAR Compensators are shunting connected static generators / absorbers whose outputs are varied so as to control voltage of the electric power systems. In its simple form, SVC is connected as Fixed Capacitor Thyristor Controlled Reactor (FC-TCR) configuration as shown in figure (1).
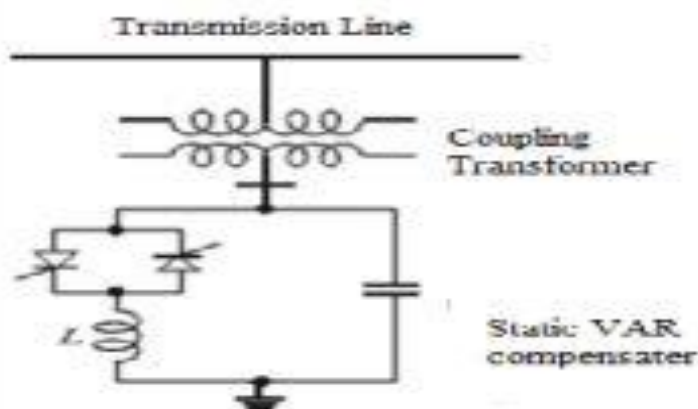
Figure 1 Static Var Compensator (SVC)

The SVC is connected to a coupling transformer that is connected directly to the ac bus whose voltage is to be regulated. The effective reactance of the FC-TCR is varied by firing angle control of thyristors. The firing angle can be controlled through a PI (Proportional + Integral) controller in such a way that the voltage of the bus, where the SVC is connected, is maintained at the reference value [10].

III. STATIC SYNCHRONOUS COMPENSATOR (STATCOM)

The STATCOM is based on a solid state synchronous voltage source which generates a balanced set of three sinusoidal voltages at the fundamental frequency with rapidly controllable amplitude and phase angle. The con- figuration of a STATCOM is shown in figure (2). Basically it consists of a voltage source converter (VSC), a coupling transformer and a dc capacitor. Control of the reactive current and hence the susceptance presented to power system is possible by variation of the magnitude of output voltage (VVSC) with respect to bus voltage (VB) and thus operating the STATCOM in inductive region or capacitive region [10].
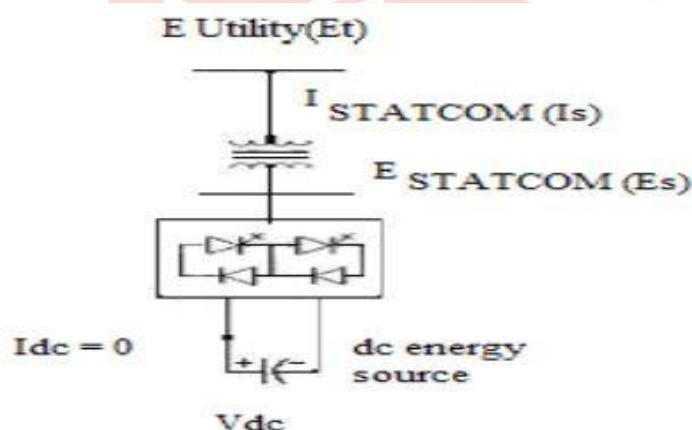

Figure 2 Static synchronous Compensator (STATCOM)

IV. CRITICAL FAULT CLEARING TIME (CFCT)

The Critical Fault Clearing Time is important to ensure the stability of the operating voltage for the induction motor load buses. Will be compared to the Critical Clearing Time of the various FACTS, whether SVC or STATCOM to see whichever can enhances the unstable system to stable system faster than the other.

V. SIMULATION AND RESULTS

A simulation to investigating the impact of increasing the dynamic load on the bus, SVC and STATCOM on power system. The IEEE 9-bus test system is simulated on PSAT 2.1.4. The single line diagram (SLD) of the simulated test system on PSAT is shown in figure (3) The Network consists of 9 Buses, 3 Generators, 3 Set-up Transformers at 230 kv transmission voltage, all network data as it is, except for load buses It has been changed loads, with the addition of induction motor at bus 6, the start-up of the induction motor at 1 second, It was the work of four levels of loading by providing loads in each level, and see the effect of increasing the load on the voltage stability, and how to control with FACTS controllers. All data for loading buses at different loading levels are given in table (1).
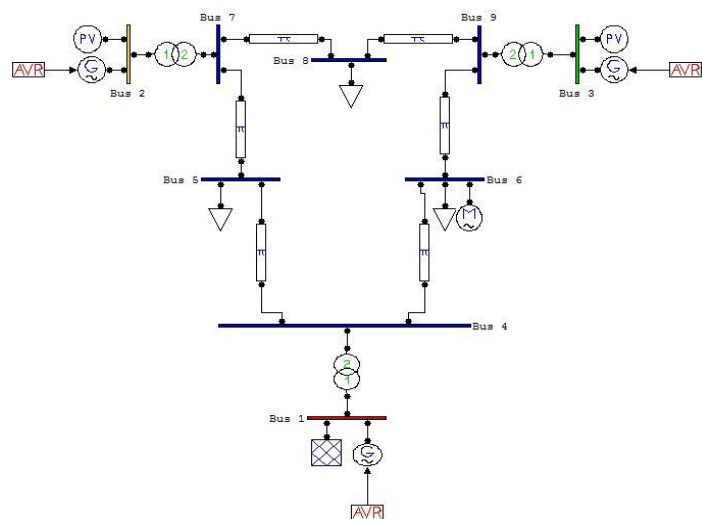
Figure 3 PSAT representation of a IEEE 9 bus WSCC test system with induction motor at bus 6

Table1.Shows active and reactive loads at load buses

Load Level	Bus(5)		Bus(6)			Bus(8)	
	P (P.U)	Q (P.U)	P (P.U)	Q (P.U)	Induction Motor (MVA)	P (P.U)	Q (P.U)
1	0.12	0.04	0.16	0.04	1	0.09	0.03
2	0.3	0.1	0.4	0.1	2.5	0.23	0.08
3	0.9	0.3	1.2	0.3	7.5	0.68	0.23
4	1.2	0.4	1.6	0.4	10	0.9	0.3

5.1. Load level (1)
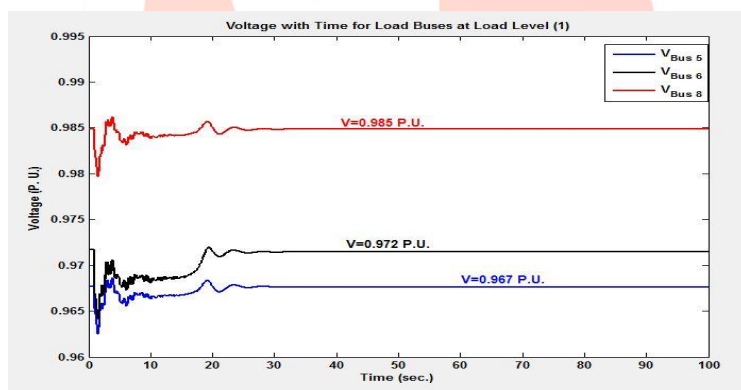
Figure 4 Voltage with time for load buses at load level (1)
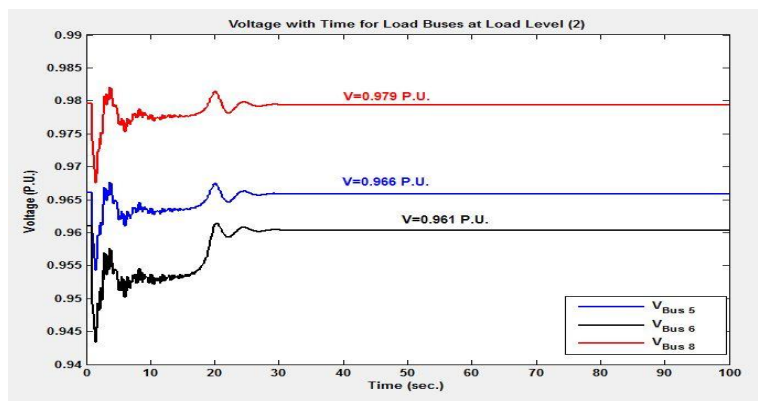
5.2. Load level (2)

Figure 5 Voltage with time for load buses at load level (2)

In the above two cases, the figures (4, 5) indicates that all the load buses are stable , but the increased load reduces the voltage at those buses, and those are shown in the table (2).

Table2.Shows voltage level (p.u.) at load levels (1, 2).

V Bus (P. U.)	BUS(5)	BUS(6)	BUS(8)	Notes
Load Level (1)	0.967	0.972	0.985	All Load Buses are Stable
Load Level (2)	0.966	0.961	0.979	All Load Buses are Stable

5.3. Load level (3)

5.3.1. Load level (3) without control
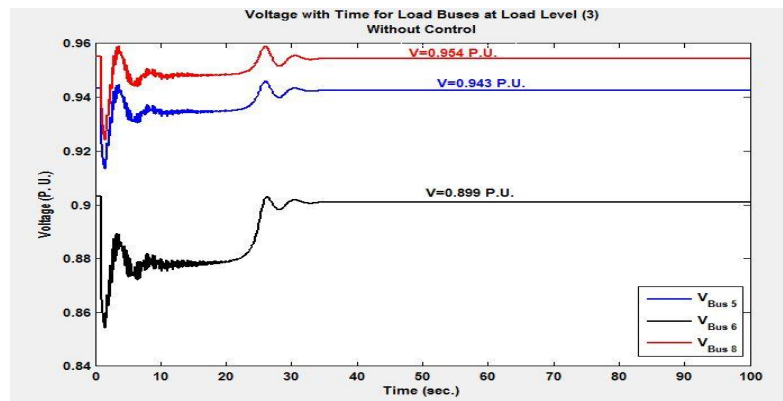
Figure 6 Voltage with time for load buses at load level (3) without control.

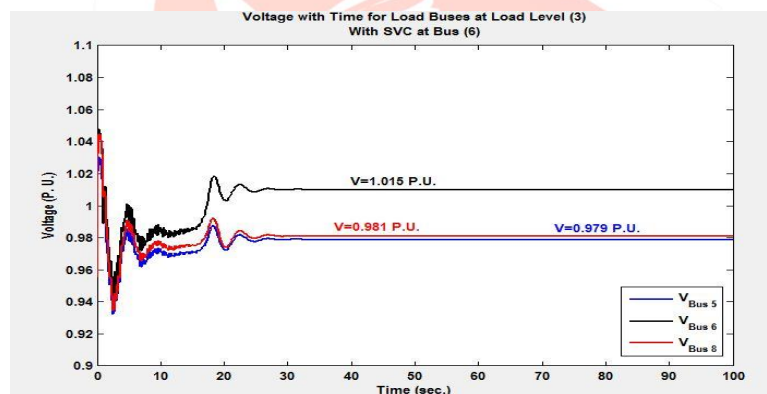### 5.3.2. Load level (3) With SVC at Bus (6)

Figure 7 Voltage with time for load buses at load level (3) with SVC at bus (6).
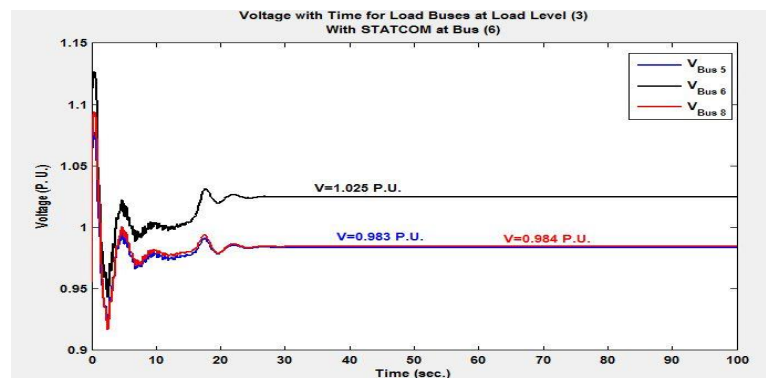
5.3.3. Load level (3) With STATCOM at Bus (6)

Figure 8 Voltage with time for load buses at load level (3) with STATCOM at bus (6)

Seen from the figures (7, 8) that SVC and STATCOM have improved the voltage and introduced the network within the limits of stability, but voltage level of the STATCOM is higher than SVC, the Critical Clearing Time of the STATCOM is less than SVC. This is illustrated in the two following figures.
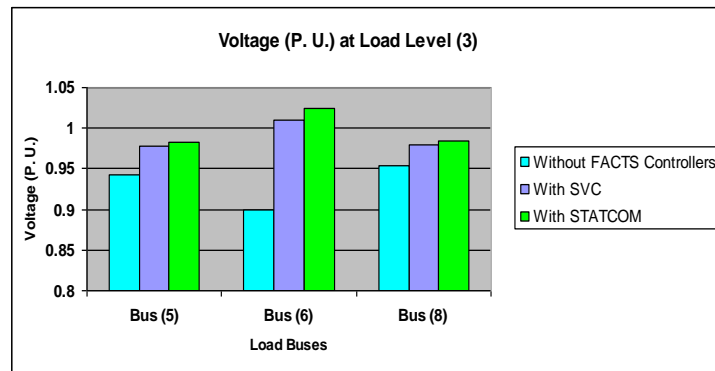
Figure 9 A comparison between voltage level without control, with SVC, and with STATCOM at load level (3).
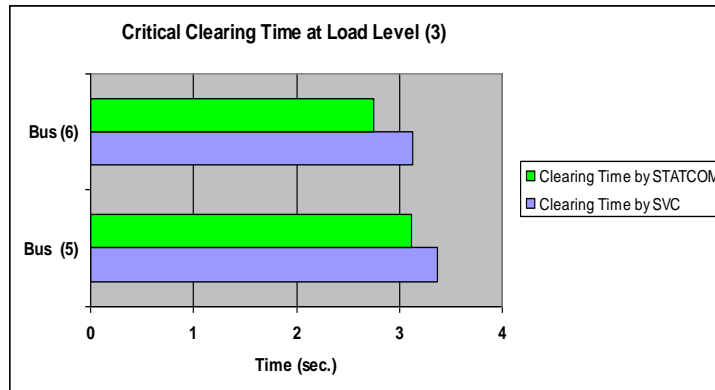

Figure 10 A comparison between Critical Clearing Time without control, with SVC, and with STATCOM at load level (3).

5.4. Load level (4)

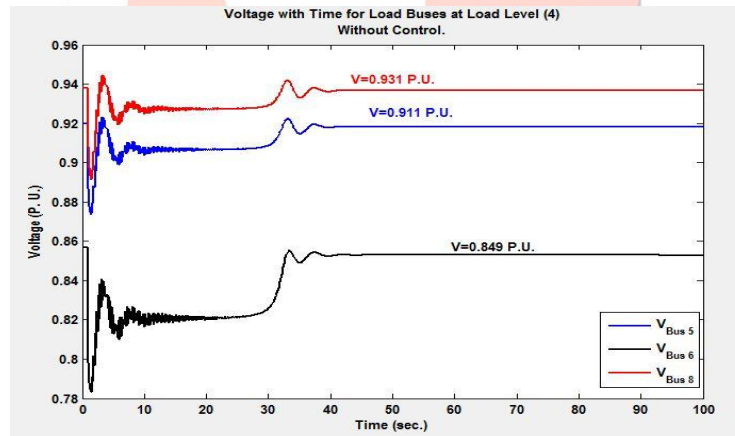### 5.4.1. Load level (4) without control

Figure.11. Voltage with time for load buses at load level (4) without control.

In this case, the figure (11) indicates that the increased load impacts significantly on the load buses. The all load buses become unstable. For this will install SVC or STATCOM at bus (6) for returning to the stability, to see the difference between them and whichever is more appropriate for this purpose.

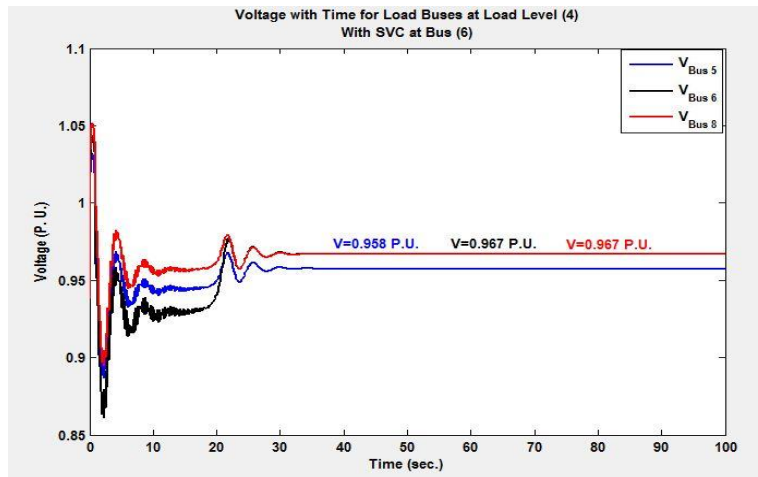### 5.4.2. Load level (4) With SVC at Bus (6)

Figure 12 Voltage with time for load buses at load level (4) with SVC at bus (6).

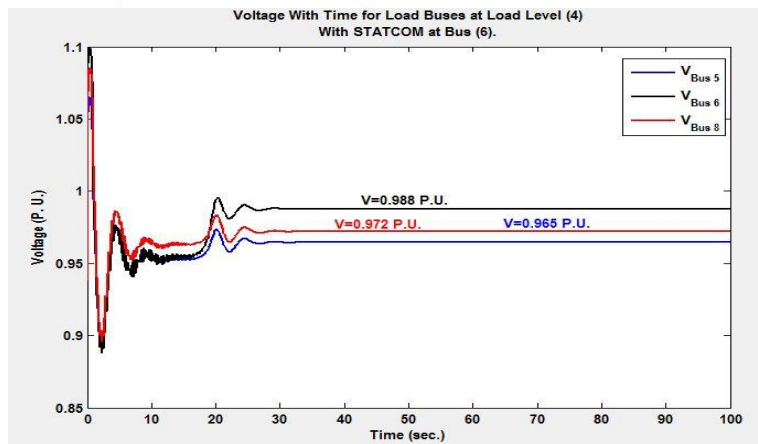### 5.4.3. Load level (4) With STATCOM at Bus (6)

Figure 13 Voltage with time for load buses at load level (4) with STATCOM at bus (6)

Seen from the figures (12, 13) that SVC and STATCOM have improved the voltage and introduced the network within the limits of stability, but voltage level of the STATCOM is higher than SVC, the Critical Clearing Time of the STATCOM is less than SVC. This is illustrated in two following Figures, and table (3).
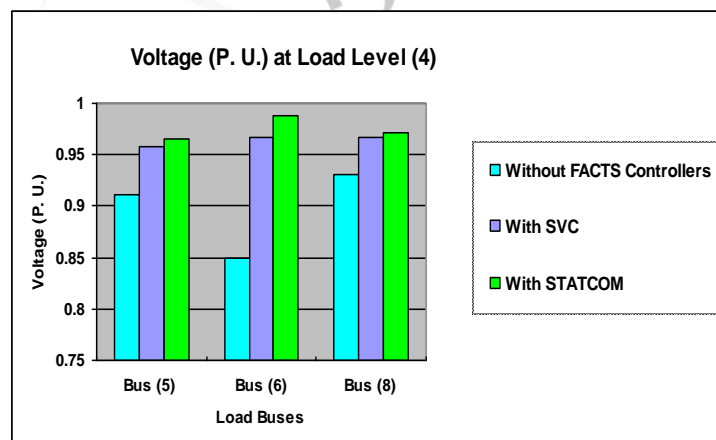

Figure 14 A comparisons between voltage level without control, with SVC, and with STATCOM at load level (4).
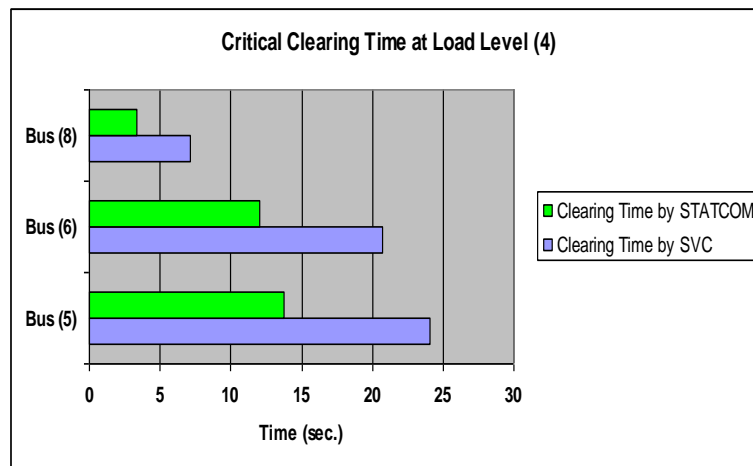
Figure 15 A comparisons between Critical Clearing Time without control, with SVC, and with STATCOM at load level (4).

Table3. Shows voltage level (p.u.) at load levels (3,4).

Voltage Level	V Bus{5} (P.U.)			V Bus{6} (P.U.)			V Bus{8} (P.U.)		
	Without control	With SVC	With STATCOM	Without control	With SVC	With STATCOM	Without control	With SVC	With STATCOM
Load level (3)	0.943	0.978	0.983	0.899	1.010	1.025	0.954	0.980	0.984
	Clearing Time (sec.)			Clearing Time (sec.)					
	unstable	3.37	3.12	unstable	3.13	2.75			
Load level (4)	0.911	0.958	0.965	0.849	0.967	0.988	0.931	0.967	0.972
	Clearing Time (sec.)			Clearing Time (sec.)			Clearing Time (sec.)		
	unstable	24.05	13.75	unstable	20.75	12.02	unstable	7.12	3.38

VI. CONCLUSION

This paper concludes to the increase of the load on the bus, effects on voltage stability and reduces voltage level. The Static Var Compensator and Static Synchronous Compensator could provide the fast acting voltage support that is necessary to prevent the possibility of voltage reduction and voltage collapse at the bus in which it is connected. This paper shows that the voltage level of the STATCOM is higher than SVC, and on the other hand, the Critical Clearing Time of the STATCOM is less than SVC. So, STATCOM has the ability to enhance an unstable system making it a stable system faster than SVC.

REFERENCE

[1] M Reddy Prasanna and C N Arpitha, "Voltage Stability Enhancement In Contingency Conditions Using Shunt FACTS Devices", ISSN 2319 – 2518, Vol. 2, No. 1, January 2013.

[2] IEEE, Special publication 90TH0358-2-PWR, Voltage stability of power systems: concepts, analytical tools, and industry experience, 1990.

[3] C.Nandi, Sumita Deb, Minakshi Deb Barma, and A.K. Chakraborty, Member, "Study and Simulation of the SVC and STATCOM Effect on Voltage Collapse and Critical Fault Clearing Time", International Journal of Modeling and Optimization, Vol. 2, No. 4, August 2012.

[4] N. G.Hingorani and L.Gyugyi, Understanding FACTS Concepts and Technology of Flexible AC Transmission Systems Piscataway, NJ; IEEE press, NewYork, 2000. Ch 5, pp. 160-206.

[5] A. Chakrabarti, D.P. Kothari and A.K. Mukhopadhyay, Performance operation amd Control of EHV Power Transmission System.,A H Wheeler Publishing Co Ltd.Ch 3.

[6] Y. H. Song and A. T. Johns, Eds., "Flexible AC Transmission Systems (FACTS)," IEEE press, London, 1999.

[7] A. E. Hammad and M. Z. EI-Sadek: "Prevantion of transient voltage instabilities due to induction motor loads by static Var Compensators", IEEE Trans.on Power Systems, vol. PWRS-4, no. 3, Aug.1989.

[8]   R.M. Mathur and R. K. Varma , "Thyrustor_based FACTS Controllers for   Electrical   Transmission   Systems,"   Piscataway, NJ IEEE press 2000. Ch 1, Ch7.

[9]   M. N. Nwohu, "Voltage Stability Improvement   using Static Var Compensator in Power Systems," Leonardo Journal of Sciences; Issn 1583-0233,issue 14,pp. 167-172, January-June, 2009.

[10] P. Bisen and A. Shrivastava, "Comparison between SVC and STATCOM FACTS Devices for Power System Stability Enhancement," International Journal on Emerging Technologies; Issn2249-3255, 07 October, 2013.