Application of SVC as Reactive Power Compensator in a Solar Grid Integrated System

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Abstract- **This paper will demonstrate and discuss how SVC will be used as a reactive power compensator to regulate the transmission system dynamic performance at different loading and thus effectively regulate system voltage. SVC is basically a shunt connected Static Var Generator or absorbers whose output is varied so as to control voltage of the electric power system. The FC-TCR type SVC is modeled under the environment MATLAB simulation. The simulation results show that the proposed system can stabilize the fluctuation of power grid voltage and the merits of fast response speed and high precision are verified.**

Keywords - **SVC, Reactive Power, PV system, MATLAB Simulation**

I. INTRODUCTION

The continuously increasing electric energy demands the significant rise of the oil price and the decrement of the fossil fuel reserves, combined with the environmental pollution caused by the conventional, thermal energy generating units has led to a worldwide concern on the development of alternative electric energy production methods. Aiming towards the achievement of this goal, the photovoltaic grid-connected systems (PVGCSs) are widely used in order to inject the energy produced by photovoltaic (PV) modules to the electric grid. The installation of PVGCSs by private investors is frequently supported in many countries by means of subsidization of the corresponding investment capital cost [7]. But output of the photovoltaic power generators is unstable, being affected strongly by weather changes and cloud motion. Therefore in a power distribution system having a high density of photovoltaic generators, there is a risk of considerable deterioration of power quality as a result of fluctuation of system voltage and frequency[2]. Therefore various devices and operation techniques are used to maintain the voltage on the distribution lines within the tolerance range. In this paper I have considered the operation of a Static Var Compensator (SVC), one of the existing control techniques. Assuming the installation of SVC at the midpoint of the solar grid integrated systems, I have examined voltage compensation at different level of loading and various locations of loads. The voltage compensation effect of SVC depends on their rated capacity and slope reactance. Here the rating of SVC is determined as per the reactive power that needs to be compensated to maintain the desired voltage level. The volume of this system is ±5MVAR.

II. PRINCIPLE OF SVC

SVC is shunt connected static generator or absorber. Utilities of SVC controller in transmission line are many: a) provides high performance in steady-state and transient voltage stability control, b) dampen powerswing, c) reduce system loss, d) Control real and reactive power flow [1, 4, 5].

Simple FC-TCR type SVC configuration is shown in figure 1. In FC-TCR, a capacitor is placed in parallel with a thyristor controlled reactor [3, 8].

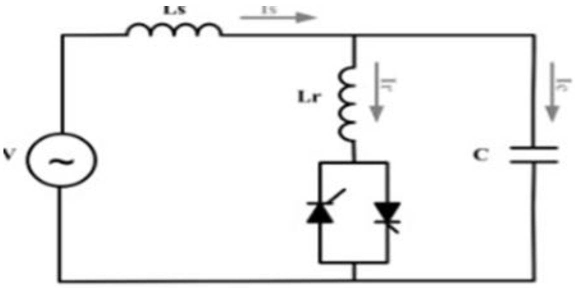

Fig.1. Fixed Capacitor Thyristor Controlled Reactor

Is, Ir and Ic are system current, reactor current and capacitor current respectively which flows through the FC-TCR circuit. Fixed Capacitor Thyristor controlled Reactor (FC-TCR) can providecontinuous lagging and leading Vars to the system. Circulating current through the reactor (Ir) iscontrolled by controlling the firing angle of anti-parallel thyristor valves connected in series with the Reactor. Leading Var to the system is supplied by the capacitor. For supplying lagging Vars to the system, TCR is generally rated larger than the capacitor[8.10].

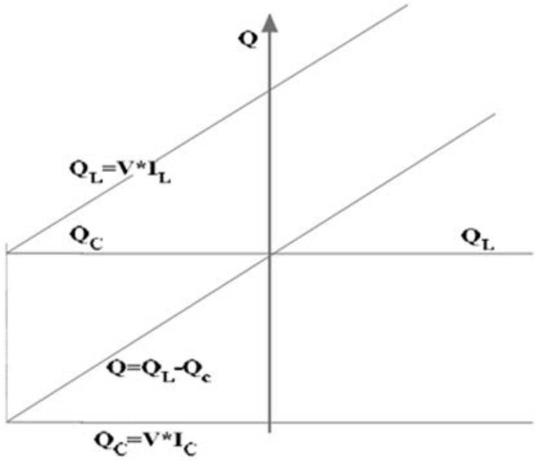

Fig. 2. Vars demand V/S Vars output characteristics

The Thyristor controlled rector is off at the maximum capacitive Var output. To decrease the capacitive output, the current in the reactor is increased by decreasing delay angle α. At zero Var output, the capacitive and inductive currents become equal and thus both the Vars cancels out. With further decrease of angle α, the inductive current becomes larger than the capacitive current, resulting in a net inductive output.

III. DESIGN AND MODELING OF SVC

Here Capacity of SVC is determined by considering allowed voltage fluctuation of ±5% and short circuit capacity (SCC) of 100MVA.

Here ΔV – Voltage Fluctuation

ΔQ – Reactive power variation (i.e. size of the compensator)

S_{SC} – System short circuit capacity

Since $\Delta V = \Delta Q / S_{sc}$ or $\Delta Q = \Delta V \times S_{sc}$

We get $\Delta Q = \pm(0.05 \times 100)$

$= \pm$ 5MVar

Hence Static Var Compensator of rating ±5MVar is connected to the 33kV bus via a 5MVA, 33/11kV transformer on the secondary side.

The Reactance of the TCR and FC are calculated as

$$X_{Lrated} = \frac{U^2 rated\ (s)}{Q_{Lrated}} = \frac{(11\times10^3)^2}{5\times10^6} = 24.2\ \Omega$$

$$X_{tranf} = 0.15\frac{U^2 rated}{P_{tranf}} = 0.15\frac{(11\times10^3)^2}{2.5\times10^6} = 7.26\Omega$$

Here 0.15 is transformer leakage reactance

$$X_{LTCR}(\Delta) = X_{Lrated} - X_{tranf} = 16.94\Omega$$

$$X_{LTCR}(1-\emptyset) = 3\times16.94 = 50.82\Omega$$

$$L_{TCR} = \frac{50.82}{(2\pi60)} = 0.135\ \mathrm{H}$$

$$X_{Crated} = \frac{U^2 rated}{Q_C rated} = \frac{(11\times10^3)^2}{5\times10^6} = 24.2\ \Omega$$

$$C = \frac{1}{(2\pi\times60\times24.2)} = 109.61\mu\mathrm{F}$$

Hence value of L for each branch is 135mH and C is 109.61µF.

IV. SIMULATION AND RESULTS

In a Simulink model two identical three phase source of 11kV, 5MW at the two ends are considered. Bus two (B2) is at the midpoint of 33kV transmission system as shown in fig.3. For the transmission system line connecting two systems, the best location for Var compensator is in the middle, whereas for a radial feed to the load the best location is at the load end. FC-TCR, SVC is connected at the B2 and its impact at B1, B2 and B3 are studied. The increases in voltage at different buses with SVC are noted. Three phase instantaneous active and reactive power measurement block are used to measure the active and reactive power at B2 with and withoutSVC and also at different loading i.e. no load, full load at different locations.

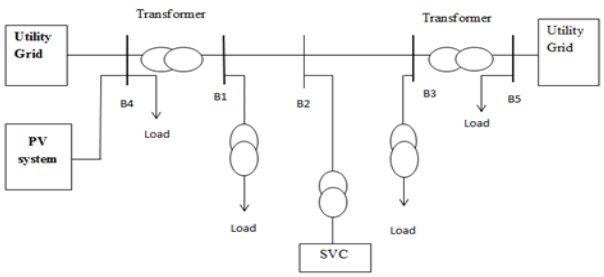

Fig. 3. Schematic diagram of PV grid system with SVC

Case 1: At no load

Table 1: Bus voltage with varying Capacitance value (L= 150mH, α=110^0)

	C (μF)	At B1 V1(pu)	AtB2 V2 (pu)	At B3 V3(pu)
Without SVC	0	1.007	1.016	1.007
With SVC	22	1.015	1.041	1.015
	15	1.011	1.029	1.011
	10	1.01	1.011	1.01

It is evident from table 1 that the voltage at the midpoint of the transmission line is maximum while the current is minimum. It clearly highlights the fact that the imbalance in the reactive power generation and demand raises the voltage at the line, particularly at the midpoint, where the system voltage is totally uncontrolled. The capacitive current at the two ends produces reactive power injection at the terminals. However, the voltage at the two ends can be kept constant provided the generators at these ends possess the capability of absorption of reactive power which is done by setting the generator in the zone of under excitationmode. However this has got some practical limitations. In case the generator is assigned to absorb reactive power more than its limits, this method of controlling the excitation does not serve the purpose and external compensation is strongly recommended. Hence after connecting SVC at B2 we see from the above table 1 that the voltages at different buses can be controlled and it increases proportionally with increase in capacitance value. Optimum performance is obtained at capacitance value of 10μF. Voltage instability in a power system occurs when the system is unable to meet the Reactive power demand [13]. This demand can be balanced by connecting a device which can inject and absorb reactive power based on the system requirements and increase the power profile thus the increase of power quality which ultimately is the goal of compensating device. Basically at no load the compensating device should function in inductive mode absorbing reactive power.

Case 2: At Full load

a) 3/4th load at B1 and 1/4th load at B3

Table 2: Variation of Bus voltage with varying Capacitance value (L=150mH, α=110^0)

	C (μF)	At B1 V1(pu)	At B2 V2(pu)	At B3 V3(pu)
Without SVC	0	0.943	0.953	0.946
With SVC	33	0.954	0.988	0.957
	47	0.961	1.012	0.964
	68	0.967	1.031	0.97
	100	0.975	1.058	0.978
	150	1.003	1.152	1.006

Table 3: Variation of power flow

	C(μF)	L(mH)	Q(MVar)	P(MW)
Without SVC	0	0	0.63	0.76
With SVC	47	150	1.59	0.44

From table 2 we see that voltage at B1 is lowest where more loads are connected. The magnitude of the midpoint voltage depends on the power transfer. This voltage influences the line insulation and therefore needs to be well understood.

For a symmetrical line where the end voltages are held at nominal values, the midpoint voltage shows the highest magnitude variation. Now when SVC are connected at B2 the then midpoint, voltage level increases in proportion to the capacitance values as shown in table 2 but real power through the system decreases while increasing the reactive power as per the variation of load angle to meet the reactive power demand as shown in table 3 [11]. The optimum operation is at a capacitance value of 47μF where voltages at all buses are maintained within 1 pu as desired.

b) All load at one side (i.e. B3)

Table 4: Bus voltage with varying Capacitance value (L=150 mH, α= 110^0)

	C (μF)	At B1 V1(pu)	At B2 V2(pu)	At B3 V3(pu)
Without SVC	0	0.986	0.961	0.921
	47	1.005	1.022	0.938
With SVC	68	1.011	1.04	0.95
	100	1.019	1.067	0.952
	150	1.049	1.163	0.980

Table 5: Power flow variation

	C(μF)	L(mH)	Q(MVar)	P(MW)
Without SVC	0	0	2.38	0.66
With SVC	68	150	1.61	1.25

From table 4 we see that voltage at B3 is low where all loads are connected. Now when SVC is connected at B2 it not only increases the voltage at that particular bus but it also increases the voltage level at other two buses simultaneously with every increase in capacitance values. Also as shown in table 5 the real power flow through B2 increases with SVC connected to it as we know[1]

$$P = \frac{2V^2}{X} sin\frac{\delta}{2}$$

$$Q = VI \sin\frac{\delta}{4} = \frac{4V^2}{X}\left(1 - cos\frac{\delta}{2}\right)$$

P is real power, Q is reactive power and δ is angle

It can be observed from above equation that the midpoint shunt compensation can significantly increase the transmittable power (doubling its maximum value) at the expense of a rapidly increasing reactive power demand on the midpoint compensator and also on the end generators. It is also evident that midpoint of the transmission line is the best location for the compensator. This is because the voltage sag along the uncompensated transmission line is the largest at the midpoint. Also the compensation at the midpoint breaks the transmission line into two equal segments of which the maximum transmittable power is the same and it reaches steady state value at a faster rate and increases the system stability and thus the power quality improvement. Here optimum capacitance value is 68μF when α is 110^0 and L of 150mH.

Case 3: Relation between firing angle (α) and reactive power

Table 6: Reactive power variation at varying firing angle (α) (C=150μF, L=150mH)

Firing angle (α in degree)	Reactive Power, Q (MVar)	Current through TCR (Ampere)
90	2.33	198.28
110	2.40	167
130	2.421	110.33
150	2.44	70.32
180	2.48	1.249

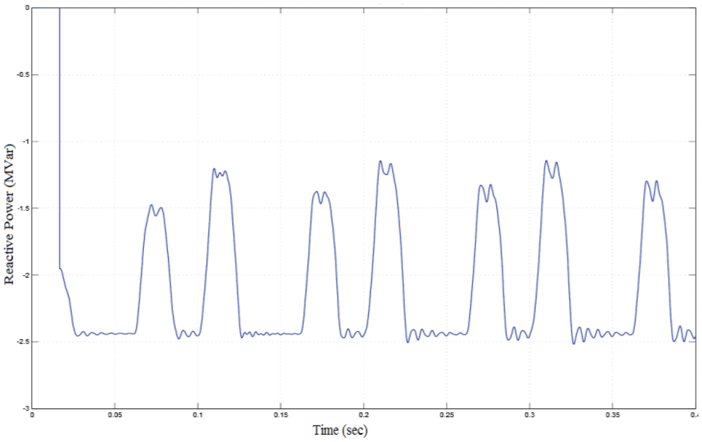

Fig.4. Waveform of reactive power with SVC at α = 110^0

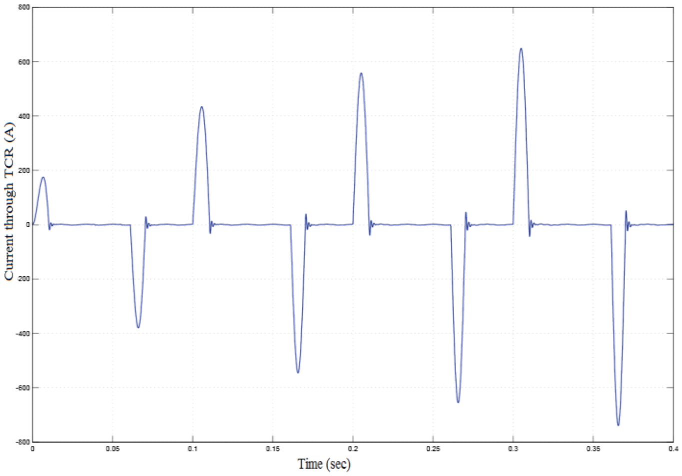

Fig.5. Current through TCR at α = 110^0

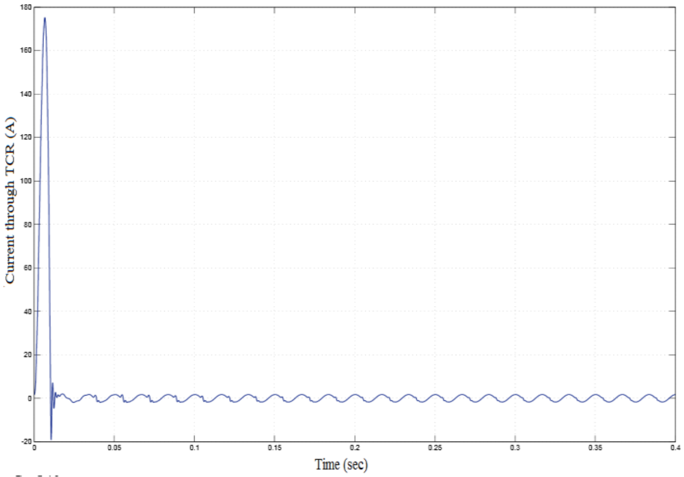

Fig.6. Current through TCR at α = 180^0

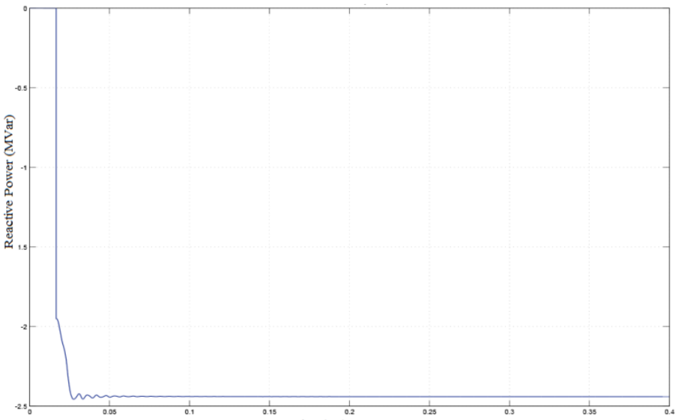

Fig.7. waveform of Reactive power with SVC atα = 180^0

In each phase anti-parallel thyristor are triggered in form of phase control and there is 180^0 phase difference between the two devices at the same branch[6]. The relationship between fundamental component of current within reactor and α is

$$i_L(\alpha) = \frac{U_{mab}}{X_l}(2 - \frac{2\alpha}{\pi} + \frac{sin2\alpha}{\pi})$$

$$(\frac{\pi}{2} \leq \alpha \leq \pi)$$

Here, Umab is voltage peak value between phases

$X_l$is reactance of reactor in series with thyristor

When α= 90^0, thyristor is on fully and $i_L$reaches the highest value. Similarly when α=180^0, thyristor is off entirely and $i_L$reaches the lowest value as shown in the table 6. Thus changing delay angle α can control the reactive current within the reactor, namely TCR will absorb varying reactive power from power grid whereby reactive power will be compensated and reliability of the system will be improved.

V. CONCLUSION

MATLAB/SIMULINK environment is used for this comparative study to model and simulate FC-TCR type SVC connected to a simple transmission line. This paper presents performance analysis of SVC at different loading in the transmission system and at different capacitance values and firing angle (α). FC-TCR type SVC provides compensation from a capacitor value as low as 22µF but as the length of the line increases on account of the line-charging capacitances, the line experiences significant over voltages at light-load and no load conditions and here SVC should function in inductive mode where by it will absorb excessive reactive power and maintain the voltage within the permissible limits.

The application of midpoint or intermediate bus Voltage controllers (Var compensators) enhances the power-transmission capacity of a line. In practical cases, Var controllers are sized by carefully selecting their continuous-operating range to hold the connecting-bus voltage within an acceptable range of values in the normal line-loading range.

Here for obtaining the optimum values of SVC numerous case studies are carried out at different loading and location and at different capacitance values and firing angle. Upon simulation optimum operation is found at a fixed capacitance value of 47µF when loads are connected at both ends of the system but when all full loads are connected only at one side of the system optimum capacitance value is 68µF, where, in both the cases α is 110^0 and L of 150mH. Power flow and voltage profile are seen to improve.

Because reactive power compensation influences the power-transmission capacity of the connected line, controlled compensation can be used to improve the system stability (by changing the maximum power transmission capacity), as well as to provide it with positive damping. Like other system components, reactive-power compensators are dimensioned, and their types are selected on the basis of both their technical and cost effectiveness. Ultimately the design and layout of a SVC system is always tailored to the specific project requirements.

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