Evaluating VAR Compensation for Improving Power System Stability

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Abstract: **In this paper, an evaluation of advanced VAR compensation employing Static VAR Compensator is presented. The evaluation includes the comparison through system utility and design, application, operation and other considerations etc. The types of SVC may include advanced voltage compensator namely power electronically switched capacitors, inverter based system without energy storage and inverter based system with energy storage.**

Key Words: **VAR, SVC, TCR, Compensation, voltage profile**

1. INTRODUCTION

In an electrical utility network, it is desirable to regulate the voltage within a narrow range of its nominal value. Most utilities attempt to maintain this voltage deviations in a +5%,-10% range around their nominal values [1]. Moreover, it is desirable to have a balanced load on all three phases to eliminate negative and zero sequence components that can have undesirable consequences such as additional heating in electrical equipment, torque pulsation in generators and turbines, and so on. The load on power system fluctuates and can result in voltage outside of their acceptable limits. In view of the fact that the internal impedance of the AC system [2] seen by the load is mainly inductive, it is the reactive power change in the load that has the most adverse effect on the voltage regulation. SVC is a solid state reactive power compensation device based on high power thyristor technology. It improves the performance of transmission and distribution utilities [3]. It can easily be installed at multiple places, where ever it is installed it increases transfer capability and reduces losses while maintaining a smooth voltage profile under different operating conditions, dynamic stability of the grid is improved and active power oscillations mitigated. To obtain this control of the reactive power, the SVCs are often combined with mechanically switched shunt reactors and capacitors.

2. BASIC SVC SCHEMES

(1)Thyristor controlled reactor and fixed capacitor (TCR/FC):-

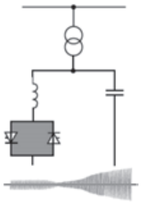


Fig 1: TCR/FC, Power control [4]

A reactor and thyristor valve are incorporated in each single phase branch. Power is changed by controlling the current through the reactor via the thyristor valve [5]. The states are controlled by triggering relative to the natural zero current crossing [5].

A thyristor controlled reactor (TCR) is used in combination with a fixed capacitor (FC) when reactive power generation or alternatively, absorption and generation is required [6-9]. This is often the optimum solution for sub-transmission and distribution.

TCR/FCs are characterized by

— Continuous control

— No transients

— Elimination of harmonics by tuning the FCs as filters

— Compact design

(2) Thyristor switched capacitor, TSC

A shunt capacitor bank is divided into an appropriate number of branches. Each branch is individually switched on or off via a thyristor valve.

Switching takes place when the voltage across the thyristor valve is zero, making it virtually transient-free.

Disconnection is effected by suppressing the firing pulses to the thyristors which will be blocked when the current reaches zero.

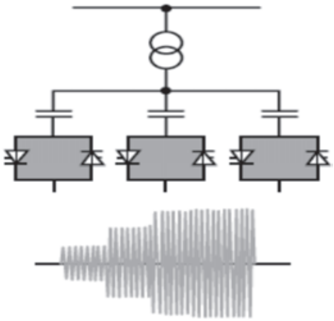


Fig 2: TSC Power control [8]

TSCs are characterized by

— Stepped control

— No transients

— No harmonics

— Low losses

— Redundancy and flexibility

(3) Thyristor controlled reactor/Thyristor switched capacitor(TCR/TSC)

It is the optimum solution in many cases, with a TCR/TSC compensator, continuously variable reactive power is obtained across the entire control range plus full control of both the inductive and the capacitive parts of the compensator [10-13].

The principal benefit is optimum performance during major disturbances in the power system, such as line faults and load rejections.

TCR/TSC combinations are characterized by

— Continuous control

— No transients

— Elimination of harmonics via filters or TSR (Thyristor Switched Reactor) control

— Low losses

— Redundancy

— Flexible control and operation

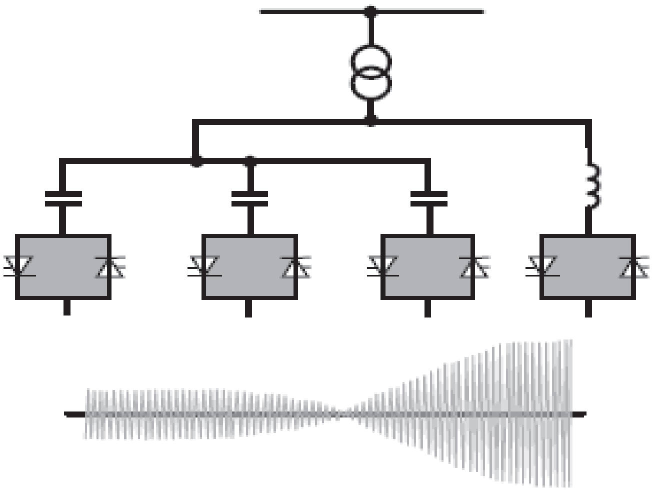


Fig 3: TCR/TSC, Power Control

3. VOLTAGE STABILISATION

SVC is the preferred tool for dynamic reactive power supporting high voltage transmission grids. Thanks to its inherent capability for high-speed, cycle-by-cycle control of VARs, it will counteract the often hazardous voltage depressions that following conjunction with faults in the grid [14-18]. These highly dynamic events, where the ever increasing use of induction motors (like those in air-conditioning units and wind power turbine-generators) stresses the grid, will need an SVC to maintain the grid voltage and safeguard the fault ride-through capability. It also suppresses over- voltages that appear upon fault clearing and provide effective regulation at normal conditions for grid voltage optimisation. It also ensures that grid voltage does not dips when power flow is heavy i.e. more power can be transmitted.

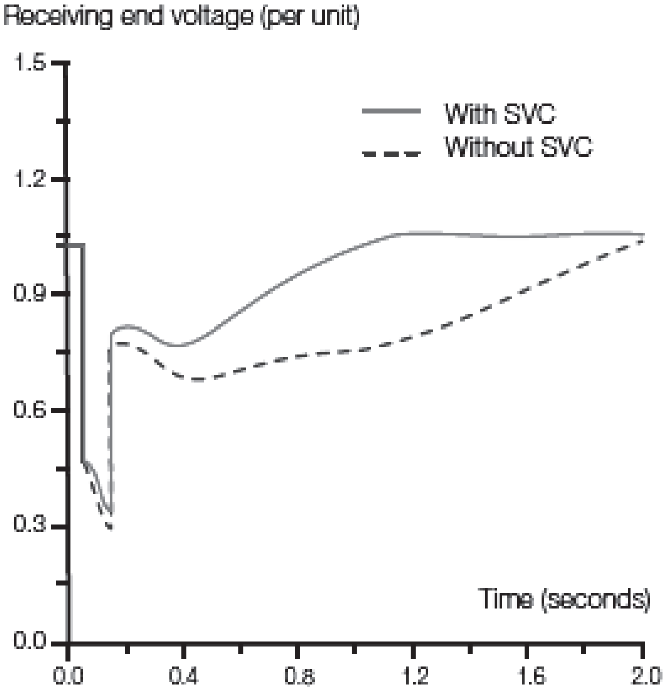


Fig 4: Post Fault Voltage Recovery With and Without SVC

4. GRID RELIABILITY IMPROVEMENT

Employing of SVC incorporates the following advantages in transmission system:

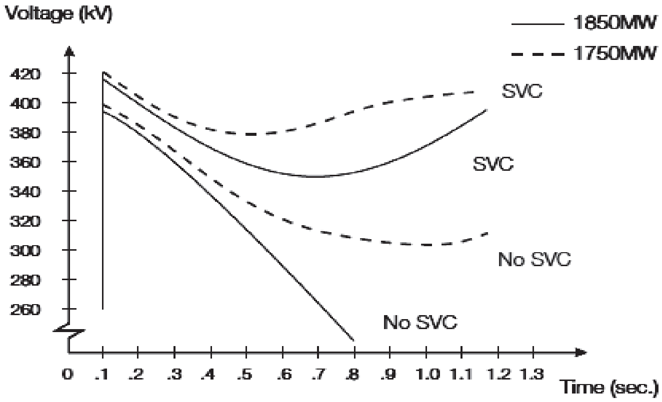


Fig 5: Post Fault Stabilising Effect of SVC (Ref. ABB)

The benefits of SVC in power transmission:

— Stabilized voltages in weak systems

— Reduced transmission losses

— Increased transmission capacity, to reduce, defer or eliminate the need for new lines

— Higher transient stability limit

— Increased damping of minor disturbances

— Greater voltage control and stability

— Power oscillation damping.

The benefits of SVC in power distribution: [19-22]

— Stabilized voltage at the receiving end of long lines

— Increased productivity as stabilized voltage means better utilized capacity

— Reduced reactive power consumption, which gives lower losses and improved tariffs

— Balanced asymmetrical loads reduce system losses and enable lower stresses in rotating machinery

— Enables better use of equipment (particularly transformers and cables)

— Reduced voltage fluctuations and light flicker

— Decreased harmonic distortion

These stabilizing effects and reliability improvements can be illustrated through figures 5, 6 and 7

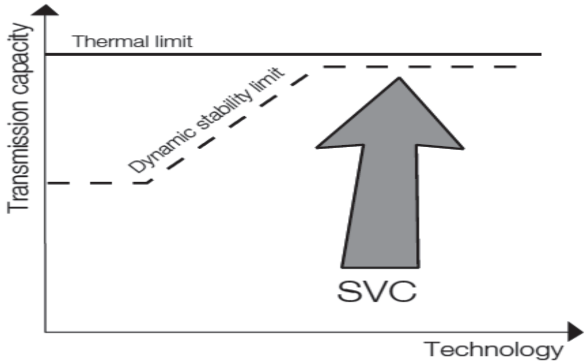


Fig 6: Capacity of Grid

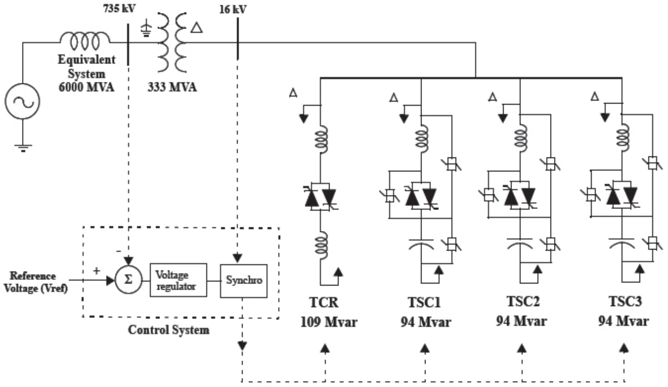


Fig 7: Single-Line Diagram of the SVC

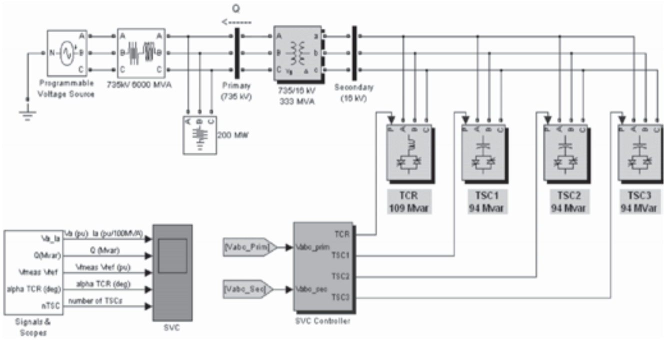


Fig 8: Simulation Model of the 300 Mvar SVC on a 735 kV Power System (mathworks.com)

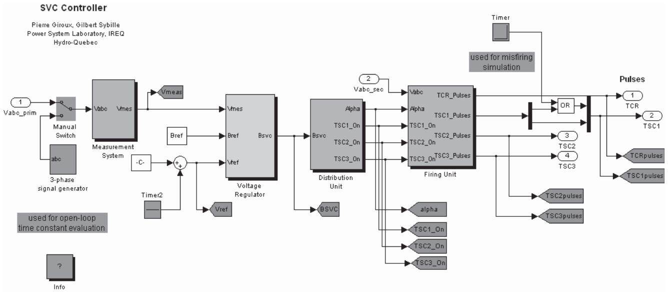


Fig 9: SVC Control System

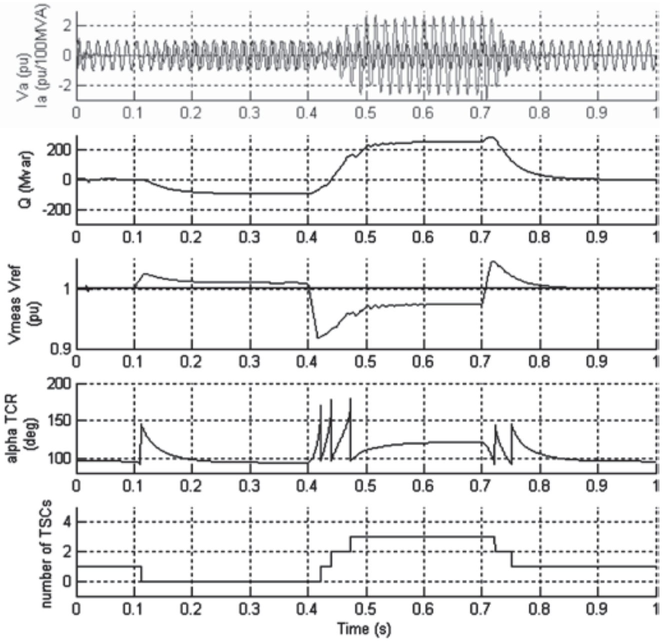


Fig 10: Performance of SVC (Steady-State & Dynamic Response) to System Voltage Steps

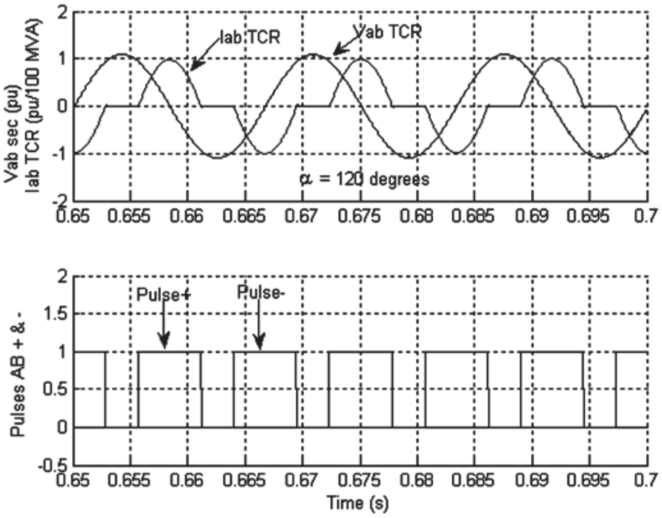
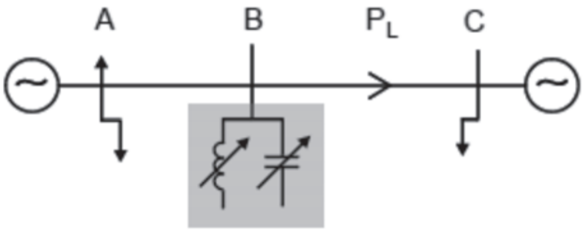


Fig 11: Steady-State Voltage and Current in TCR AB



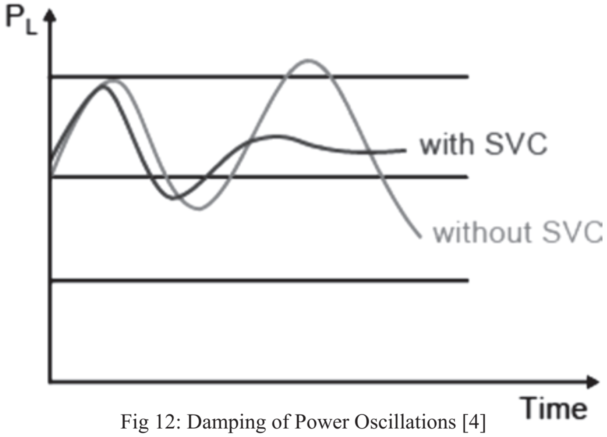


Fig 12: Damping of Power Oscillations [4]

5. ADVANCED VAR COMPENSATORS

In addition to SVC advanced VAR compensators are also employed.

The advanced compensators include:

- Power-electronically-switched capacitors.
- Inverter-based systems without energy storage.
- Inverter-based systems with energy storage.

Compensator Design and Concept of Operation

(I) Power-electronically-switched capacitors: Utilizing power-electronically-switched capacitors banks sized in proportion and reactors are arranged in series with each bank to detune the harmonic response and inrush currents. The banks are switched when a bank is charged to rated capacity. It can respond in 1 cycle of operation and is rated up to 24MVAr at 690V or 120 MVAR at 15KV. E.g.: AVC [23].

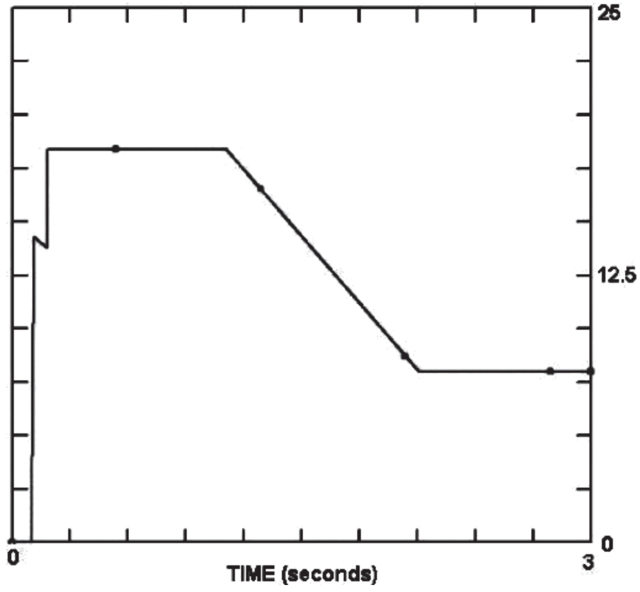


Fig 13: Reactive power output of a ±8MVAR D-VAR connected via step up transformer [2]

It is applied for dynamic voltage support and a transformer is used to step up banks output voltage up to required level.

Since shunt capacitors are employed, reactive power output is proportional to square of bus voltage ($Q \propto V^2$).

(II) Inverter-based systems without energy storage: These utilise shunt connected voltage source inverters to control power flow. The reactive power is controlled by regulating the voltage of output of inverter. It employs filters and step up transformers to meet the demand. It can be a Dynamic VAR Compensator (D-VAR) or Distribution Static Compensator (DSC) [24].

A D-VAR unit is rated at 480V and consists of numerous 250KVA inverter modules which supply ±8MVAR. Its power output id proportional to bus voltage ($Q \propto V$).

(3) Inverter-based systems with energy storage: These form the backbone of smart grid and smart distribution system, it is employed as Distributed- Super conducting Magnetic Energy Storage (D-SEMS). It is similar to D-VAR with output capability of 3MW and average output power capability of 2.5MW for first .5 sec of discharge [25].

The reactive power output is proportional to the bus voltage ($Q \propto V$).

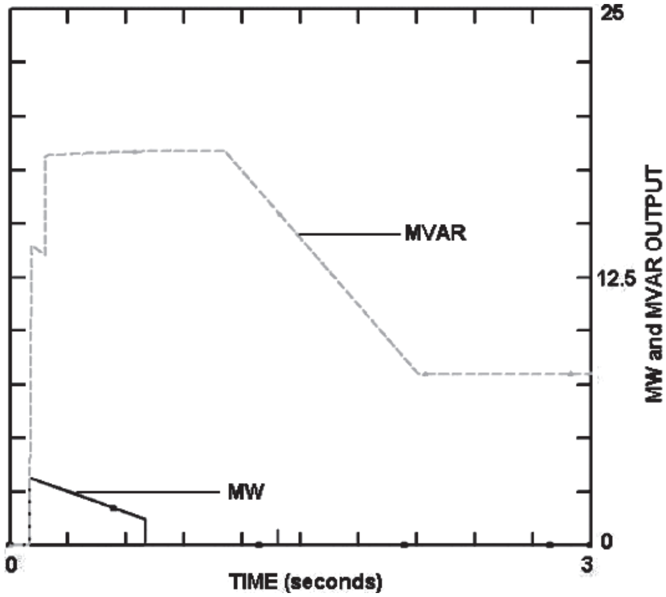


Fig 14: Real and reactive power output of a ±8MVAR, 3MWpeak output power of D-SMES connected via step up transformer [2]

6. CONCLUSION

The advancement in the science and technology for eg.plant equipments demands for more reliability and minimum errors so that voltage profile can be maintained almost flat. Because in current scenario the equipments are very much sensitive to supply voltage regulations. Any type of contingency or fluctuation may cause either damage to the costly equipment or harmful for further used equipments.

The results obtained shows that developed methodology is insensitive to the random voltage fluctuations in transmission line, and provide an efficient voltage regulation.In this paper, it has been observed that the scope of various VAR compensating devices such as TSC, TCR and SVC has been enriched with time and increase in complexity of power system. The relative advantages and disadvantages of compensating devices are also presented.

The recent advancements in the field are also mentioned along with idea of DVAR connected in step up transformer. As it can be seen from various diagrams, the power transfer capability and voltage profile are maintained. Power oscillations are damped out. Thermal stability limit are also taken care of. The transmission capacity does not cross the thermal stability limit. Post fault conditions are more favourable with the compensating devices described earlier.

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