Investigating the impacts of the SVCs and the SCs affecting to the transient stability in multi-machine power system

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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 multi-machine 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 asynchronous torques…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.

Keywords: *Transient Stability; Multi-Machine Power System; Static VAR Compensator (SVC); Transient Energy Margin (TEM);*

1. 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 (SVCs), the synchronous machines/condensers or regulating transformers...

The synchronous condensers and SVCs provide reactive power compensation, together with the generators they have 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 provide an amount of reactive power to hold the voltage at a specific bus in power network with its V/I characteristic showing in fig.1 as follow

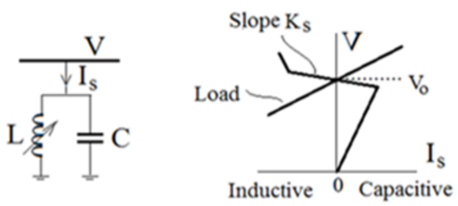

Figure 1. Equivalent circuit and V/I characteristic of SVC

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

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

where EThe is thevenin e.m.f. ; XThe is thevenin reactance at the bus of SVC locating in multi-machine power system.

2. MATHEMATICAL MODELLING

Commonly, the technical movement is described by a set of differential equations. Referring to [1],[3],[5],[6],[7],[8], the electro-mechanical transient state of power system is considered as the technical movement modelling by the differential equations as follow

$$\begin{cases} \dfrac{d^2\delta_i^t}{dt^2} = \dfrac{\omega_o}{2H_i}\begin{pmatrix} T_{tur\,i}^t(x_i, \Delta\delta_i^t) \\ -\dfrac{p_i(E_i^t, \delta_i^t)}{1+\dfrac{d\delta_i^t}{dt}\dfrac{1}{\omega_o}} \\ -T_{coi}^t - T_{b2i}^t - T_{asi}^t \\ -\dfrac{p_{di}^t}{\omega_o}\dfrac{d\delta_i^t}{dt} \end{pmatrix}; \qquad (2) \\ i = 1,2..M\_generator\ number; \end{cases}$$

where T_{coi}^t is an equivalent torque simulating the effect of an infinite bus at the t-th time interval in multi-machine power system; T_{b2i}^t, T_{asi}^t is the asynchronous torque and negative-sequence braking torque calculated for i-th synchronous machine at the t-th time interval; p_{di}^t is i-th variable damping factor depending on a set of different parameters such as the i-th elements of the eigen-image matrix, the phase angles δ_i^t at the t-th time interval, the voltages V_i^t at the i-th observing bus in power network at the t-th tim interval, the subtransient time constants T''_d, T''_q, the transient and subtransient reactances X'_d, X'_q, X''_d, X''_q and the rated frequency of the power system.

Developing the flowchart in [5] and referring to [6],[7] and [8], the set of equations (2) can be solved by a numerical method using formulas relating to the Taylor's series expansion.

Referring to [2], [3], [4], using the transient energy margin (TEM) to comparatively assess the dynamic stability in case of SVCs operation with those in case of SCs operation

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

where V^t_{KE} is 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} is 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.

The TEM is larger the system is more stable.

3. NUMERICAL EXAMPLE

Let's survey the electro-mechanical transient process in a 21-bus power system consisting of 2 power plants with 5 synchronous generators (SGs), 3 SCs (may be replaced by SVCs of the same rating powers) and 11 composite loads. The basic power is 100 MVA. The positive-sequence line-data and load bus-data are given in the table 1 and table 2 as follows

Table 1. Line-data

Bus		R	X	0.5B	Circuit Number
m	n	p.u.			
1	2	0.01938	0.05917	0.0528	2
1	5	0.05403	0.22304	0.0492	1
2	3	0.04699	0.19797	0.0438	1
2	4	0.05811	0.17632	0.034	1
2	5	0.05695	0.17388	0.0346	1
3	4	0.06701	0.17103	0.0128	1
4	5	0.01335	0.04211	0	1
4	7	0	0.20912	0	1
4	9	0	0.55618	0	1
5	6	0	0.25202	0	1
6	11	0.09498	0.1989	0	1
6	12	0.12291	0.25581	0	1
6	13	0.06615	0.13027	0	1
7	16	0	0.17615	0	1
7	9	0	0.11001	0	1
9	10	0.03181	0.0845	0	1
9	8	0.12711	0.27038	0	1
10	11	0.08205	0.19207	0	1
12	13	0.22092	0.19988	0	1
13	8	0.17093	0.34802	0	1
15	6	4.54E-03	0.14000	0	1
14	3	4.28E-03	0.12208	0	1
17	2	4.28E-03	0.12208	0	1
18	2	4.28E-03	0.12208	0	1
19	1	1.80E-03	0.07680	0	1
20	1	1.56E-03	0.06334	0	1
21	1	1.56E-03	0.06334	0	1

Table 2. Load bus-data

Bus	P	Q	Injected MVAR
	MW	MVAR	
2	21.7	12.7	0
3	94.2	19	0
4	47.8	2	5.9
5	7.6	1.6	0
6	11.2	7.5	0
8	14.9	5	0
9	29.5	16.6	0.19
10	9	5.8	0
11	3.5	1.8	0
12	6.1	1.6	0
13	13.5	5.8	0

The data of the synchronous machines are given in the tables 3, 4 and 5 as follows

Table 3. Initial generation bus-data

Bus	Device	Generation	
		MW	MVAR
14	SC	-0.15	38.4
15	SC	-0.1	37.5
16	SC	-0.12	17
17	SG	27	18.033
18	SG	31	18.021
19	SG	67	1.89
20	SG	71	1.997
21	SG	76.86	2.102

Table 4. Synchronous Machine Reactances

Bus	X_d	X_q	X'_d	X''_d	X''_q
	p.u.				
14	1.172	0.74	0.1291	0.0921	0.11
15	1.381	0.77	0.1459	0.0914	0.12
16	1.1511	0.69	0.1423	0.0923	0.135
17	1.1404	1.03	0.1346	0.0907	0.1273
18	1.1404	1.03	0.1346	0.0907	0.1273
19	1.558	1.42	0.1983	0.1381	0.15
20	1.2665	1.15	0.2224	0.1515	0.1713
21	1.2665	1.15	0.2224	0.1515	0.1713

Table 5. Time and Inertia Constants.

Bus	T"d	T"q	Tdo	Te	2H
	Second				
14	0.155	0.177	9.8	0.61	4.17
15	0.15	0.17	10.4	0.63	4.65
16	0.16	0.175	9.1	0.57	5.28
17	0.147	0.158	8.15	0.55	9.12
18	0.147	0.158	8.15	0.55	9.12
19	0.151	0.164	8.23	0.52	6.98
20	0.151	0.164	8.5	0.52	8.78
21	0.151	0.164	8.5	0.52	8.78

Let's compare the transient stability of two configurations of system as follow: the first configuration of system is designated to have 3 synchronous condensers locating on the buses from 14, 15 and 16 as described above, briefly called the SCs-Configuration; and the second configuration of system is designated to have 2 SVCs replacing the SCs locating on the buses 14 and 15 of the first system configuration, briefly called the SVCs-Configuration. Let's assume that the V/I characteristics of the SVCs in p.u. on the buses 14 and 15 are given for input-data of this example showing in the fig.2 as follows

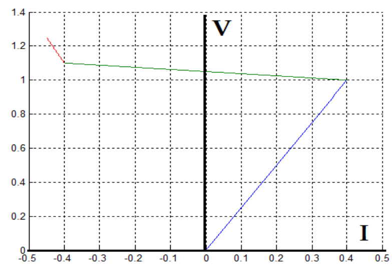

Figure 2. V/I characteristic of SVC 14 and SVC 15

First studying case:

A high voltage transmission line (1-5), connecting the buses 1 and 5, is chosen to simulate the fault type of 3 phase short circuit to assess the transient stability of the power system. Let's suppose that the fault occurs near the bus 1 and will be cleared at 0.2sec 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

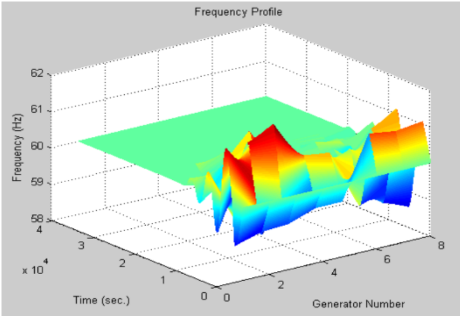

Figure 5a. Frequency Profile of Synchronous Machines of SCs-Configuration.

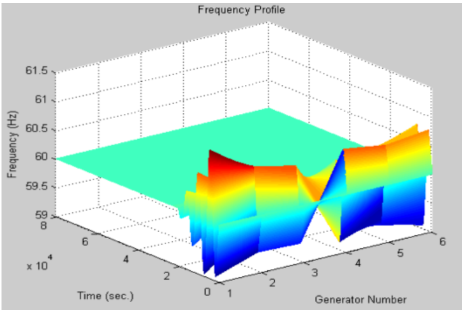

Figure 5b. Frequency Profile of Synchronous Machines of SVCs-Configuration.

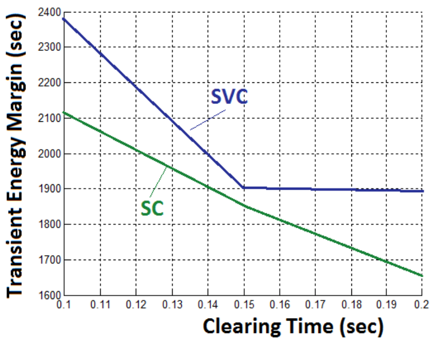

Figure 5c. Comparing the TEM of the first studying case.

Under condition of the first studying desribed above, the voltage variation at the bus 16 relating to the SCs-Configuration is compared with those relating to the SVCs-Configuration as shown in the fig.5d and fig.5e, as following

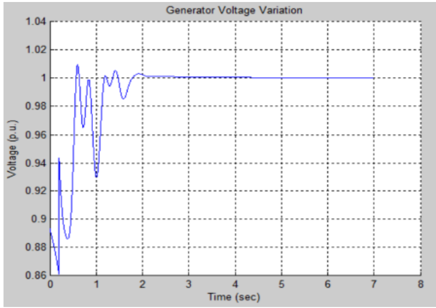

Figure 5d. Voltage Variation at the bus 16 relating to the SCs-Configuration.

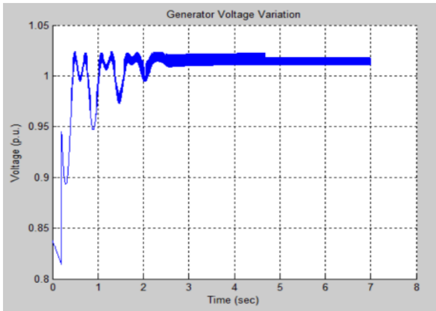

Figure 5e. Voltage Variation at the bus 16 relating to the SVCs-Configuration.

Another studying cases:

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

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

Studying Case	Line (bus-bus)	Clearin Time	Inllus trating Figures	Configu ration Winner/ Loser
First	(1-5)	0.2 sec	5a, 5b, 5c, 5d, 5e	SVCs/ SCs
Second	(1-2)	0.15 sec	6a, 6b, 6c 6d, 6e	SVCs/ SCs
Third	(2-4)	0.13 sec	7a, 7b, 7c 7d, 7e	SVCs/ SCs

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

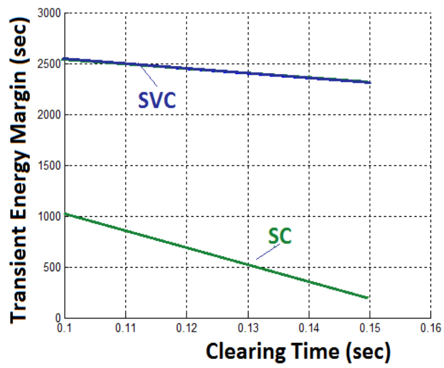

Figure 6a. Comparing the TEM of the second studying case

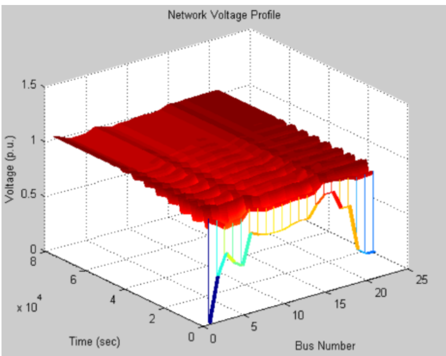

Figure 6b. Network Voltage Profile relating to the SCs-Configuration.

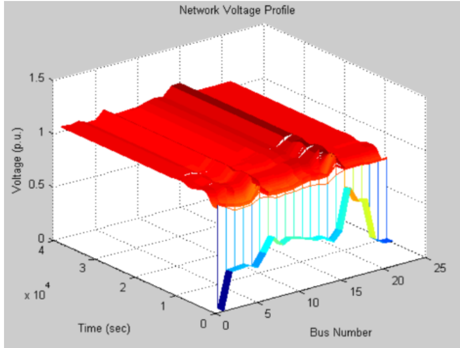

Figure 6c. Network Voltage Profile relating to the SVCs-Configuration.

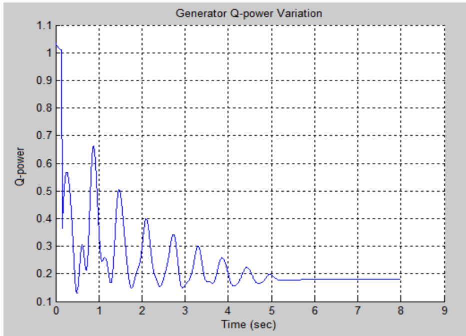

Figure 6d. Q power output of SC at the bus 16 relating to the SCs-Configuration.

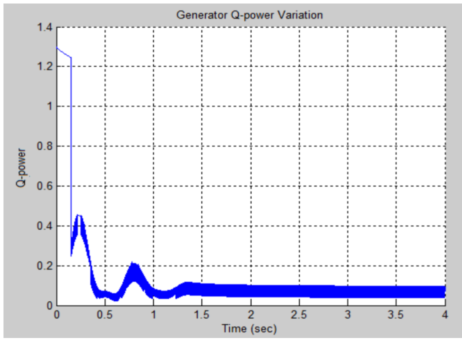

Figure 6e. Q power output of SC at the bus 16 relating to the SVCs-Configuration.

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

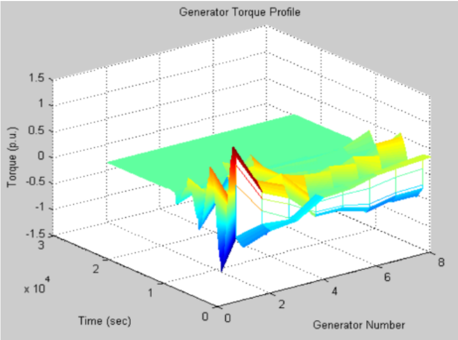

Figure 7a. Accelerating Torque Profile relating to the SCs-Configuration.

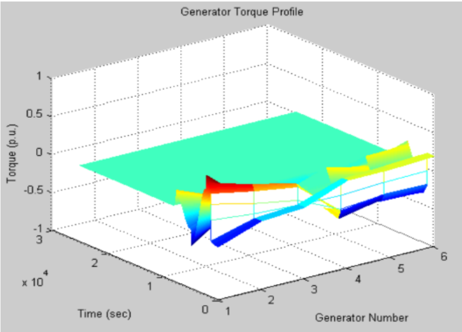

Figure 7b. Accelerating Torque Profile relating to the SVCs-Configuration.

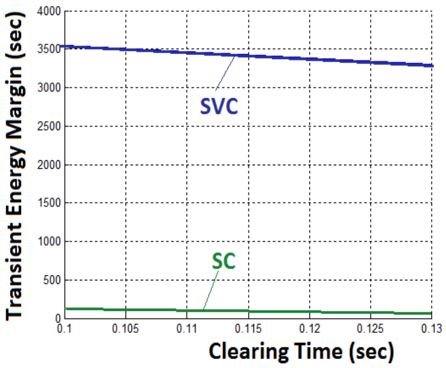

Figure 7c. Comparing the TEM of the third studying case.

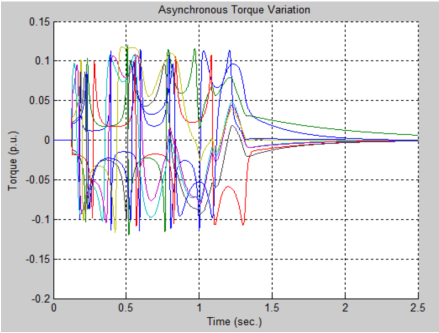

Figure 7d. Asynchronous Torque Variation relating to the SCs-Configuration.

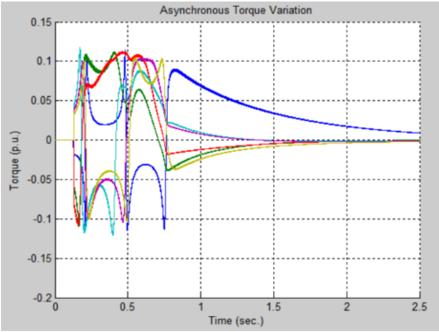

Figure 7e. Asynchronous Torque Variation relating to the SVCs-Configuration.

4. CONCLUSION

Implementing the different studying cases results in 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 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 condition of symmetrical disturbances and to assess the dynamic stability in multi-machine power system.

Khảo sát các tác động của SVC và SCs ảnh hưởng đến ổn định động của hệ thống điện nhiều máy phát

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TÓM TẮT

Một giải thuật mới mô phỏng tác động của các thiết bị hỗ trợ công suất phản kháng, như SVCs và SCs (máy bù quay) trong điều kiện sự cố đối xứng trong hệ thống điện nhiều máy phát được đề cập. Một số ví dụ tính số tiêu biểu được trình bày trong bài báo này.

Sự so sánh về sự biến đổi của các thông số trạng thái, như điện áp, tần số, công suất phản kháng phát ra và mô-men không đồng bộ … được mô phỏng trong điều kiện tác động của hệ thống điều chỉnh điện áp của các máy phát điện và cúa các thiết bị hỗ trợ công suất phản kháng.

Độ dự trữ năng lượng quá độ được tính toán và so sánh để đánh giá ổn định động của hệ thống điện nhiều máy phát. Căn cứ vào giải thuật được đề nghị thì chương trình máy tính sử dụng các phần tử của ma trận ảnh trị riêng để đem lại các ưu điểm đặc biệt nhằm để mô phỏng các tính chất quá độ của các biến trạng thái.

Từ khóa : *Ổn định động; Hệ thống điện nhiều nguồn; Thiết bị bù tĩnh (SVC); Mức dự trữ năng lượng quá độ (TEM);*

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