COMPARING THE IMPACTS OF THE SVCs AND THE SCs AFFECTING TO THE TRANSIENT STABILITY IN MULTI-MACHINE POWER SYSTEM

Luu Huu Vinh Quang

HCMUT HCMC Vietnam

lhv2uang@hotmail.com

ABSTRACT A new algorithm simulating the impacts of the VAR supporting devices such as the static var compensators (SVCs) and the synchronous condensers (SCs) under condition of symmetrical disturbances in the power system is mentioned. Some typical numerical examples are presented in this article. The comparisons of variation of the state parameters, such as the voltage, frequency, reactive power outputs and angles... are simulated under condition of the action of the automatic voltage regulation systems of generators and of the VAR supporting devices. The transient energy margins are calculated and compared to assess the transient stability in multi-machine power system. Basing on this algorithm, the PC program uses the elements of the eigen-image matrix to bring the specific advantages for the simulation of the transient features of state variables.

INTRODUCTION

The control of voltage levels is accomplished by controlling the production, absorption and flows of reactive power. The device use for voltage control may be the static var systems, the synchronous machines or regulating transformers...

The synchronous condensers and SVCs provide reactive power compensation, together with the generators they have the specific influence to the steady-states and the transient states in the power system.

A synchronous condenser (SC) is a synchronous machine running without a prime mover or a mechanical load. By controlling the field excitation, the SC can generate or absorb reactive power. During electro-mechanical oscillation there is an exchange of kinetic energy between a SC and the power system.

A static VAR system is an aggregation of Static VAR Compensator, the mechanically switched capacitors and reactors, whose outputs are coordinated. In contrast to the SC, the SVC, being composed of the thyristor-switched reactors and capacitors, becomes a fixed capacitive admittance at full output. Thus, the maximum attainable compensating current of the SVC decreases with the square of this voltage. The SVC can enhance the transient stability and the damping of system oscillations. Referring to (Prabha Kundur, 1993) the performance of the SVC is instantaneously providing an amount of reactive power to hold the voltage at a specific bus in the power network with its V/I characteristic showing in fig.1 as follow

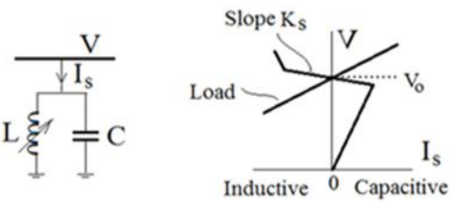

Fig.1 Equivalent circuit and V/I characteristic of SVC

The composite characteristic of SVC - Power System, within the control range defined by the slope K_S with reactance X_{SL} may be expressed as

$$V_o + X_{SL} I_S = E_{The} - X_{The} I_S; \qquad (1)$$

MATHEMATICAL MODELLING

Commonly, the technical movement is described by a set of differential equations. The transient state of the power system is considered as the technical movement modelling by the differential equations as follow

$$\sum_{j=1}^{M} \left(A_{ij} \frac{d^2 x_j}{dt^2} + B_{ij} \frac{dx_j}{dt} + C_{ij} x_j \right) = F_i(t); \qquad (2)$$

The real coefficients A_{ij}, B_{ij}, C_{ij} are determined by the parameters of the system and the nonlinear functions $G_i(x_j)$ describing the state of the system at any moment of time.

$F_i(t)$ are external forces varying with time and characterizing the changes in the external conditions of the system.

In general, the set of equations (2) can be transformed into the first order differential and specifically expressed in detail forms, referring to (3),(4),..,(7) and (8) of (Luu H.V.Quang, 2015), and solved by a numerical method using formulas relating to the Taylor's series expansion.

Comparing the transient energy margin (TEM) to assess the dynamic stability in case of SVCs operation with those in case of SCs operation

$$TEM = V_{KE}^{t}(H_i\,\omega_i^{t}) + V_{PE}^{t}(P_{mi}^{t}, E_i^{t}, \delta_i^{t}, Y_e^{t}); \qquad (3)$$

The TEM is larger the system is more stable.

NUMERICAL EXAMPLE

Let's survey the electro-mechanical transient process in a 45-bus power system consisting of 3 power plants with 6 synchronous generators (SGs), 5 synchronous condensers (SCs) and 28 composite loads. Therein, 4 SCs may be replaced by 4 SVCs. The basic power is 100 MVA. The positive-sequence line-data and load bus-data are given in (Luu H.V.Quang, 2016). The data of the synchronous machines are given in the tables 1, 2 and 3 as follows

Table 1. Initial generation bus-data

Bus	Device	Generation	
		MW	MVAR
35	SC	-1	19
36	SC	-0.7	10
37	SC	-0.9	14
38	SC	-0.7	10
39	SC	-1.5	75
40	SG	35	-0.036
41	SG	55	0.936
42	SG	100.5	18.28
43	SG	105	18.696
44	SG	101	18.232
45	SG	123.96	20.538

Table 2. Synchronous Machine Reactances

Bus	X_d (pu)	X_q (pu)	X'_d (pu)	X''_d (pu)	X''_q (pu)
35	11	5.8	2.15	0.95	1.15
36	11.5	6.35	2.35	0.925	1.25
37	12.5	6.45	2.55	0.975	1.35
38	11.5	6.35	2.35	0.925	1.25
39	2.1	1.26	0.4	0.2	0.21
40	2.1	1.9	0.31	0.21	0.31
41	2.1	1.9	0.31	0.21	0.31
42	1.5	1.3	0.22	0.15	0.21
43	1.5	1.3	0.22	0.15	0.21
44	1.6	1.35	0.28	0.17	0.23
45	1.6	1.35	0.28	0.17	0.23

Table 3. Time and Inertia Constants.

Bus	T"d	T"q	Tdo	Te	2H
	Second				
35	0.11	0.15	9.1	0.6	3.9
36	0.12	0.152	9.2	0.6	3.8
37	0.13	0.153	9.26	0.6	3.7
38	0.12	0.152	9.2	0.6	3.8
39	0.1	0.15	9	0.6	4.1
40	0.07	0.09	10.6	0.55	4.39
41	0.07	0.09	10.6	0.55	4.39
42	0.08	0.1	11.5	0.56	4.39
43	0.08	0.1	11.5	0.56	4.39
44	0.08	0.1	11.8	0.57	2.18
45	0.08	0.1	11.8	0.57	2.18

Let's compare the transient stability of two system configurations following: the first system configuration is designated to have 5 SCs locating on the buses from 35 to 39 as given above, called the SCs-Configuration; and the second system configuration is designated to have 4 SVCs replacing the SCs locating on the buses from 35 to 38 of the first system configuration, called the SVCs-Configuration. Let's assume that the V/I characteristics of the SVCs in p.u. on the buses 35, 36, 37 and 38 are given for input-data of this example showing in the fig.2, fig.3 and fig.4 as follows

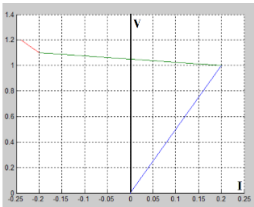

Fig.2 V/I characteristic of SVC 35

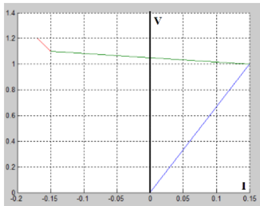

Fig.3 V/I characteristic of SVC 37

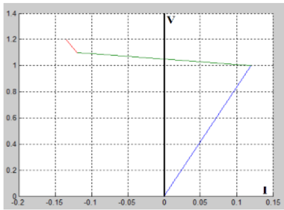

Fig.4 V/I characteristic of SVC 36 and SVC 38

First studying case:

A double high voltage transmission line (21-34), connecting the buses 21 and 34, is chosen to simulate the fault of 3 phase short circuit to assess the transient stability of the power system. Let's suppose that the fault occurs near the bus 34 and will be cleared at 0.135sec by removing of the fault line, causing a transient condition, under which the frequencies of generator of SCs-Configuration are changed more than those of the SVCs-Configuration, as shown in the fig.5a and fig.5b, and the transient energy margin (TEM) of SVCs-Configuration is larger than those of SCs-Configuration as shown in fig.5c, this means that the SCs-Configuration is more vulnerable to lose the transient stability in comparison with the SVCs-Configuration, the illustration is as following

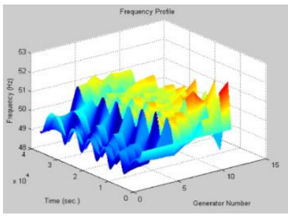

Fig.5a SCs-Configuration: Frequency Profile of the Synchronous Machines

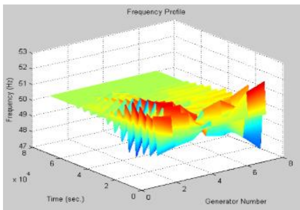

Fig.5b SVCs-Configuration: Frequency Profile of the Synchronous Machines

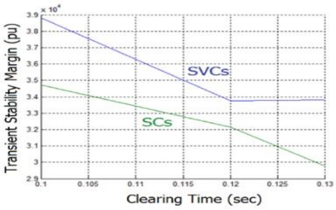

Fig.5c Comparing the TEMs of first studying case.

Under the condition of the first studying described above, the voltage variation at the bus 39 of SCs-Configuration is higher than those of SVCs-Configuration as shown in the fig.5d and fig.5e, as follows

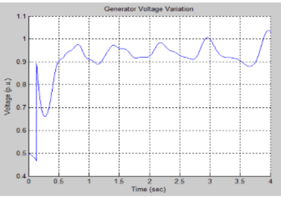

Fig.5d SCs-Configuration: Voltage Variation at the bus 39

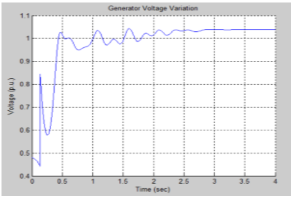

Fig.5e SVCs-Configuration: Voltage Variation at the bus 39

Another studying cases:

There are three studying cases are additionally realized in the same manner with the first studying case. The second, third and fourth studying cases are effectuated under condition of fault type of 3 phase short circuit, the main investigating factors of which are shown in the table 4 as follow

Table 4. Investigating the impacts of the SVCs/SDs to the transient stability of power system

Studying Case	Line (bus-bus)	Clearing Time	Inllustrating Figures	Configuration Winner/Loser
Second	(2-3)	0.13 sec	6a, 6b, 6c, 6d, 6e	SVCs / SDs
Third	(12-34)	0.13 sec	7a, 7b, 7c	SVCs / SDs
Fourth	(1-30)	0.183 sec	8a, 8b, 8c	SVCs / SDs

The illustrating figures of second studying case are shown in the fig.6a, fig.6b, fig.6c, fig.6d and fig.6e as follows

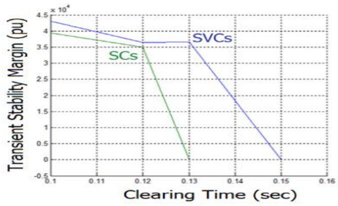

Fig.6a Comparing the TEMs of second studying case

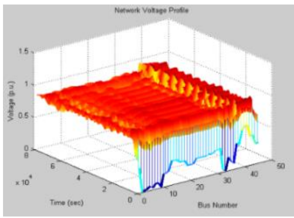

Fig.6b SCs-Configuration: Network Voltage Variation

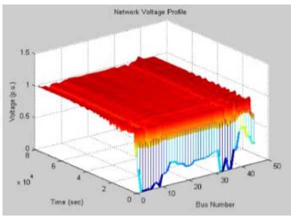

Fig.6c SVCs-Configuration: Network Voltage Variation

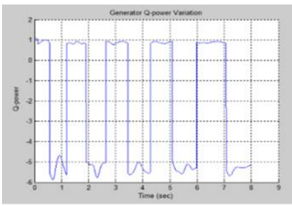

Fig.6d SCs-Configuration: Q power of SC at the bus 39

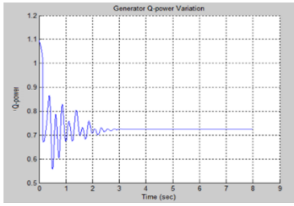

Fig.6e SVCs-Configuration: Q power of SC at the bus 39

The illustrating figures of third studying case are showin in the fig.7a, fig.7b and fig.7c as follows

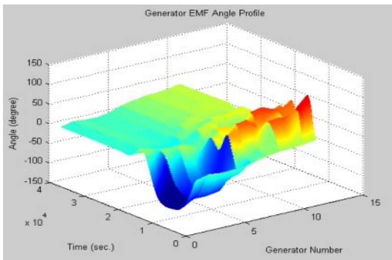

Fig.7a SCs-Configuration: Generator Angles Variation

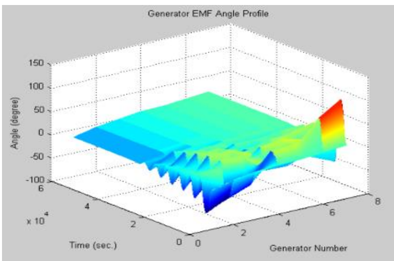

Fig.7b SVCs-Configuration: Generator Angles Variation

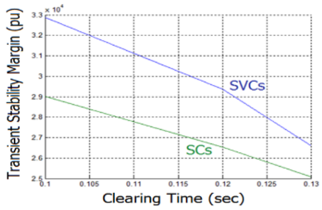

Fig.7c Comparing the TEMs of third studying case.

The illustrating figures of fourth studying case are shown in the fig.8a, fig.8b and fig.8c as follows

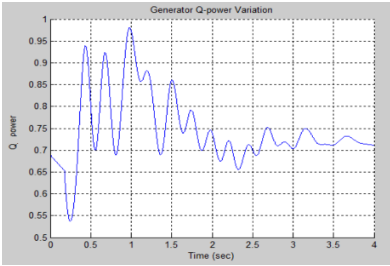

Fig.8a SCs-Configuration : Q power of SC at the bus 39

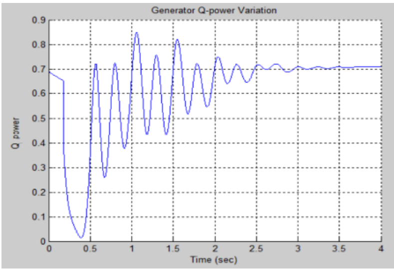

Fig.8b SVCs-Configuration : Q power of SC at the bus 39

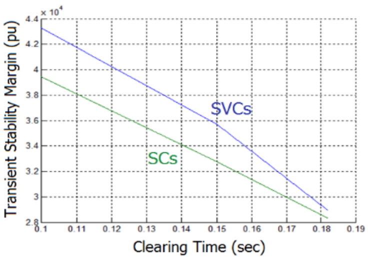

Fig.8c Comparing the TEMs of fourth studying case.

CONCLUSION

Implementing a set of different studying cases results to the outcome following: the SCs operation causes more vulnerability of losing of the transient stability of power system in comparison with the SVCs operation under the same conditions of disturbance. The SCs replaced by the SVCs will increase the critical clearing time, bring the specific advantages for the relay protection operating in multi-machine power system under transient conditions.

The transient energy margins allow to compare the impacts of SVCs with those of SCs affecting to the transient prosecces under conditions of symmetrical disturbances and to assess the dynamic stability in multi-machine power system.

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NOMENCLATURE

E_{The} : thevenin e.m.f.

X_{The} : thevenin reactance at the bus of SVC locating in multi-machine power system.

V^t_{ke} : kinetic energy function depending on i^{th} inertia constant (H_i) and i^{th} angular frequency (ω^t_i) at t^{th} instance of time.

V^t_{pe} : potential energy function depending on i^{th} turbine power ($P^t_{m\,i}$), i^{th} electrical power ($P^t_{e\,i}$) calculating by e.m.f. $E^t_i\angle\delta^t_i$ and equivalent bus admittance matrix Y^t_e at t^{th} instance of time.