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Modelling a Static VAr Compensator consist of TCR and TSC

Onur TURAN[1*], Yavuz SARI[2], Rasit KOKER[3]
[1] Electrical Engineering, Faculty of Electrical & Electronics, Yildiz Technical University, Istanbul, Turkey
[2] Electronics Technology, Hendek Vocational School, Sakarya University of Applied Sciences, Sakarya, Turkey
[3] Electrical and Electronic Engineering, Faculty of Technology, Sakarya University of Applied Sciences, Sakarya, Turkey
[*1]f4920029@std.yildiz.edu.tr, [2]sari@subu.edu.tr, [3]rkoker@subu.edu.tr

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Abstract: As an alternative to traditional solutions, systems that flexible alternating current transmission systems (FACTS) have been developed in order to make electrical energy systems more efficient, to improve stability and power quality, and these systems have been used in different parts of the world including our country. In general, FACTS can be described as systems providing voltage, impedance and phase angle control in AC systems. With the recent studies, the use of modern technology devices such as static VAr compensator and static synchronous compensator is becoming more common in order to ensure the energy quality in power systems. Furthermore, due to the developments in semiconductor technology, static VAr compensation systems have been started to be applied on medium and high voltage side. The most important feature of these systems is that they can compensate without needing reactive power from the grid. In this study, necessary reactive power required by the system provided by using a static VAr compensator consisting of thyristor-controlled reactor and thyristor switched capacitor structures. In the simulation studies, the reactive energy is supplied through the static compensator instead of the voltage source. In this way, unnecessary capacity utilization in the system was prevented. It is recommended to use static VAr compensators especially where there is unbalanced load and instant reactive power is required.

Key words: Svc, Tcr, Tsc, Facts, Power System Stability

TCR ve TSC'den Oluşan Bir Statik VAr Kompansatör Modellemesi

Öz: Geleneksel çözümlere alternatif olarak, elektrik enerjisi sistemlerini daha verimli hale getirmek, kararlılık ve güç kalitesini artırmak için esnek alternatif akım iletim sistemleri (FACTS) geliştirilmiştir ve bu sistemler ülkemizin de içinde bulunduğu dünyanın farklı yerlerinde kullanılmaktadır. Genel olarak, FACTS, AC sistemlerde voltaj, empedans ve faz açısı kontrolü sağlayan sistemler olarak tanımlanabilir. Son yıllarda yapılan çalışmalar ile, statik VAr kompanzatör ve statik senkron kompanzatör gibi modern teknoloji cihazlarının kullanımı güç sistemlerinde enerji kalitesini sağlamak için daha yaygın hale gelmektedir. Ayrıca, yarıiletken teknolojisindeki gelişmeler sonucunda orta ve yüksek gerilimlerde statik VAr kompanzasyon sistemlerinin uygulanmasına başlanmıştır. Bu sistemlerin en önemli özelliği şebekeden reaktif güce ihtiyaç duymadan kompanzasyon yapabilmeleridir. Bu çalışmada, sistemin ihtiyaç duyduğu reaktif güç tristör anahtarlamalı kapasitör ve tristör kontrollü reaktör yapılarından oluşan bir static Var kompanzatörü kullanılarak sağlanmaktadır. Simülasyon çalışmalarında, reaktif enerji, voltaj kaynağı yerine statik kompansatör yoluyla sağlanır. Böylelikle sistemde gereksiz kapasite kullanımı önlenmiş olmaktadır. Özellikle dengesiz yüklerde ve anlık reaktif gücün gerekli olduğu durumlarda statik VAr kompansatörlerinin kullanılması tavsiye edilir.

Anahtar kelimeler: Svc, Tcr, Tsc, Facts, Güç Sistem Kararlılığı

1. Introduction

In recent years, due to high switching speeds, power electronics components have been used in electrical power systems compensation applications. Thus, it is foreseen that voltage collapses can be prevented and stability can be increased. The developments in the elements of power electronics system have made a revolutionary impact on the electric power systems all over the world. The use of thyristors in power systems for control and switching operations has resulted in new generation thyristor-based rapid operating devices. These new devices, based on power electronics, enable the controllable, stable and power transfer capability of alternating current transmission systems, called flexible alternating current transmission systems (FACTS). FACTS devices are installed to improve power system stability. Power system stability is the major part of electrical engineering work. Basically, it depends on the minimum amount of loss by the generation of electricity and the transmission from the sending end to the receiving end according to the consumer need. The power at the end of the consumer is usually subject to changes due to changes in the load or disturbances along the transmission line. Therefore, the term power system

* Corresponding author: f4920029@std.yildiz.edu.tr. ORCID Number of authors: [1]0000-0001-6523-3428, [2]0000-0002-5212-4246, [3]0000-0002-3811-2310

stability is extremely important and is used to describe the ability of the system to stabilize the operation as soon as possible after some kind of temporary disturbance [1-2].

The correction of the power factor of fast-acting and unbalanced loads with traditional electro-mechanical compensation mechanisms is problematic in order to ensure power system stability. One reason for this is that conventional compensation systems (with reactive power control relay and contactor) cannot respond immediately to the load of the reactive power demand and that the required capacitive reactive power cannot be compensated from the compensation system. On the other hand, in the case of unbalanced loading, there is no possibility of three-phase systems to respond to the needs of each phase. With static VAr compensation systems, instant compensation of unstable loads can be made quickly, such as spot welding machine, arc furnaces, port cranes used in sectors such as automotive, glass, cement, iron and steel, where power factor can show frequent and large changes [3-4].

2. Basic Principles of Static VAr Compensator Systems

SVC is one of the FACTS devices, which are connected in parallel to the power system, which generate or absorb reactive power from the system to control power system parameters such as voltage. They are safe and operationally flexible, capable of producing or consuming continuous reactive power, operating at an unlimited range, with high response times [5]. SVCs are mainly used in power systems to improve voltage control and system stability. In recent years, many researchers have proposed the technique of improving stability with SVC to extinguish electromechanical fluctuations in power systems [6-7-8]. Generally the SVC structure consists of a combination of thyristor controlled reactor (TCR) and / or thyristor switched capacitor (TSC) structures. Figure 1 shows general schematic block diagram of SVC control systems. In this study, a static VAr compensator formed by TCR and TSC structures is modeled.

The problem of voltage fluctuations caused by arc furnaces during steel production has always been serious concern about power quality all over the world. SVC systems are widely used today, especially in facilities such as arc furnaces and rolling mills where fast-changing loads has. The reactive power consumption of the arc furnaces becomes quite dynamic due to the random variation of the arc length during the melting of the scrap. Besides the use of SVC improves the transient stability of the transmission line and thesis where it use [9-10].

On the other hand, static VAr compensator systems are also used in wind power plants where improve the voltage stability and prevent the wind power plant from being disabled in the case of voltage drops caused by the transmission lines [11].

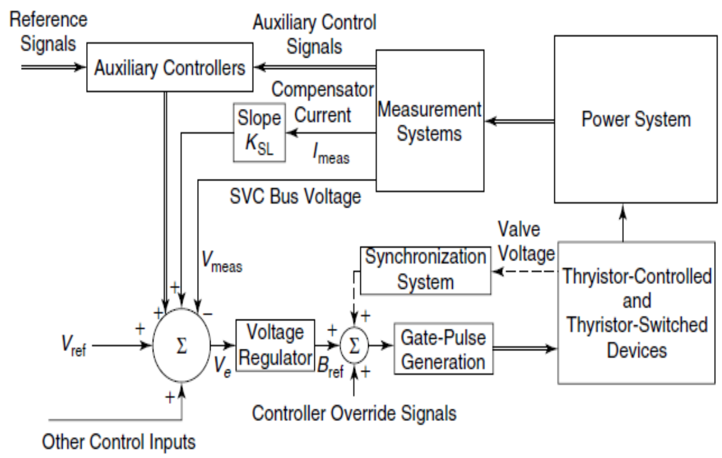

Figure 1. General schematic block diagram of SVC control systems [2-4].

In voltage control cycles, the SVC can effectively switch off power system surges and improve the stability of power systems. An ideal SVC is defined as a controller that does not have an active and reactive power loss, the voltage is equal to the reference voltage, it cannot be changed and can respond very quickly.

2.1. V-I Characteristic of the SVC

The variation of SVC bus voltage and SVC current or reactive power is defined by the steady state and dynamic properties of SVC. Figure 2 shows the voltage–current characteristic of the SVC.

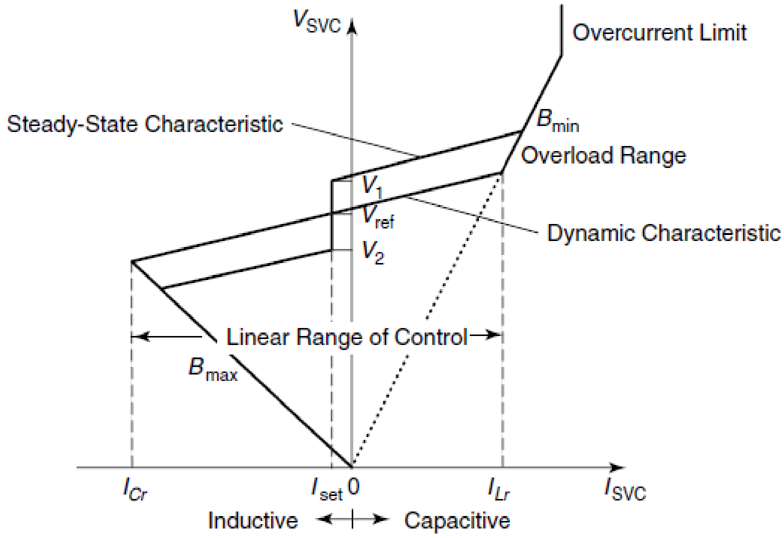

Figure 2. The voltage–current characteristic of the SVC [4].

At the reference voltage V_{ref}. the voltage is regulated while the SVC susceptance (B) continues among the maximum and minimum susceptance values enforced by the total reactive power of capacitor banks (B_{cmax}) and reactor banks (B_{lmax}) [12].

SVC V-I curve can be described following three equations (1-3).

$$V = V_{ref} + X_s . I \qquad -B_{cmax} < B < B_{lmax} \tag{1}$$

$$V = -\frac{I}{B_{cmax}} \quad SVC\ capacitive\ B = B_{cmax} \tag{2}$$

$$V = \frac{I}{B_{lmax}} \quad SVC\ inductive\ B = B_{lmax} \tag{3}$$

3. TCR and TSC Structures

3.1. TCR Structure

One of the most significant blocks of thyristor-based SVCs is TCR. Although it can be used alone, to provide quick and continuous control of reactive power across the selected lagging-to-leading range, it is more often used with fixed or thyristor switched capacitors [4].

As denoted in Figure 3, a fundamental single phase TCR contains a pair of thyristor valves anti-parallel connected in series with a linear air-core reactor as T_1 and T_2. The attitude of the anti-parallel–connected thyristor pair is similar with a bidirectional switch. In positive half-cycles the thyristor valve T_1 conducts and in negative half-cycles of the supply voltage the thyristor valve T_2 conducts. The measurement of the firing angle of the thyristors can be implemented from the zero crossing voltage seen across its terminals [2-4-13].

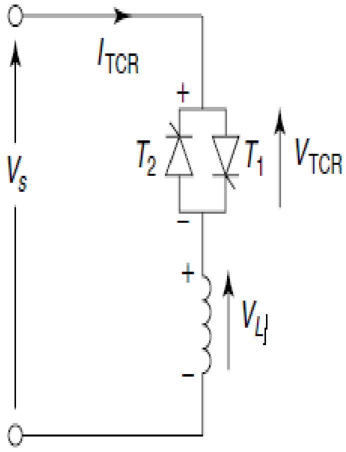

Figure 3. Basic structure of a TCR [4]

In the thyristors inside the systems which generally constitute the static VAr control system, it is very important to know which intervals to trigger. In the first half of the alternance, ie in the triggers to be performed below 90º, the inverted thyristor groups generate DC current, so that the thyristors connected to each other symmetrically are disrupted. Also, a change in the trigger angle after a thyristor has been transmitted can only take place at the next period. This is called the dead time of the thyristor [4].

There is a relationship between the trigger angle α and the transmission angle σ as follows.

$$\alpha + \frac{\sigma}{2} = \pi \tag{4}$$

TCR current can be expressed as equation 5.

$$i(t) = \frac{1}{L}\int V_s\,(t)dt + C \tag{5}$$

Boundary condition $i(\omega t = \alpha) = 0$;

If we solve Equation 5 according to boundary condition and then do fourier analysis we get;

$$I_1(\alpha) = \frac{V}{\omega L}(1 - \frac{2\alpha}{\pi} - \frac{1}{\pi}\sin 2\alpha) \tag{6}$$

Equation 6 can also be written as;

$$I_1(\alpha) = VB_{TCR}(\alpha) \tag{7}$$

Where;

$$B_{TCR}(\alpha) = B_{MAX}(1 - \frac{2\alpha}{\pi} - \frac{1}{\pi}\sin 2\alpha) \tag{8}$$

$$B_{MAX} = \frac{1}{\omega L} \tag{9}$$

Substituting Equation 4 in Equation 6 gives the alternative expression of the fundamental component of the TCR current:

$$I_1(\sigma) = VB_{MAX}(\frac{\sigma - sin\sigma}{\pi}) \tag{10}$$

$$I_1(\sigma) = VB_{TCR}(\sigma) \tag{11}$$

As a result, the TCR susceptance value; using the Equations 10 and 11 is expressed as in Equation 12.

$$B_{TCR}(\sigma) = B_{MAX}\left(\frac{\sigma - sin\sigma}{\pi}\right) \tag{12}$$

Control characteristics of the TCR susceptance, B_{TCR} is shown in Figure 4.

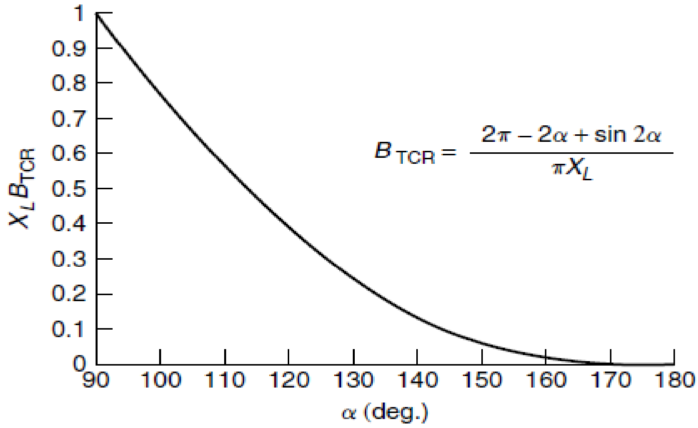

Figure 4. Control characteristics of the TCR susceptance, B_{TCR} [2-4]

3.2. TSC Structure

Thyristor switched capacitors (TSC) are generally used instead of constant capacity thyristor controlled reactor (FC-TCR). TSC is also a subset of SVC, where thyristor-based ac switches are used to turn on and off the shunt capacitor units (without firing angle control), unlike shunt reactors, to provide the necessary step change in the reactive power supplied to the system. The shunt capacitors cannot be changed continuously with variable firing angle control. Basic structure of a TSC is shown in Figure 5.

Generally single or more than one TSC structure is connected to the same load bus in parallel (the reactive power values of TCS are chosen approximately equal to each other). As the demand for reactive power increases, the thyristors are triggered and the required number of TSCs are activated. We can say that TSCs are commissioned in sequence step by step.

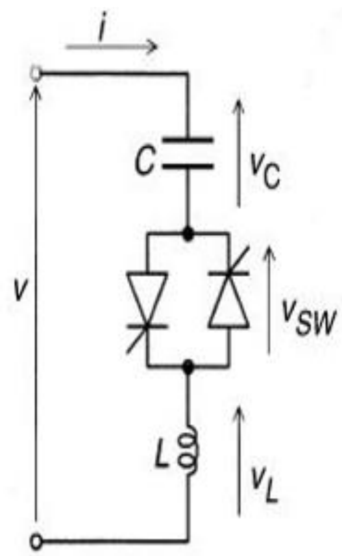

Figure 5. Basic structure of a TSC [4]

The operating logic of the TSC is done by switching on and off the capacitor, which is pre-charged to the peak value of the source voltage [14]. Under steady-state conditions, when the TSC branch is connected to a sinusoidal AC voltage source $V(t) = Vsin\omega t$ and the thyristor valve is closed, the current in the branch is given by (13);

$$i(\omega t) = V\frac{n^2}{n^2-1}\omega C\cos\omega t \quad (13)$$

$$n = \sqrt{\frac{X_C}{X_L}} \quad (14)$$

$$V_c = V\frac{n^2}{n^2-1} \quad (15)$$

4. Simulation Studies

In this paper, in order to analyze a static VAr compensator behavior which consist of a TCR and 3 TCS Matlab/Simulink program used. Modeled SVC system single line diagram is shown in Figure 6.

The SVC connected to 154 KV, 50 Hz, 6000 MVA short circuit level transmission line with a 154KV/15.8 KV, 85 MVA coupling transformer. SVC consist of a 100 Mvar TCR bank and three 80 Mvar TSC banks (TSC_1, TSC_2, TSC_3) connected on the secondary side of the transformer.

Here, with the SVC, 3 TSCs are controlled 240 MVAr (each of them has 80 MVAr capacity) capacitive reactive power and a TCR 100 MVAr inductive reactive power. This means that the control field of the SVC is 100MVAr inductive and 240 MVAr capacitive. Therefore the working area of the system is between +240 MVAr / -100 MVAr. As seen from the single-line diagram, the SVC system was installed on the secondary side of the transformer.

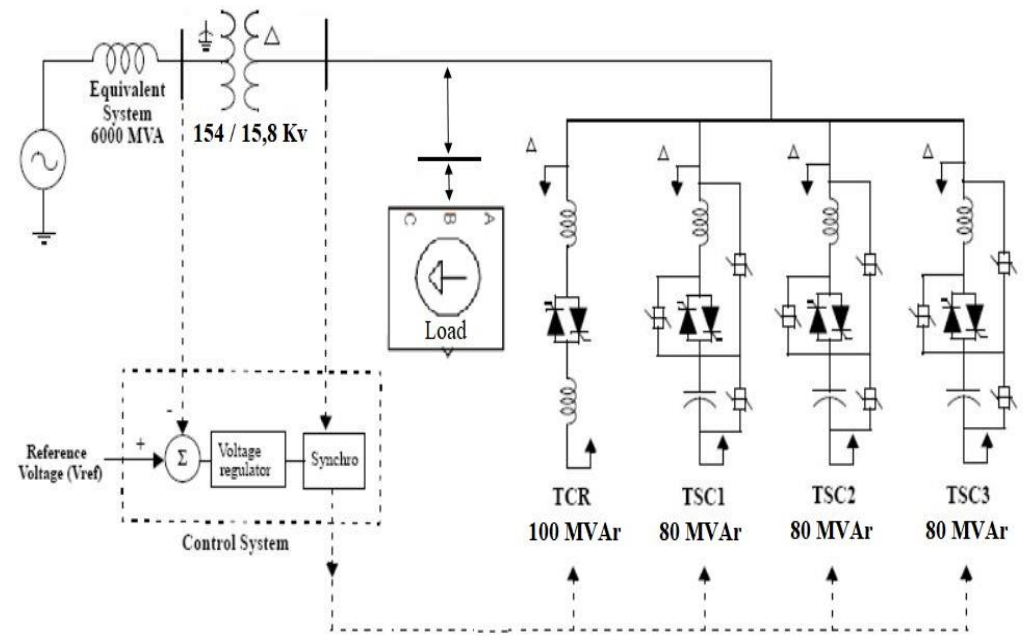

Figure 6. Modeled SVC system single line diagram.

When the thyristor controlled reactor is activated, it is ensured that the triggering angle of TCR is above 90º. In this way, the formation of DC current is prevented from the connections of the thyristors which connected opposite to each other. On-off controls of TSCs have been made compatible with the TCR. In this way, synchronous operation of the system is provided.

Besides in this paper, a dynamic load which has 55-40MW active power and 6-10 MVAr reactive power capacity used in order to see SVC behavior under the dynamic load condition. Modeled dynamic load swings as its stated Figure 7 and Simulink model of designed system is shown in Figure 8.

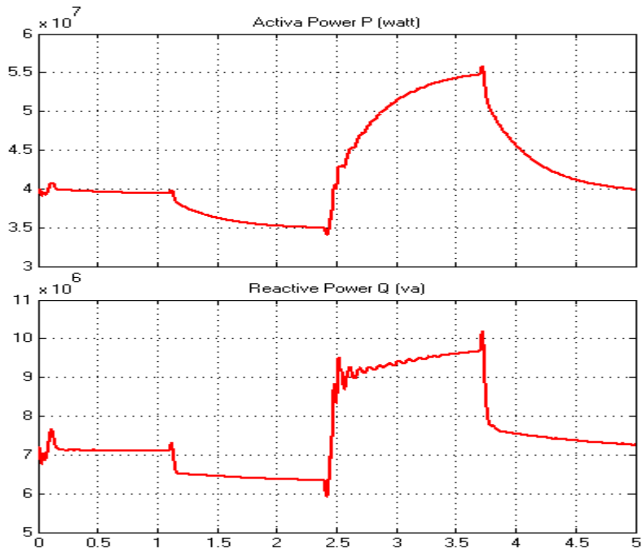

Figure 7. Dynamic load active and reactive capacity swings.

In the designed model, SVC controller block monitors the primary voltage and sends appropriate pulses to the all thyristors bank in order to obtain the susceptance required by the voltage regulator. For one phase TCR and TSC thyristors banks are shown in the Figure 9 a. and 9 b. respectively and designed SVC system controlling unit is shown in Figure 10.

Total 24 thyristors are controlled in the modeled system. There are 6 thyristors in each phase and the thyristors are activated with the appropriate firing pulses in order to produce the required susceptance value in the voltage regulator section.

Measurement system: measures the voltage of the primary side of transformer. This system calculates the fundamental voltage value using a discrete fourier transform in a single-count window to calculate the fundamental voltage value. This unit is controlled by PLL (phase locked loop) to take into account the changes in system frequency.

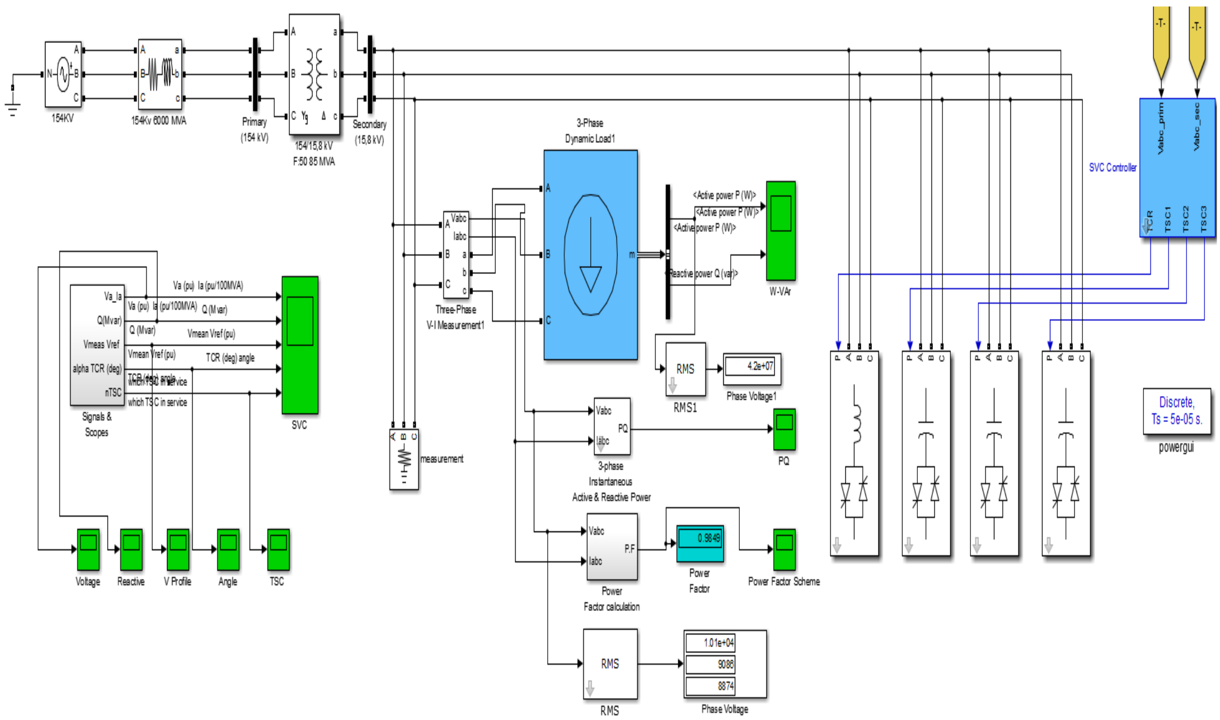

Figure 8. Simulink model of designed system

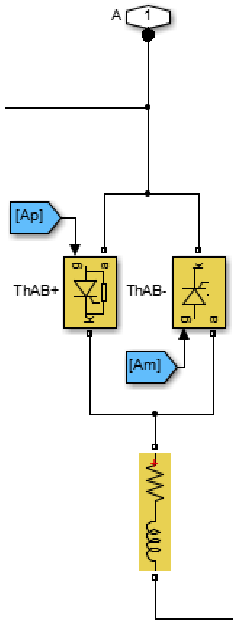

Figure 9 a. TCR bank

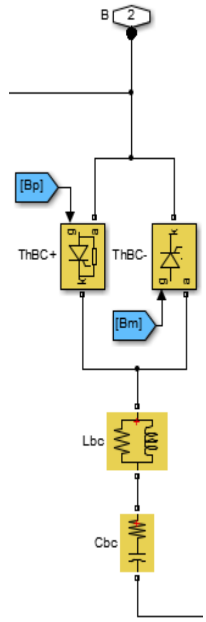

Figure 9 b. TSC bank

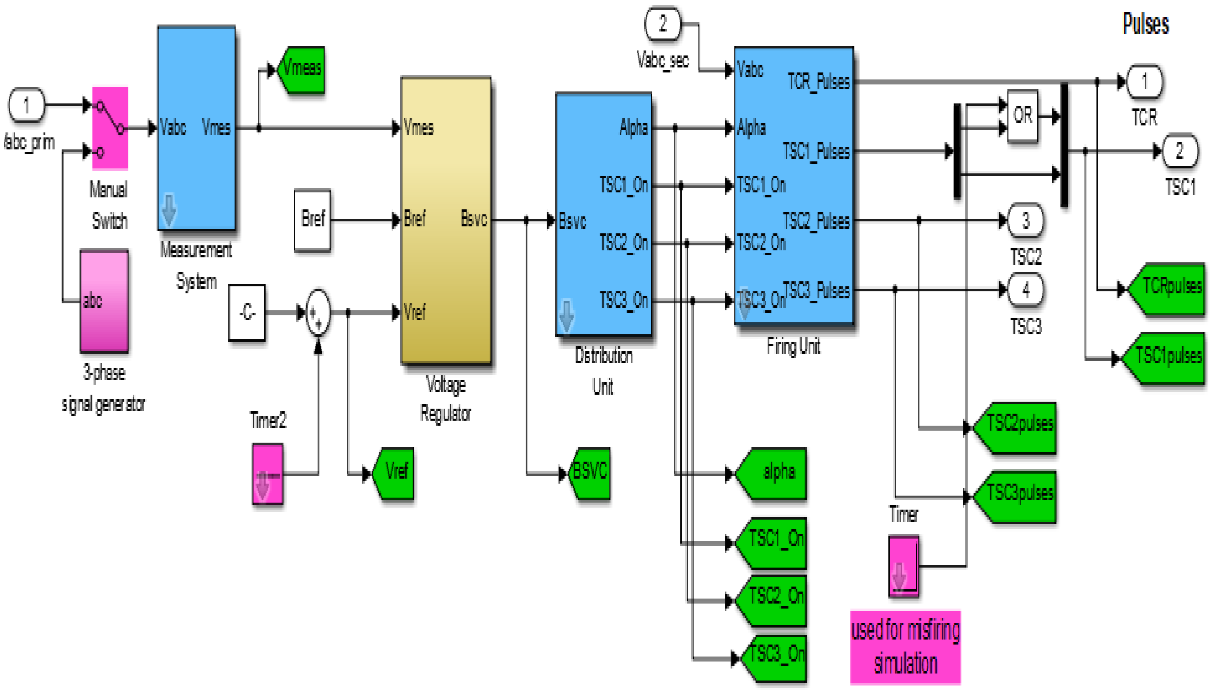

Figure 10. Designed SVC system controlling unit [15].

Voltage regulator: This unit regulates primary side voltage regulation through PI regulator.

Distrubution Unit: Uses B_{svc}, the susceptibility that calculated by the voltage regulator to determine the triggering angle α and the three TSC's on-off status.

Firing Unit: This unit consists of three independent subsystems, which are AB, BC and CA where one for each phase. Each subsystem consists of a pulse generator for each of the TCR and TSC branches and a PLL synchronized to line-line secondary voltage. Pulse generators generate pulses by using the triggering angle α and the TSC on / off information which coming from the distribution unit. Designed SVC system firing unit is shown in Figure 11.

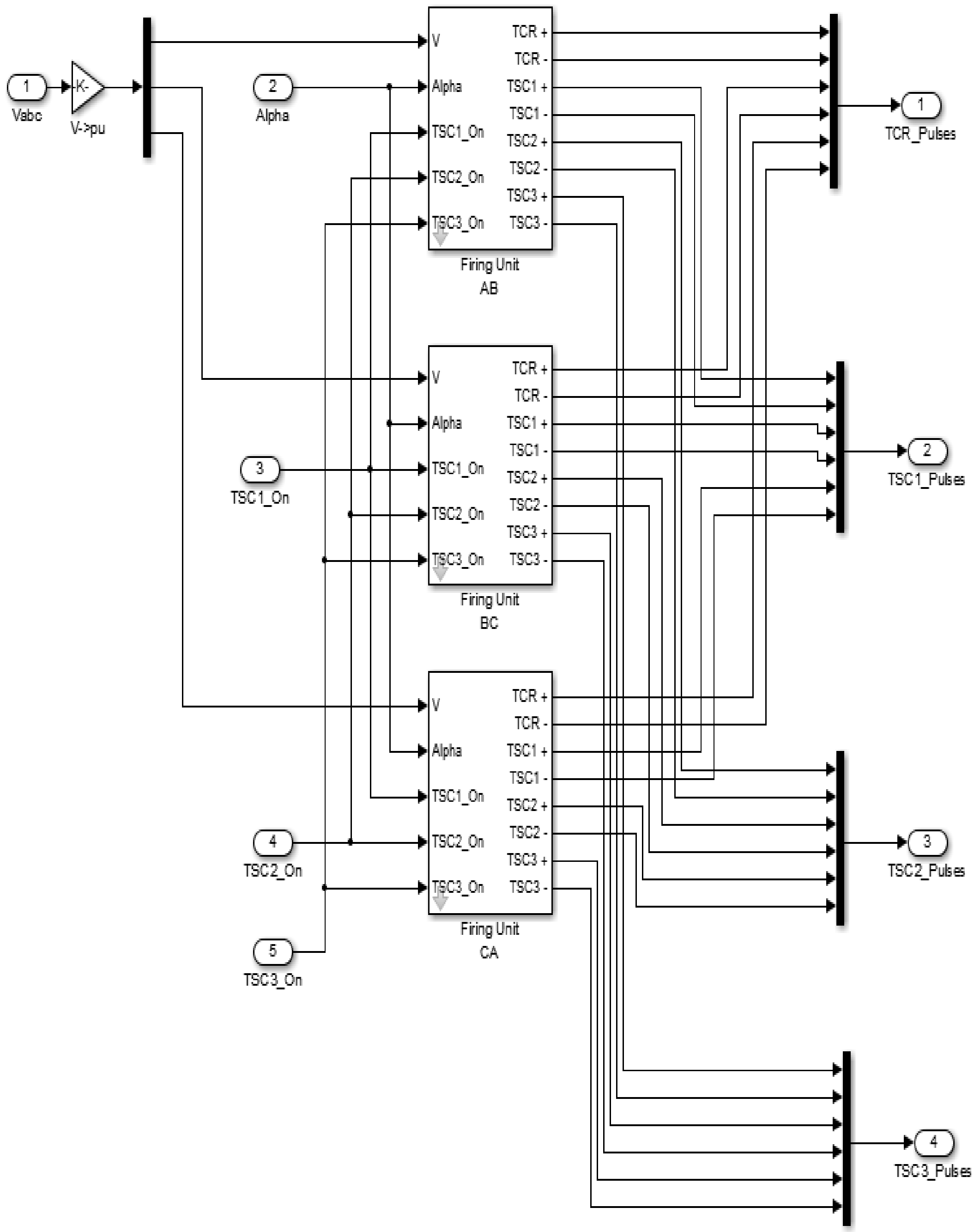

Figure 11. Designed SVC system firing unit [15].

5. Simulation Results

In this study, the simulation time set to 5 seconds. In addition, the adjustable voltage source is arranged according to the values in Table 1. Simulation results are shown in Figure 12 a, b, c, d, e.

Table 1. Programable voltage source parameter values

Disturbance moment (s)	0	1.1	2.4	3.7	5
Corresponding voltage (p.u.)	1,0	1,06	0,93	0,98	1,0

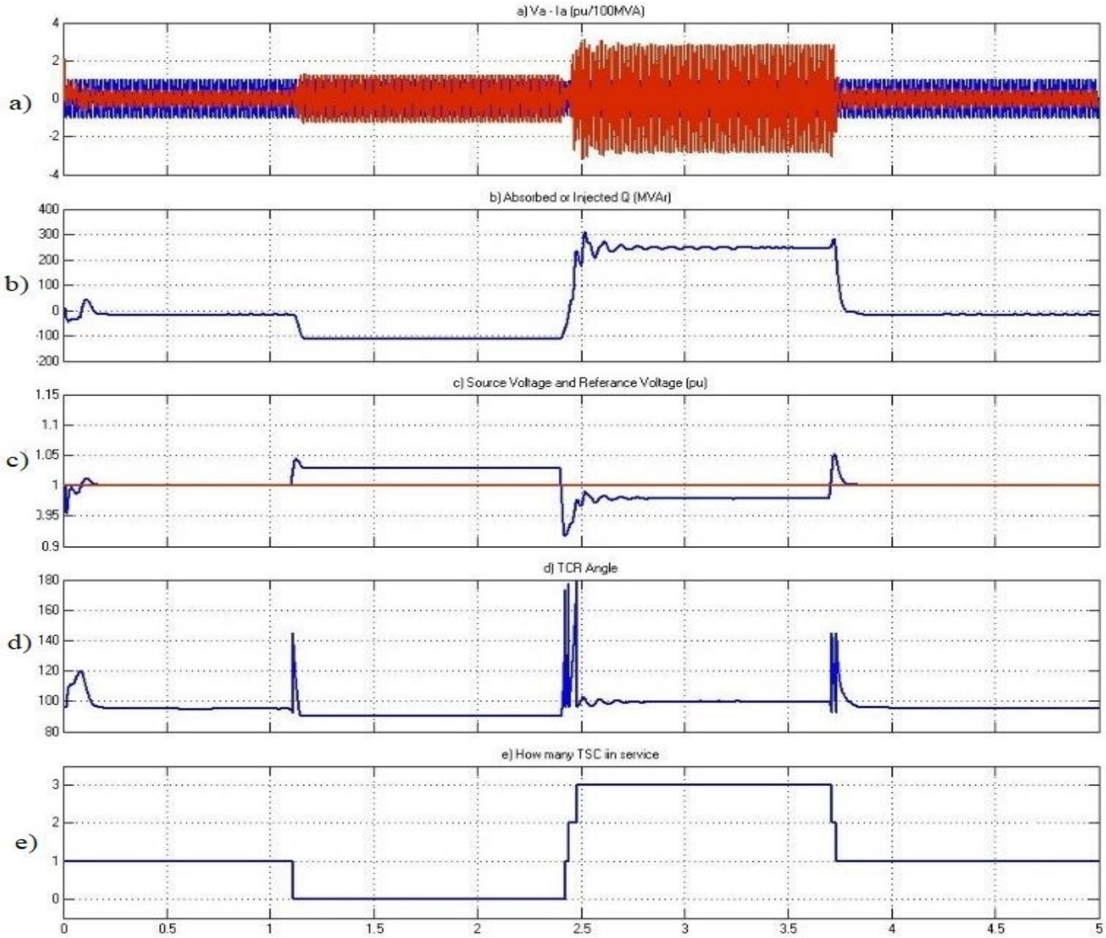

Figure 12. Simulation results a) Transformer primary side voltage and current b) SVC reactive power response c) Referance and source voltage condition d) Firing angle of TCR e) Number of TCS conduction condition

When the results of the simulation are examined at 1,1. seconds; the source voltage suddenly increases to 1.05 Pu. At this point it is seen that the Static VAr compensator compensates the voltage to the value of 1,03 pu by switching on the TCR with absorbing 90 Mvar reactive power. At this point all TCS are out off service.

The source voltage is suddenly decreases to 0.93 pu at 2.4. seconds. The SVC generates approximately 300 MVAr reactive power, increasing the voltage to 0.98 pu. At this point, all TSCs are activated gradually within 0.1 seconds. The TCR absorbs approximately 40% of the nominal reactive power (α = 100 degrees).

Figure 12. d and e show how TSCs are opened and closed in sequence. Each time a TSC is switched on. The TCR angle α, changes from 90 degrees (full conduction) to 180 degrees (no conduction).

Finally, as shown in Figure 12 c., the voltage is increased to 1.0 pu and the SVC reactive power is reduced to zero at 3,7. seconds.

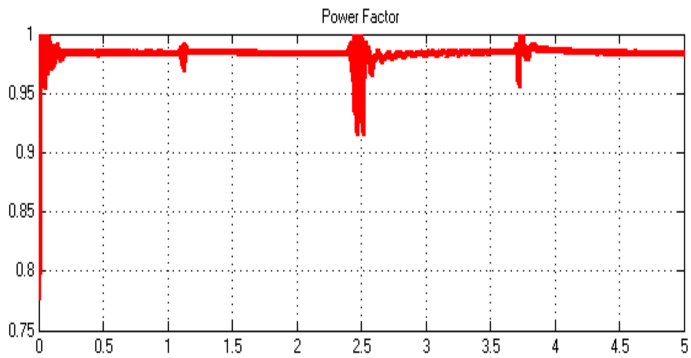

Figure 13. Measured system power factor

As it seen that Figure 13 with SVC system average power factor (φ) has increased to 0,99. This an important improvement for the secondary side voltage of transformer [16].

With these simulation results, we prove that static VAr compensation systems can solve many problems such as power factor correction, active-reactive power problems in power systems.

6. Conclusion

For the control of the parameters of the power transmission system in conventional power systems the methods used are sometimes insufficient in dynamic system conditions. Therefore, it is necessary to ensure that the system is adapted to the new conditions by intervening rapidly and effectively in the power system under dynamic conditions.

Static VAr compensator systems compensates the reactive power in the system by using modern power electronics and control systems where reactive power is needed or where reactive power is required. By using static VAr compensation systems, quality and reliability are increased in power networks, and in an inductive and capacitive region, an effective compensation process is performed in a shorter time than classical compensation systems.

In this study, modeling system with Matlab/Simulink environment simulations revealed that static VAr compensator provides voltage regulation, corrects the power factor and prevents the need for reactive power supply from the grid and prevents unnecessary capacity increase and consequently additional costs.

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