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Comparative analysis of single phase TCR, TSC and TSR static var compensators.

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Abstract
This paper gives a study of behavioral comparison the operation of a thyristor controlled reactor (TCR) which consists of an inductance and a bi-directional thyristor switch connected in parallel, thyristor switched capacitor (TSC),which consist of a capacitance in series with a two bidirectional capacitors, the thyristor switched reactor inductor (TSRL) which consist of only an inductor in the SVC. Firing angle control of the TCR switches regulates the time for which the inductance is included in the circuit. a firing angle of between 90 degrees to 180 degrees was observed for the TCR and a continuous firing signal for the TSC by using a step generator, then voltage regulation was observed when the a combination of TCR and TSC compensator called hybrid reactive power controlling model to prevent occurrence of voltage amplification as a result of the receiving end voltage becoming twice of the sending end voltage
Key words: *thyristor controlled reactor (TCR),thyristor switched capacitor (TSC),static var compensator (SVC),Thyristor switched reactor (TSR),Thyristor valve.*

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I. Introduction

The stability of an interconnected power system is related to its ability to return to normal or stable operation after being subjected to some form of disturbance. Conversely, a condition denoting loss of synchronism means instability. Power system stability has been recognized as an essential part of power system planning for a long time [1]. With interconnected systems continually growing in size and extending over vast geographical regions, it is becoming increasingly more difficult to maintain synchronism between the various parts of a large power system. small disturbances are continually occurring in power systems. In a dynamically unstable system, the oscillation amplitude is large and persists for a long time. This constitutes a serious threat to system security and creates undesirable operating conditions. Following a sudden disturbance on the power system, the rotor speed, rotor angular differences and the power transfer undergo fast changes in which the magnitudes depend on the severity of the disturbance. For a large disturbance, changes in angular differences may be large enough to make the machines out of step. Static VAR Compensator (SVC) is currently widely used in power systems. By adjusting the firing angle, it can smoothly and rapidly provide reactive power control and therefore provide effective control to the bus voltage [2]. In addition, SVC can enhance the transient stability and provide additional damping to the power system as well.

In transmission applications, SVCs are used to regulate the grid voltage. If the power system's reactive load is capacitive (leading), the SVC will use TCR to consume reactive power from the system, lowering the system voltage. Under inductive (lagging) conditions, the capacitor banks are automatically connected, thus providing a higher system voltage [3]. By connecting the thyristor-controlled reactor, which is continuously variable, along with a capacitor bank step, the result is continuously variable and could provide leading or lagging power.

In general, SVCs are cheaper, faster and more reliable than dynamic compensation schemes such as synchronous condensers [4]. However, static VAR compensators are more expensive than mechanically switched capacitors, so many system operators use a combination of the two technologies (sometimes in the same installation), the static VAR compensators provide support for fast changes of the mechanically switched capacitors [5]. It also can provide steady-state VAR's. Static reactive power compensation devices have been developed in the 1970s.

The early compensators were synchronous condensers and parallel capacitors, mostly used for centralized compensation in the high-pressure side of the system. One traditional approach is to connect the inductive load with the capacitor, which is a method of reactive power compensation. It has a wide range of applications. The parallel capacitor reactive power compensator has many advantages, such as low cool, convenient and simple structure. But its impedance is immutable, it cannot change along with the load, which means it cannot achieve dynamic reactive power compensation. For today's power system, synchronous condensers are specifically designed for generating reactive power in the case of over-excitation; it can generate the dynamic reactive power. It can also generate the inductive reactive power at the under-excitation state. Based on the rotation of the synchronous motor, the loss in the operation and noise could not be avoided. The response speed is slow and the operation and maintenance is complex. It is difficult to meet the requirements of fast dynamic response [6]. In the last 20 years or so, new technologies of static VAR compensator have been introduced. Before Facts were introduced, this approach has been successfully applied and widely used around the world. Static VAR compensator is defined as switching (on and off) reactors or capacitors through different static switches. Therefore, it has the ability to emit or absorb the reactive current [7]. This approach could maintain system voltage and improve power system factor. This is mainly divided into two types: electronic switches and circuit breakers. Because a circuit breaker is a contact device, its switching speed is relatively slow. Therefore, it is impossible to achieve fast response when the load reactive power change rapidly. Also, it will come with some serious side effects, such as severe surge current and over-voltage operation.

Power electronic devices have seen important development, the speed of SCR, GTR, and GTO has improved rapidly. No matter what the parameters of the system are, the reactive compensation can be done in one period and realize the single-phase regulation. For now, the technology of SCR is widely used in power systems [8].

In power transmission, reactive power plays an important role. Real power accomplices the useful work while reactive power supports the voltage that must be controlled for system reliability. Reactive power has a profound effect on the security of power systems because it affects voltages throughout the system. Decreasing reactive power causing voltage to fall while increasing it causing voltage to rise. Voltage collapse may be occurring when the system tries to serve much more load than the voltage can support. Voltage control and reactive power management are the two aspects of a single activity that both supports reliability and facilitates commercial transactions across transmission networks. Voltage is controlled by absorbing and generating reactive power [10-16]. Thus, reactive power is essential to maintain the voltage to deliver active power through transmission lines. If the line voltage is in phase quadrature with the line current, the series controller absorbs or produces reactive power, if it is not, the controllers absorb or produces real and reactive power. Examples of such controllers are Static Synchronous Series Compensator (SSSC), Thyristor Switched Series Capacitor (TSSC), and Thyristor-Controlled Series Reactor (TCSR), to cite a few. They can be effectively used to control current and power flow in the system and to damp system's oscillations. Among these Static Synchronous Series Compensator (SSSC) is one of the important series FACTS devices. SSSC is a solid-state voltage source inverter, injects an almost sinusoidal voltage, of variable magnitude in series with the transmission line. The injected voltage is almost in quadrature with the line current. A small part of the injected voltage, which in phase with the line current, provides the losses in the inverter [17]. Variable shunt impedance connected to a line causes variable current flow by injecting a current into the system. If the injected current is in phase quadrature with the line voltage, the controller adjusts reactive power while if the current is not in phase quadrature, the controller adjusts real power. The paper tends to give a comparative analysis of the performance of the different types of SVCs on the stability and reliability of output voltage, current, active and reactive powers of power system.

II. Materials and Methods

A. Materials

The comparative analysis was carried out using matlab/simulink.simulink blocks used include
The SVC components

- Detailed thyristors (connected back-to-back in parallel
- Ac voltage source, (424.4 Kv rms,60 Hz)
- Linear transformer; two winding (110 MVA, 424.4 KV/16KV)
- Grid connected loads (RLC line load,70.5 mOhms 18.7 Mh and 1.5mOhms 1.13 mH)
- Pulse generators for triggering the TCR
- Step generator for continuous triggering of the TSC
- Inductor/reactor (18.7 mH)
- Capacitor (308 microfarad)
- Continuous Powergui (SIMULATOR).
- Current and voltage measurement blocks

B. Methods

1 TCR Firing

The controllable range of TCR firing angle extends from 900 to 1800.in case of ideal reactor of L Henry firing angle of 900 results in full conduction with continuous sinusoidal current flow

1.1 Current and Voltage behavior

A single phase TCR static var compensator will be simulated when connected to a power grid and the thyristor voltage and current as shown in figure 1, one RL series branch is shown connected the secondary of the transformer and another to the primary to reduce the voltage. we use two anti-parallel thyristors to build the TCR and pulse signals to trigger the thyristors. The data pertaining to the system is shown in table 1.

Table 1: Firing Angles and The Thyristor Current And Voltage When Fired

Firing angle (α) Thyristor 1	Firing angle (α) Thyristor 2	Thyristor Voltage	Thyristor Current
90	90	1.12KV	135A
120	120	0.546KV	128A
150	150	1.124KV	86.65A
180	180	1.66KV	0A

The table shows the TCR voltage and current when the thyristors are fired at different firing angles, a maximum current or full conduction is obtained at 90 degrees. the TCR current as a function of time, is then given from equation

For $\omega t\ < \ \pi - \alpha : I(\omega t) = I_{tcr-max}\sqrt{2}[-\cos(\alpha) - \cos(\omega t)]$ (1)

For $\alpha < \ \omega t < 2\pi - \alpha : I(\omega t) = I_{tcr-max}\sqrt{2}[\cos(\alpha) - \cos(\omega t)]$ (2)

For $\omega t\ < \ \pi + \alpha : I(\omega t) = I_{tcr-max}\sqrt{2}[-\cos(\alpha) - \cos(\omega t)]$ (3)

Otherwise zero.

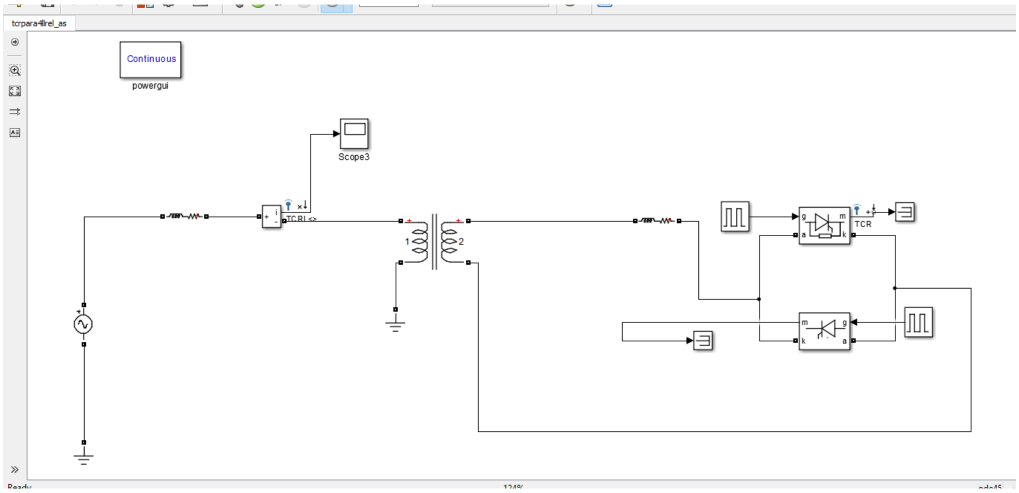

Figure 1: Simulink Model of Single Phase TCR Compensator Fired by a Sinusoidal Pulse Signal.

2 TSC firing

2.1 Current and Voltage behavior

TSC are not fired by pulse signals, rather requires a continuous pulse, a tuned frequency is usually chosen to be in the range 150-250 Hz on a 60 Hz system [9] it is an economical choice between the size of the TSC reactor (which increases with decreasing frequency) and the need to protect the thyristor valve from excessive oscillatory current when the TSC is turned on at an incorrect point of wave (''misfiring'').The TSC is first turned off, here no current flows and only an ac voltage will be observed at the thyristor valve. Here the ac voltage and capacitor voltages were studied when the TSC is on and when off.

Table 2: Source voltage and capacitor voltage for TSC continuous firing.

Firing pulse Thyristor 1	**Firing pulse Thyristor 2**	**Ac Voltage**	**Capacitor Voltage**
0	0	2.031KV	2.036KV
1	1	1.891KV	1.9KV
0	1	2.02KV	2.02KV

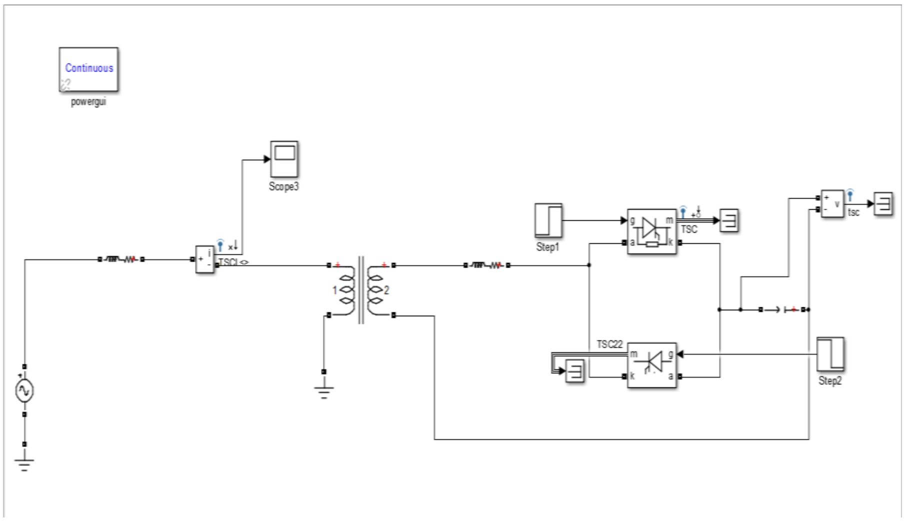

Figure 2: Simulink Model of Single Phase TSC Compensator Fired by A Step Signal.

The Simulink model to harness this procedure is shown in figure 2 an RL branch is connected at both the primary and secondary of the transformer, two anti-parallel thyristors are used to build the TSC and a step pulse are used to trigger the thyristors. The step pulse of 1 shows the capacitor will be fully or pre-charged.

3 Combined TSC and TCR compensation

A continuous variable reactive power can be achieved by using a TCR in combination with a TSC. A continuous change in the control order from fully lagging to fully leading current is obtained by this combination. By using a different combination an SVC can get various requirements to absorb/supply reactive power from/to the power supply.

Figure 4 shows the general form of a TSC-TSR SVC, the compensators are usually connected in parallel, so that the SVC can supply a varying amount of leading or lagging VAR to the leading or lagging system, by phase angle control of the thyristors, the conduction interval is reduced from maximum to zero.

The TSC-TSR compensator shown in figure usually comprises of a *n* TSC banks and a single TCR that are connected in parallel. The rating of the TCR is a chosen of the total SVC rating. The capacitor can be switched into discrete steps, whereas continuous control within the reactive power-span of each step is provided by the TCR thus, the maximum inductive range of the SVC corresponds to the rating of the relatively small interpolating TCR

As the size of TCR is small, the harmonic generation is also substantially reduced, a situation in which all TSC’s and consequently, the associated filters are switched off, an additional non switchable capacitive-filter branch is provided [10].

Figure 3 shows the Simulink model of the TCR/TSC combination, the Simulink model shows a parallel combination of TCR and TSC as this combination automatically provides a smooth current control range from capacitive to inductive values by varying the firing angle of thyristors.

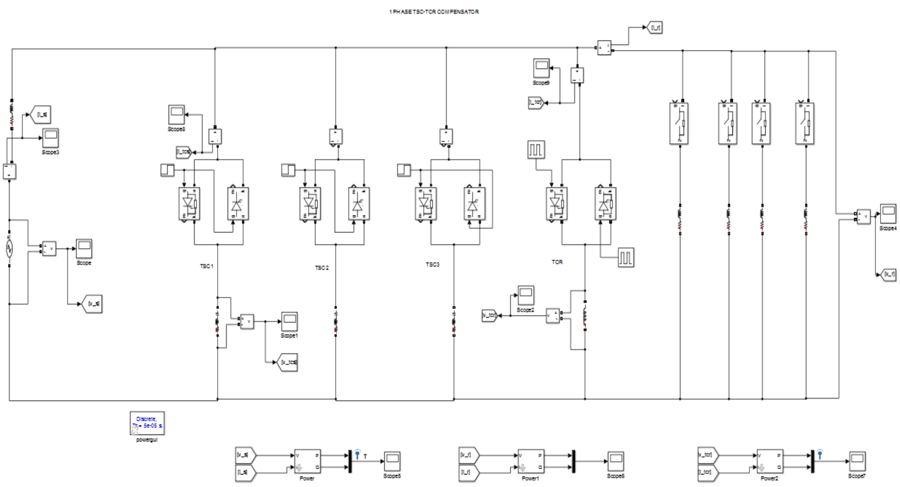

Figure 3: Overall Simulink Model TSC-TSR Compensated SVC.

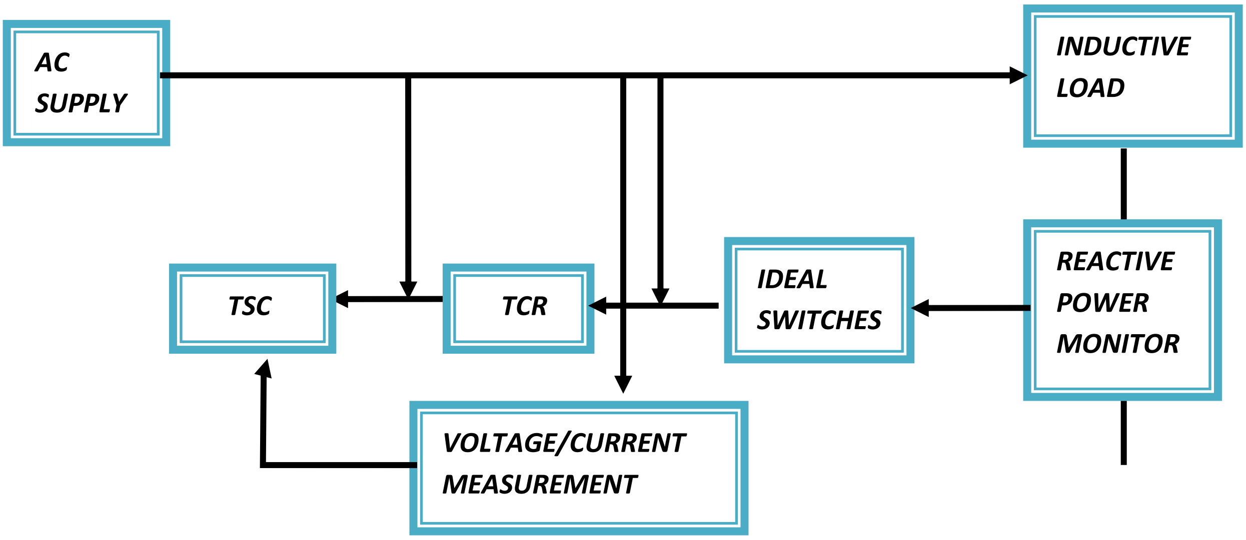

Figure 4: A General TSC-TSR SVC

III. Results

1. TCR voltage and current results

The general effect of the thyristor-controlled reactor is always to make a system working with small reactive power to operate with almost 100% reactive power produced at the reactor unit. It also reduces the general system reactive power is decreased. it can draw-up sustainable reactive power at the primary frequency of the power system network, but it delivers appreciable odd harmonics which could cause many unpleasant consequences, such as over currents, extra losses and noises to telecommunication systems

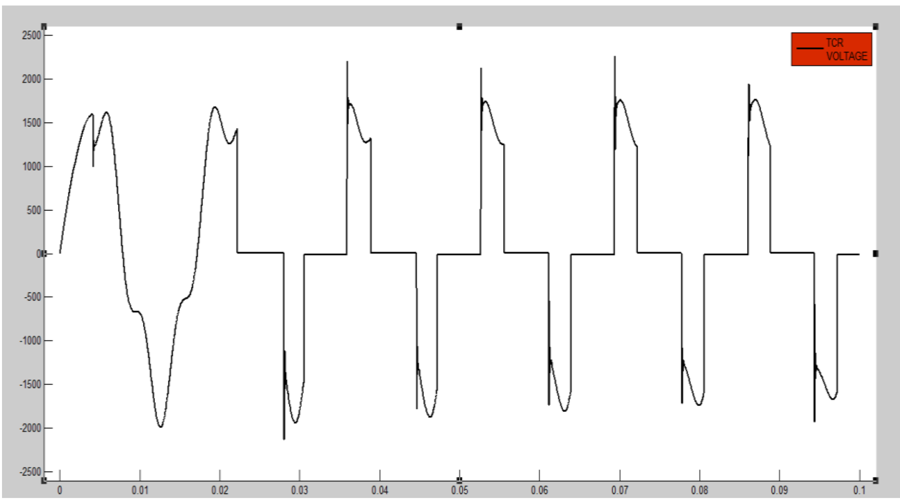

Figure 5: TCR voltage at firing angle of 120 degrees; voltage not at full conduction.

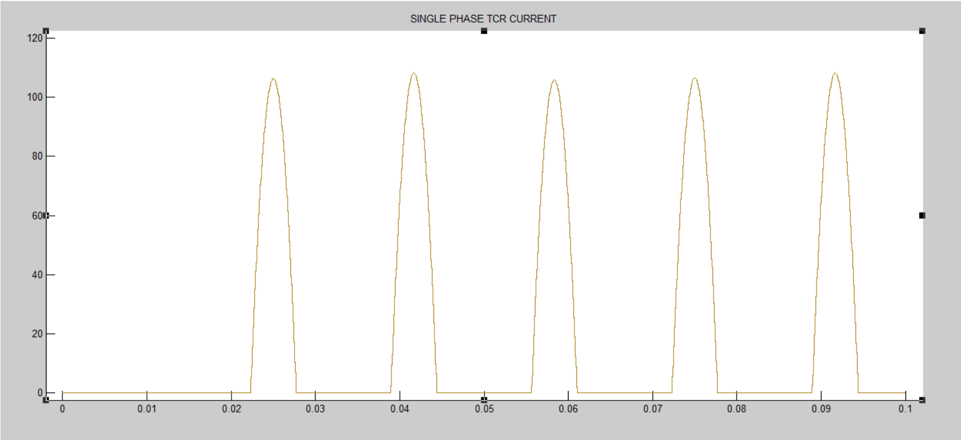

Figure 6: TCR current waveform at firing angle of 120 degrees,it is clear that there is a distortion in the current waveform as TCR is partially conducting.

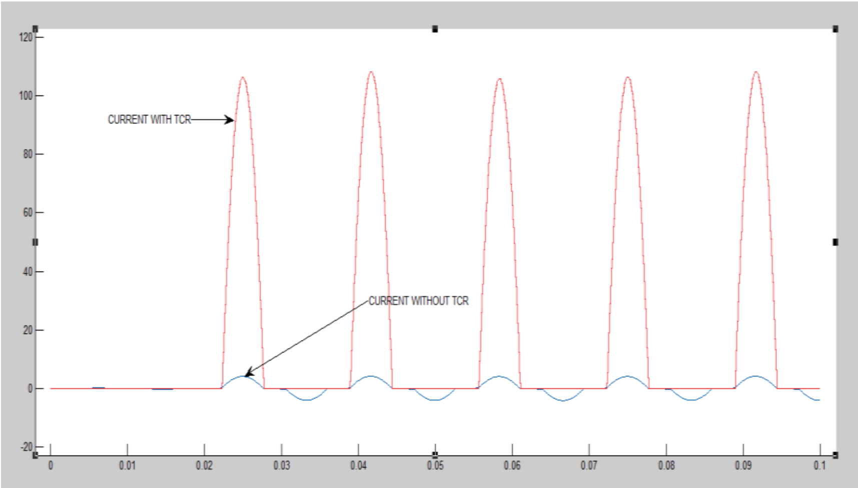

Figure 7: Simulation result showing current with and without TCR.

2. TSC voltage and current results

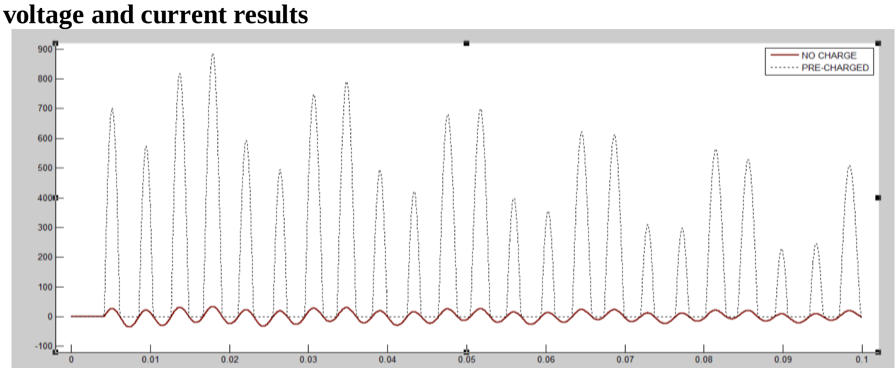

Figure 8: TSC voltage showing current with compensated capacitor and current with no capacitor, the legend indicating No Charge shows current without capacitor, while the legend with pre-charged show the current with compensated capacitor, therefore operating with a TCR gives an amplified voltage.

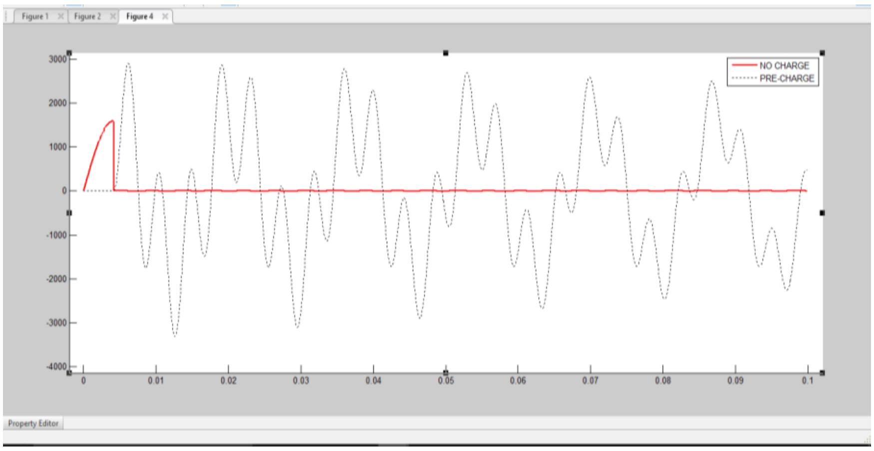

Figure 9: TSC voltage result showing voltage when charged and un-charged.

3. TCR voltage and current at various firing angle

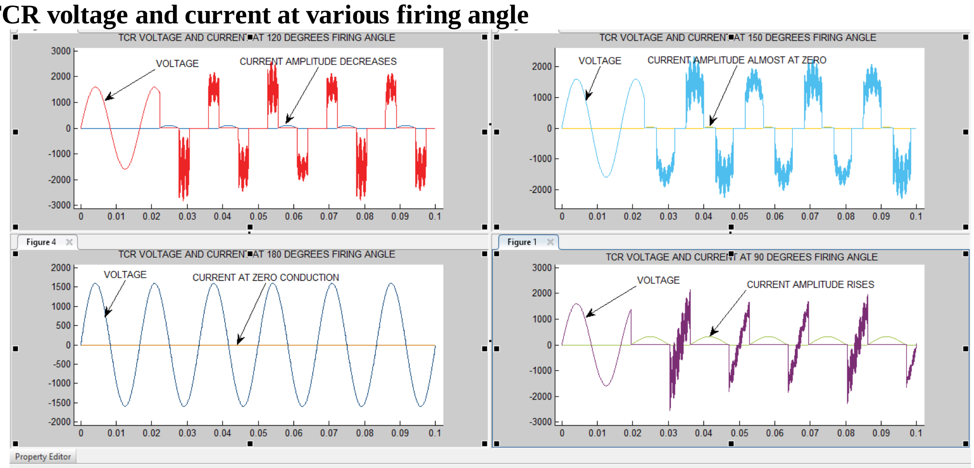

Figure 10: TCR Voltage and Current At $\alpha = 90{,}120{,}150$ And 180 Degree

4. Combined TSC-TCR Static Var Compensator

4.1 Current/Voltage Result

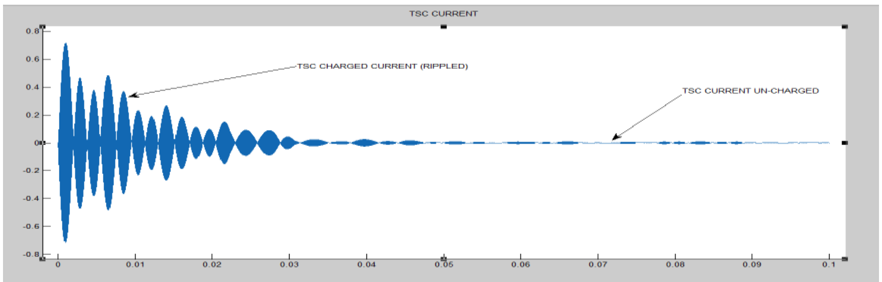

Figure 11: TSC current when capacitors become charged (ON) and then uncharged (OFF).

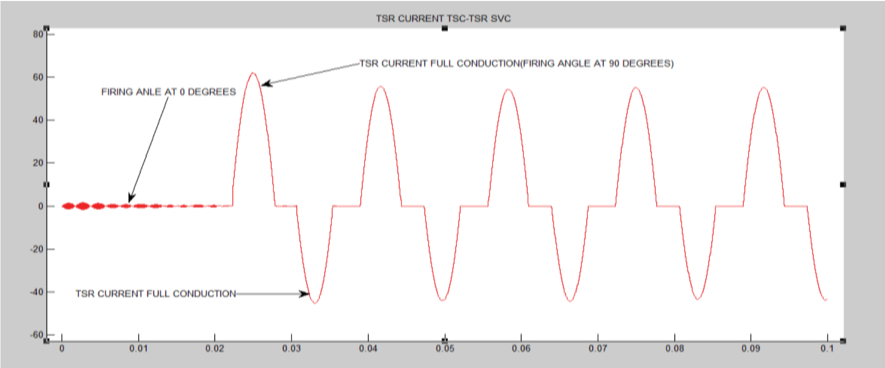

Figure 12: Simulation result showing TCR current at full conduction (firing angle = 90 degrees)

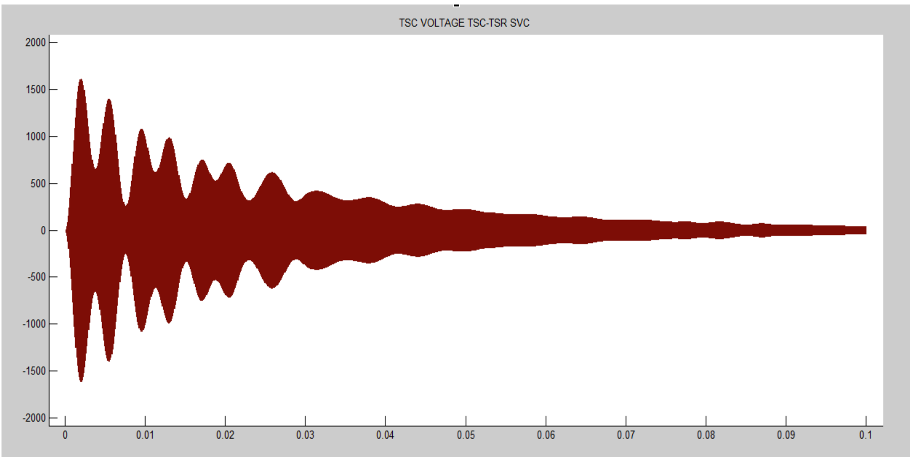

Figure 13: Capacitor Voltage TSC-TCR Compensator: the waveform shows that amplitude charged states until the TSC becomes uncharged and becomes zero.

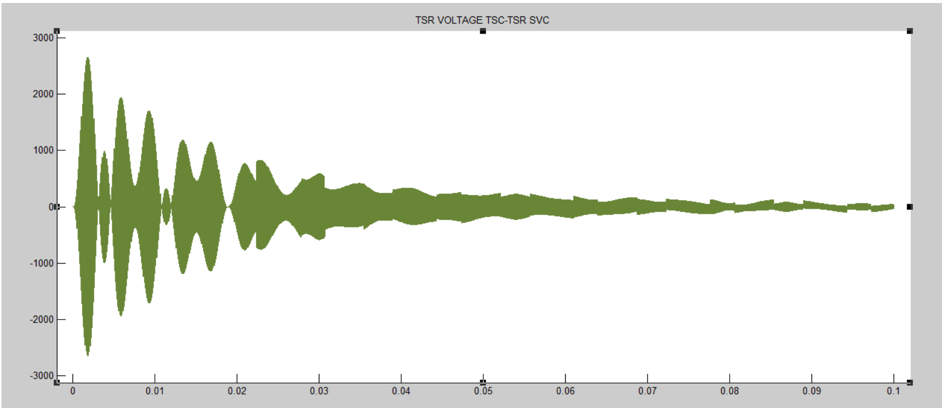

Figure 14: TSR voltage TSC-TSR compensator.

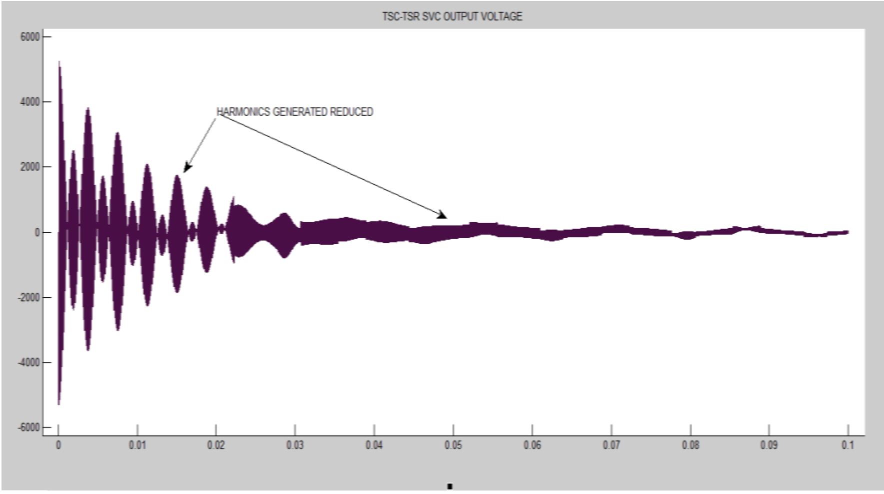

Figure 15: Overall output voltage due to TSC-TSR compensator; the result shows reduced harmonics due to the combined effect of the two compensators, also the result shows a stabilized voltage.

5. Active and Reactive Power TSC-TSR Compensator

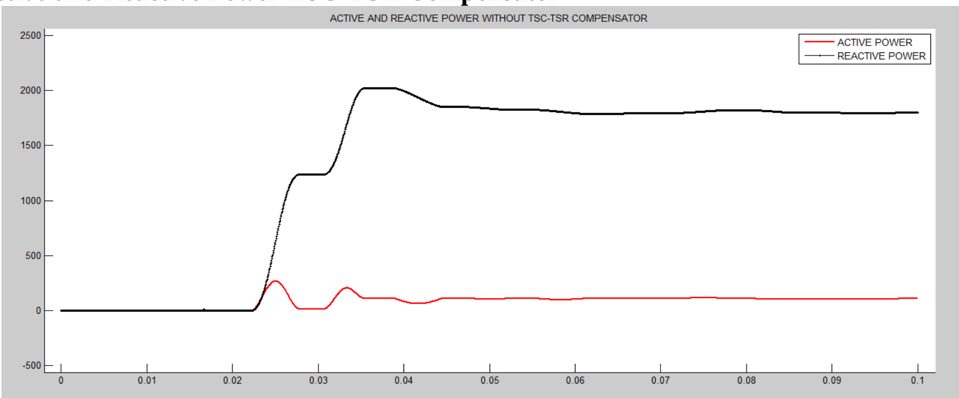

Figure 16: Active and reactive power without the TSC-TSR compensator

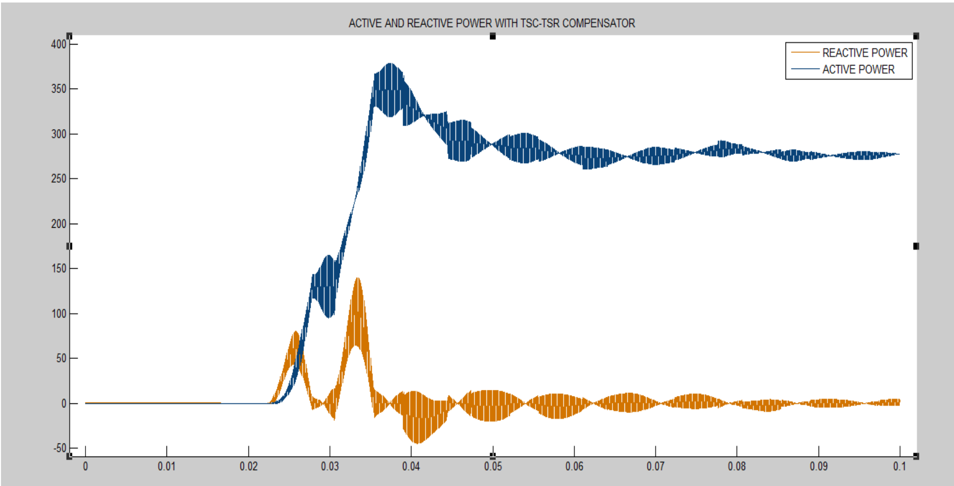

Figure 17: active and reactive power with TSC-TCR compensator.

IV. Conclusion

Static VAR compensators are widely used in power systems. They can be used to regulate the system voltage through compensating the reactive power, and thus stabilize the power system. To study the effect of SVC on power system, we discussed the characteristics of the two different compensators (TCR and TCS) in this report. We also built the Simulink models for both single and hybrid system to discuss the applications of SVC. Through comparisons and analysis, it can be shown that the static VAR compensator can enhance power system stability and power quality. The main results of this paper are as follows:

(1) Building the models of the two types of SVC (TCR and TSC) to discuss the characteristics of the two compensators. The basic features of the two compensators are explained in detail through simulation results.
(2) the effect of SVCs on the active and reactive power of systems was also explained using simulation results through comparing the systems with SVC and without SVC, it is clearly shown that the SVC can regulate and compensate reactive power quickly and effectively.
(4) In conclusion, Static Var Compensator has a significant effect on improving the dynamic stability of power system.

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