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Mitigation of Voltage Sag in Nine Bus System with STATCOM

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***Abstract* — In this paper STATCOM is used to mitigate the voltage sag by controlling the reactive power at bus number 6 of nine bus system the voltage sag of bus number 6 is improved by STATCOM nearly 100% during the fault.**

***Keywords* — Nine bus system, voltage sag, STATCOM, PSCAD.**

I. INTRODUCTION

Static synchronous compensator (STATCOM) is a custom power device which is based on a voltage source converter (VSC) shunt connected to the network [1]. By injecting a controllable current, a STATCOM can mitigate voltage dip at the point of connected with the network. This work will be focuses on the STATCOM for mitigating voltage. Firstly the characteristics of the STATCOM for mitigation voltage dips will studied, such as the required shunt compensation current, injected active and reactive power for given voltage dip magnitude. The pulse width modulation (PWM) strategy will be implementing in model. In order to obtain the phase and frequency information of grid voltage, phase-locked loop will be used in the controller system. The simulation model will design for mitigation of voltage sag in 9 bus system. All result will be simulated in PSCAD/EMTDC. Voltage sags for 0.5-30 cycles 0.1-0.9 pu are short duration reductions in rms voltage, mainly caused by short circuits and starting of large motors, transformers energy sing, overloads and short circuit faults [2]. The interest in voltage sag is due to the problems they cause on several types of equipment. Adjustable-speed drives, process-control equipment, and computers are especially notorious for their sensitivity [3]. The typical unbalanced voltage dip is shown in figure 1.

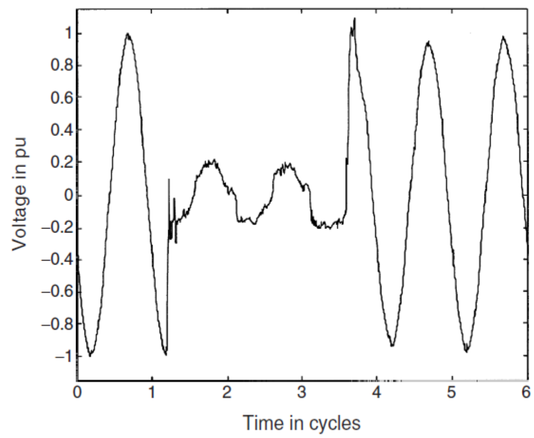

Figure-1 Typical unbalanced voltage dip [2]

II. NINE BUS SYSTEM

A Nine-bus three-machine system is described in Power System Control and Stability by Anderson and Fouad [4]. This system consist three generator and three large equivalent loads which are connected in a meshed transmission network through transmission lines as shown in figure2. In This system the generators are dynamically modelled with the classical equivalent model. A case study will be presented here on a small nine-bus power system [4] that has three generators and three loads a single-line impedance diagram for the system is shown in figure 2. Generator data for the three machines are given in table 1.1.

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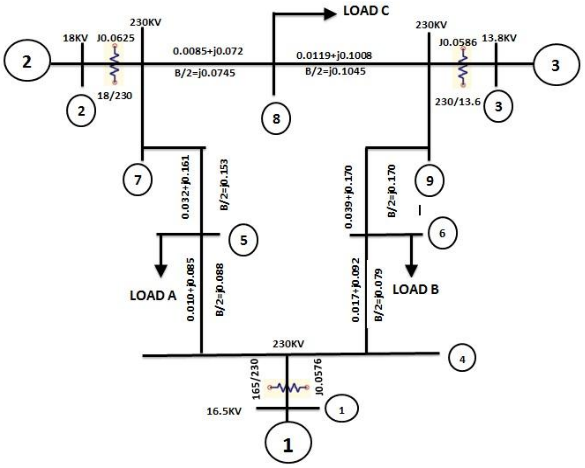

Figure 2 Nine bus system impedance diagram [4]

III. 2.1 Nine Bus System Generator Data

A. Table 1.1 Generator data for the three machines are given in table [4]

Generator	1	2	3
Rated MVA	247.5	192.0	128.0
KV	16.5	18.0	13.8
PF	1.0	0.85	0.85
Type	Hydro	Steam	Steam
Speed	180 r/min	3600 r/min	3600 r/min
Xd	0.1460	0.8950	1.3125
X'd	0.0608	0.1198	0.1813
Xq	0.0969	0.8645	1.2570
X'q	0.0969	0.1969	0.25
Xl(leakage)	0.0336	0.0531	0.0742
τ 'do	8.96	6.0	5.89
τ 'qo	0.0	0.535	0.6
Stored energy At rated speed	2364MW.s	640MW.s	301MW.s

B. Nine bus system Pre fault Network Data

Table 1.2
Pre fault Network Data [4]

Generators	Bus No	Impedance		Admittance	
		R	X	G	B
No 1	1-4	0.0	0.1184	0.0	-8.4459
No2	2-7	0.0	0.1823	0.0	-5.4855
No3	3-9	0.0	0.2399	0.0	-4.1684
Transmission lines	4-5	0.0100	0.0850	1 .3652	-11.6041
	4-6	0.0170	0 .0920	1. 9422	-10. 5107
	5-7	0.0320	0 .1610	1.1876	-5. 9751
	6-9	0.0390	0 .1700	1.2820	-5. 5882
	7-8	0 .0085	0 .0720	1 .6171	- 13. 6980
	8-9	0.0119	0 .1008	1.1551	-9.7843
Shunt admittances					
Load A	5-0			1. 2610	-0.2634
Load B	6-0			0 .8777	-0.0346
Load C	8-0			0.9690	-0.1601
	4-0				0. 1670
	7-0				0.2275
	9-0				0.2835

C. STATCOM

STATCOM is shunt connected flexible AC transmission system (FACTS) device which generate a set of three phase sinusoidal voltages at fundamental frequency which have controlled amplitude and phase angle[5]. STATCOM consists of the voltage source converter, input filter, controller and coupling transformer as shown in figure 3. When two AC sources of same frequency are connected through a series inductance, active power flows from higher voltage magnitude AC source to lower voltage magnitude AC source.

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Active power flow is determined by the phase angle difference between the sources [6-7]. Hence, STATCOM can control reactive power flow by changing the fundamental component of the converter voltage with respect to the AC bus bar voltage both magnitude wise and phase wise.

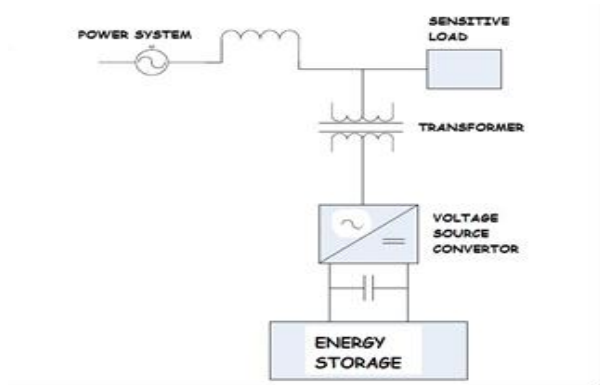

Figure-3 Shunt connected compensator (STATCOM) [6]

D. V-I Characteristics of STSTCOM

The STATCOM is essentially an alternating voltage source behind a coupling reactance with the corresponding V-I and V-Q characteristics shown in figure-4(a) and 4(b). In these figure shows that the STATCOM can be operated over its full output current range at very low means theoretically zero, typically about 0.2 per unit system voltage levels. In other words say that, the maximum capacitive or inductive output current of the STATCOM can be maintained independently of the system voltage.

The STATCOM is providing voltage support under large system disturbances during which the voltage excursions would be well outside of the linear operating range of the compensator. The figure 4(a) and 4(b) illustrate the STATCOM may, depending on the power semiconductors used, have an increased transient rating of both the inductive and capacitive operating regions

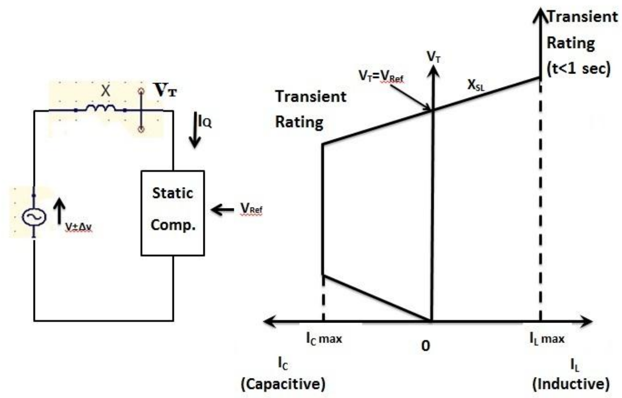

Figure-4 (a) V-I Characteristics of STATCOM [7]

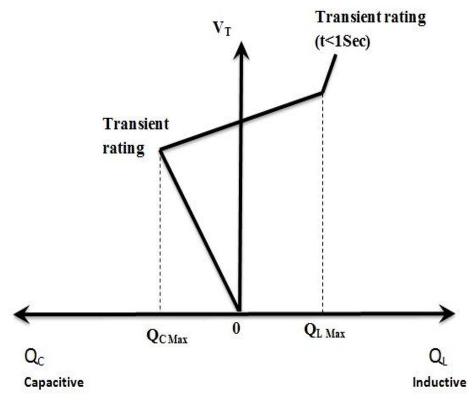

Figure-4 (b) V-Q Characteristics of STATCOM

The maximum attainable transient overcurrent of the STATCOM in the capacitive region is determined by the maximum current turn-off capability of the power semiconductor (i.e. GTO thyristor) employed. In the inductive operating region the power semiconductors of an elementary converter, switched at the fundamental frequency are naturally commutated. This means that the transient current rating of the STATCOM in the inductive range is, theoretically, limited only by the maximum permissible GTO junction temperature, which would in principle allow the realization of a higher transient rating in this range than that attainable in the capacitive range.

E. ANALYSIS OF SHUNT COMPENSATION

When the fault occurs in the system at that time circuit diagram of the power system shown in figure- 5.1, in this having

$\bar{Z}_S$ = Source impedance
$\bar{Z}_L$ = Load impedance under normal operation
$\bar{E}_S$ = Source voltage
$\bar{V}_{load}$ = Terminal voltage
$\bar{V}_{dip}$ = Voltage drop or lower voltage level

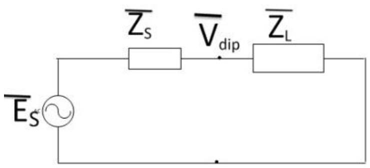

Figure-5.1 Equivalent circuit diagram of the power system during the fault

When the STATCOM is shunt connected with the load for the mitigation of the voltage dip at the load terminal, the STATCOM can be represented by a current source [8-12], because it is a shunt device. As shown in the top part of figure-5.2 obtaining a simple model, the circuit with STATCOM can be equivalent splitted into two circuits as shown in figure-5.2

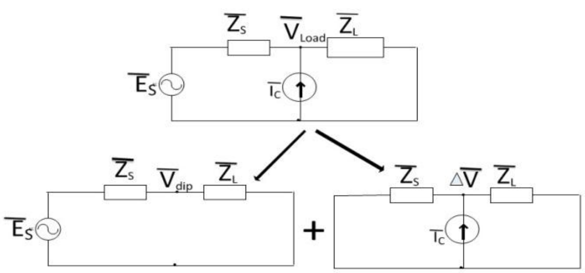

Figure-5.2 Equivalent circuit diagram of the power system with STATCOM during the voltage dip

In this only one has source voltage during the dip, other only has current source during the dip. Here the current which is injected by the STATCOM is obtained by $\bar{I}_C$ and the missing voltage at the load terminal during the dip, and $\Delta\bar{V}$, is given by

$$\Delta\bar{V} = \bar{V}_{load} - \bar{V}_{dip} \qquad \dots (1)$$

By this equation the missing voltage is equal to the current injected by the STATCOM time the impedance, which is the source impedance, in parallel with the load impedance. So that, the current injected by STATCOM to have 1 per unit voltage will be determined by the source impedance, the load impedance and the missing voltage at the load terminal.

Figure-5.2 shows to analyse the injecting current of the STATCOM. In this the current injected by the STATCOM to mitigate the dip is different for the constant impedance load. The injecting current of STATCOM is given by

$$\bar{I}_C = \frac{\bar{Z}_S \bar{Z}_L}{Z_S + Z_L} (\bar{V}_{load} - \bar{V}_{dip}) \qquad \dots (2)$$

The complex voltage dip is given by

$$\bar{V}_{dip} = V_{dip}(\text{Cos}\Psi - j\text{Sin}\Psi) \qquad \dots (3)$$

If the load voltage before the fault is considered as reference voltage, i.e. 1 per unit the equation-2 in per unit will becomes

$$\bar{I}_C = \frac{\bar{Z}_S \bar{Z}_L}{\bar{Z}_S + \bar{Z}_L} (1 - \bar{V}_{dip}) \qquad \dots (4)$$

This means that all injected current of the STATCOM only flows through the source impedance. Thus by this the constant current load branch can be considered as open circuit under this situation the current injected by the STATCOM during the dip is given by

$$\bar{I}_C = \frac{1}{\bar{Z}_S} (\bar{V}_{load} - \bar{V}_{dip}) \qquad \dots (5)$$

If the load voltage before the fault is consider as exactly 1 per unit then equation-5 will be given by

$$\bar{I}_C = \frac{1}{\bar{Z}_S} (1 - \bar{V}_{dip}) \qquad \dots (6)$$

The source impedance will become very small for faults at the same bus with the STATCOM. This will draw huge current from the STATCOM to mitigate the voltage dip.

F. Voltage Sag on Bus Number 6 During Three Phase Fault At Bus Number 5

Three phase fault at bus 5 at time 1.0second for duration of 0.75second

Figure-6.1 shows the three phase voltage wave form during fault without STATCOM. When the fault will be occurs in the three phase system then the maximum voltage dip occurs in the system, voltage dip will be occurs in the system at time 0.1 second for duration of 0.75 seconds when the fault is introduced in the system.

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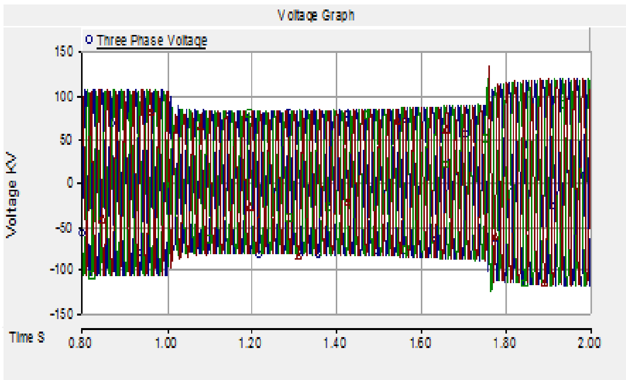

Figure-6.1 Three phase voltage dip wave form during the fault

Figure-6.2 shows the wave form of the current with respect to time during the fault occurs in the system for the voltage dip, at the 1.0 second for duration of 0.75 seconds, when the large voltage dip introduced in the system by occurring fault.

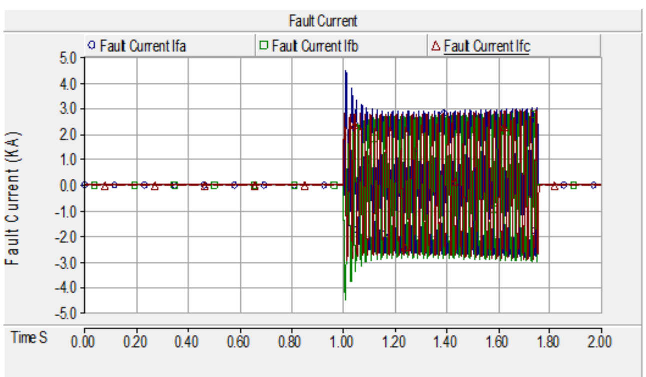

Figure-6.2 Fault current wave form during the fault

Figure-6.3 shows the wave form during the fault occurring in the system at 1.0 second for the duration of 0.75 seconds, by the figure can understand that when the fault is occurring in system and maximum voltage dip will be generated then at that time we get a non-uniform wave form as shown in figure-6.3

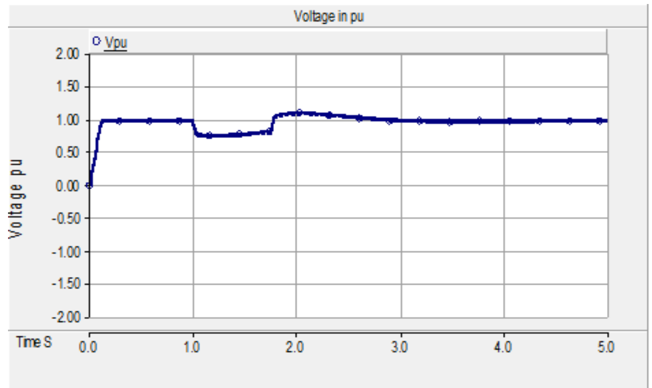

Figure-6.3 Wave form of voltage per unit during the fault

G. Mitigation of Voltage Sag With STATCOM on Bus Number 6

Figure-6.4 shows the three phase voltage wave form during fault with STATCOM. In this wave form the voltage dip is mitigated by using STATCOM, when the fault occurs in the system at 1.0 second for the duration of 0.75 seconds. Thus by this we get three phase balanced wave form.

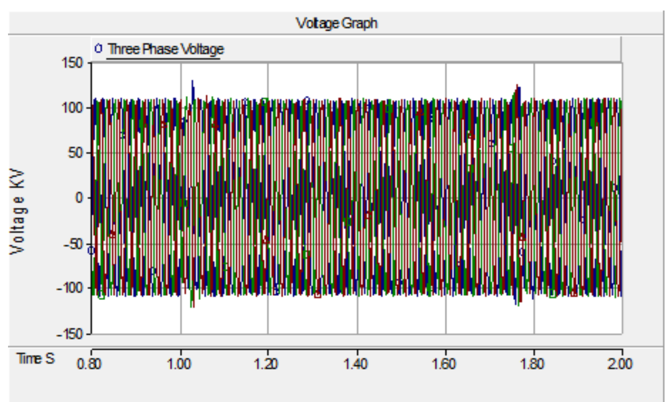

Figure-6.4 Three phase voltage wave form during fault with STATCOM.

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Figure-6.5 shows the wave form of the current with respect to time during the fault occurs in the system for the voltage dip, at 1.0 second for the duration of 0.75 seconds, when the large voltage dip introduced in the system by occurring fault.

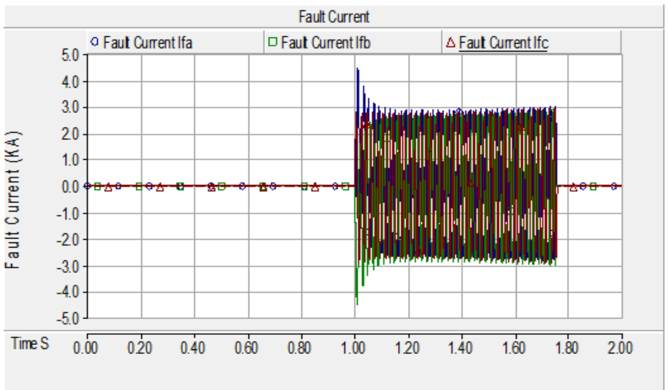

Figure-6.5 Fault current wave form during the fault with STATCOM

The wave form of the fault current may not be changed because the STATCOM be used for the voltage dip means mitigation of voltage dip.

Figure-6.6 shows the wave form during the fault occurring in the system using with STATCOM at 1.0 second for duration of 0.75 seconds, in this get a uniform wave form, by the figure can understand that when the fault is occurring in system and maximum voltage dip will be generated and at that time STATCOM also connected in the system we get a uniform wave form as shown in figure-6.6, here the voltage dip will be minimise and at 1.0 second for duration of 0.75 seconds wave form will be uniform.

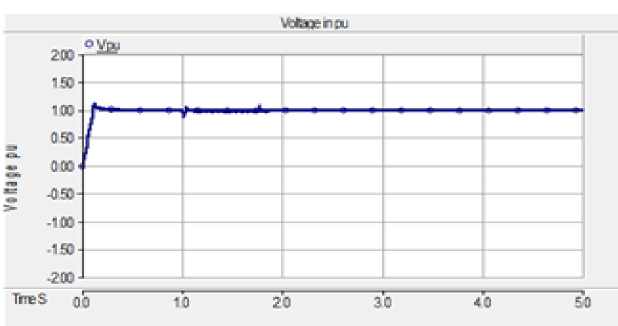

Figure-6.6 Wave form of voltage in per unit during the fault with STATCOM

H. Conclusion

In this shunt compensator for voltage dip mitigation is presented. The equation must be calculate the current, active and reactive power injected by shunt compensator for mitigating voltage dips are derived. Based on these equations the characteristics of the shunt compensation for various system parameters are studied. Finally a simplified simulation circuit is built in PSCAD/EMTDC. It has been shown that the voltage dip can be mitigating shunt compensator. By this the shunt compensation current, injected active and reactive power increases when the dip magnitude decreases.

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