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Modelling and Simulation of Static VAR Compensator

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Abstract: *In recent years, greater power demand has been placed on the transmission network and it will continue to increase because of advances in technology giving rise to products which requires electrical energy. Increase in power demand, absence of long term planning of network, need of open network for the generation unit etc.; degrades the quality of power supply. The FACTs (Flexible AC Transmission system) technology is essential to alleviate some of the difficulties. FACTs technology does not consist of a single controller but it is collection of controllers which can be applied individually or collectively. This paper presents the modelling and simulation of one of the type of FACT devices. The configuration of SVC used in this paper is Fixed Capacitor with Thyristor Controlled Reactor (FC-TCR). This have been implemented using Simulink model.*
Keywords – *Controller, FACTs, FC-TCR, Power demand, SVC*

I. Introduction

The ability of FACTs controllers is to control the interrelated parameter that includes impedance of transmission line current, voltage, phase angel and the damping of oscillation at various frequencies below the rated frequency. FACTs controllers can enable a line to carry power closer to its thermal rating. The Static VAR Compensator (SVC) is shunt connected device of the FACTS family, was first demonstrated in Nebraska in 1974[1]. It uses for reactive power compensation [2]. The purpose of this reactive compensation is to change the natural electrical characteristics of the transmission line to make it more compatible with prevailing load demand. It is an automated impedance matching device, designed to bring the system closer to unity power factor.

BENEFITS:
- Voltage support, and regulation
- Transient stability improvement
- Power transfer capability increases and line loss minimization
- Power system oscillation damping

FACTs controllers can be divided into four categories:
1. Series Controllers
2. Shunt controllers
3. Combined Series-Series Controller
4. Combines Series-Shunt Controller

The shunt controllers may be a variable impedance, variable source. Shunt controllers inject the current into the system. Variable shunt impedance causes the variable current flow and thus injection of variable reactive power to the system.

A shunt connected reactive power absorber or generator whose output is adjusted to exchange the inductive or capacitive current to maintain the specific parameters of the line. SVC is based on thyristor without turn-off circuit. It included with different controllers like thyristor Switched Reactor (TSR) and Thyristor Controlled Reactor (TCR) for absorbing the reactive power form load. Thyristor Switched Capacitor (TSC) for supplying the reactive power to load and FC-TCR for both purposes.

Houari Boudjella, et.al. [1], have modeled the small disturbances including control action, resulting in determination of the required rating of SVC for the given subject matter. Jitendra Kumar Dash [3], has concluded that SVC controls the dynamic performance and voltage regulation of the power system. The range of reactive power control can be increase by using combination of TCR and FC system.

Table no 1: Proposed FACTS device in India

State	Location	Voltage level	MVA Rating
Tamilnadu	Tappagndu	420kV	300
Andhra Pradesh	Kondapur	420kV	150
Maharashtra	Kolhapur Dhule	765kV 220kV	240 250
Karnataka	Davangiri Narendra	420kV 765kV	150 240

Table no 2 : Future Projects in India

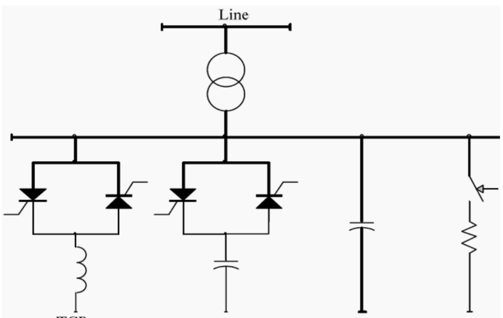
Location	Voltage Rating	MVA Rating	Estimated cost
Kolhapur	400kV	400	211.75cr
Udamlpe	400kV	400	211.75cr

II. Problem Formulation

a. FC-TCR:

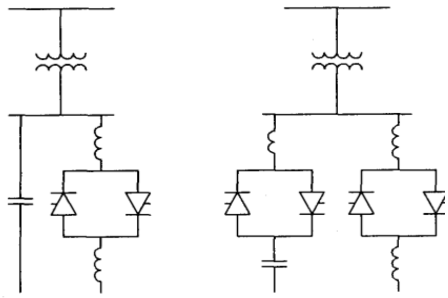
A VAR generator arrangement using fixed capacitor with thyristor controlled reactor (FC-TCR) consists with bidirectional thyristor valve along with a fixed reactor (usually air core type structure) and a fixed capacitor. A fixed capacitor acts as a filter network which has capacitive impedance at a fundamental frequency to generate the reactive power required by the load. Also, it provides the low impedance path at a selected frequency (to remove dominant harmonics generated by TCR) [4]. A thyristor valve can bring into the conduction by simultaneous application of gate pulse. It can block the conduction immediately after the natural current zero. The current in the reactor can be controlled from maximum to minimum by firing pulse. That is the closure of anti-parallel thyristor valve is delayed with the peak of the voltage in each cycle, thus the duration of conduction is controlled.

When α=0, the thyristor valve switch closes at the peak of the applied voltage (V) the resulting current in reactor is maximum. As the delay angle (α) increases, corresponding decrease in the reactor current and the conduction angle (σ = π-α). At maximum delay, α = π/2 the current reaches to zero. By controlling the firing angle of thyristors, the fundamental component of the current, thus the reactive power can be regulated.



TCR TSC FC

Fig.1 Classification of SVC



FC-TCR TSC-TSR

Fig.2 Combination of different types of SVC

b. Mathematical operation:

The amplitude of fundamental reactor current $I_L(\alpha)$ can be expressed as a function of α,

$$I_L(\alpha) = \frac{V}{\omega L}\left(1 - \frac{2}{\pi}\alpha - \frac{1}{\pi} sin\, sin\, 2\alpha\right)$$

Where L= Inductance of thyristor controlled reactor, w= angular frequency of V. TCR can control the fundamental current continuously from zero to maximum as if it was a variable reactive admittance ($B_L(\alpha)$). Thus $B_L(\alpha)$ can be given as

$$B_L(\alpha) = \frac{1}{\omega L}\left(1 - \frac{2}{\pi}\alpha - \frac{1}{\pi} sin\, sin\, 2\alpha\right)$$

This equation states that at each of the α an effective admittance can be defined, which determines the $I_L(\alpha)$. The maximal magnitude of the V and $I_L(\alpha)$ can be limited by the rating of all the power components (reactor and thyristor valve). FC-TCR provides the maximum capacitive var output when then thyristor valve is cut-off ($\alpha = \pi/2$). To reduce this capacitive var output, $I_L(\alpha)$ increases by reducing α. At zero Var output, the $I_C(\alpha)$ and $I_L(\alpha)$ become equal and thus the inductive and capacitive reactive power cancel out. A further decrease in α, $I_L(\alpha)$ becomes more than $I_C(\alpha)$, thus net inductive Var output provided.

FC-TCR has larger power losses in the inductive region because of large inductive current. Also, fixed capacitor is found to have adverse effect on power system behavior under large system disturbance [5]. To address this small capacitor is replaced by TSC, for inductive region capacitor is totally disconnected, and for capacitive region the number of capacitor switched as per the demand.

III. Simulation of SVC

The models for 1-ph and 3-ph have been shown in the figures along with the variation of the TCR branch current resulting in reactive power variation. It can be seen that there is decay in TCR branch current as the firing angle (α) is increased. The decaying current gives reduced lagging KVAR to the system thereby increasing the system power factor. Ideally the firing angle (α) is minimum during light loading of the system.

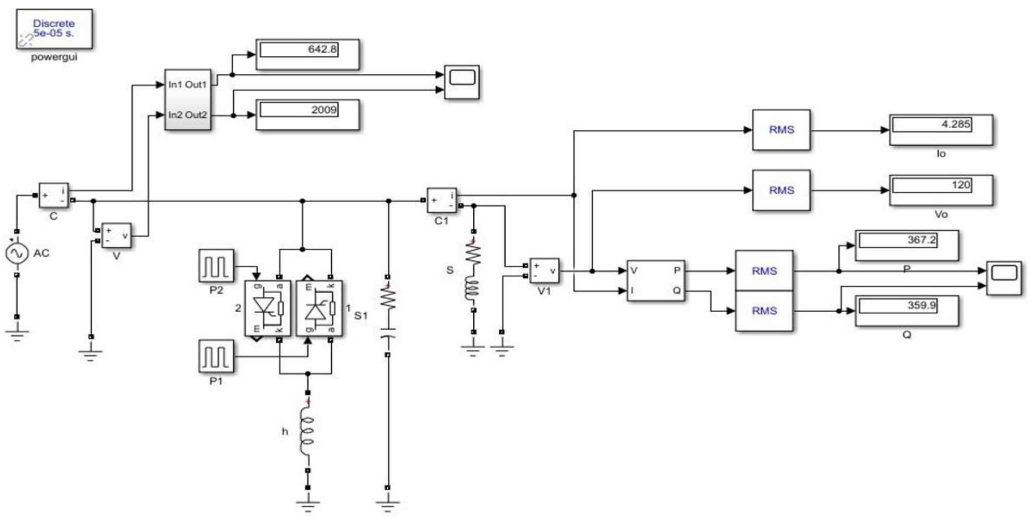


Fig.3 Simulink model of Single Phase FC-TCR

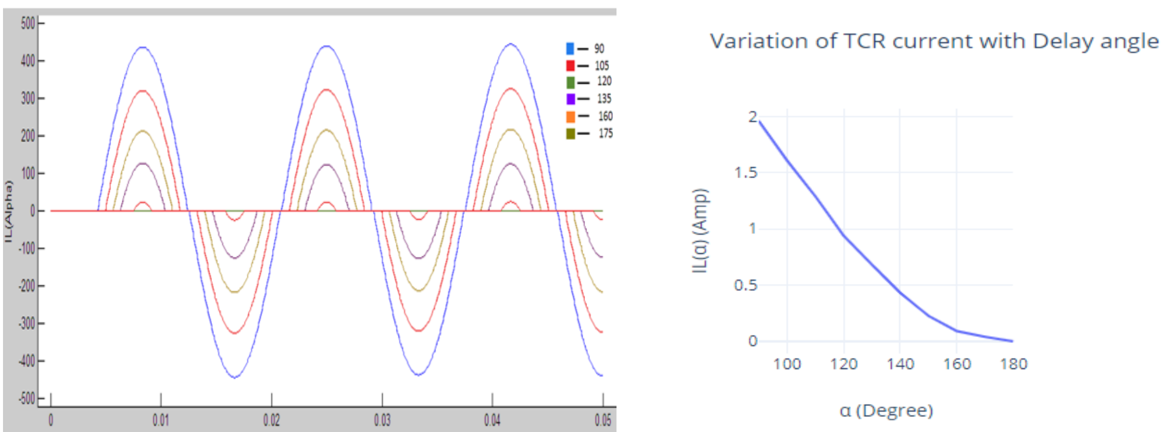


Fig.4 Change in $I_L(\alpha)$ w.r.t. α

Table no 3: Variation of α followed by other independent and dependent variables in 1 phase

Alpha (α)	I_S (Amp)	P_S (Watt)	Q_S (Var)	$I_{L\,(TCR)}$ (Amp)	Power factor
Without SVC	3.16	299.5	627.3	0	0.43
With FC	1.386	299.5	56.96	0	0.982
90	2.714	496.9	304.5	1.96	0.852
100	2.337	433.1	242.3	1.609	0.87
110	2.021	385.9	180	1.286	0.9
120	1.75	349.7	116.5	0.9702	0.948
130	1.56	325.3	58.06	0.6825	0.984
140	1.446	310	8.22	0.4309	0.999
150	1.399	303.4	29.37	0.2249	0.995

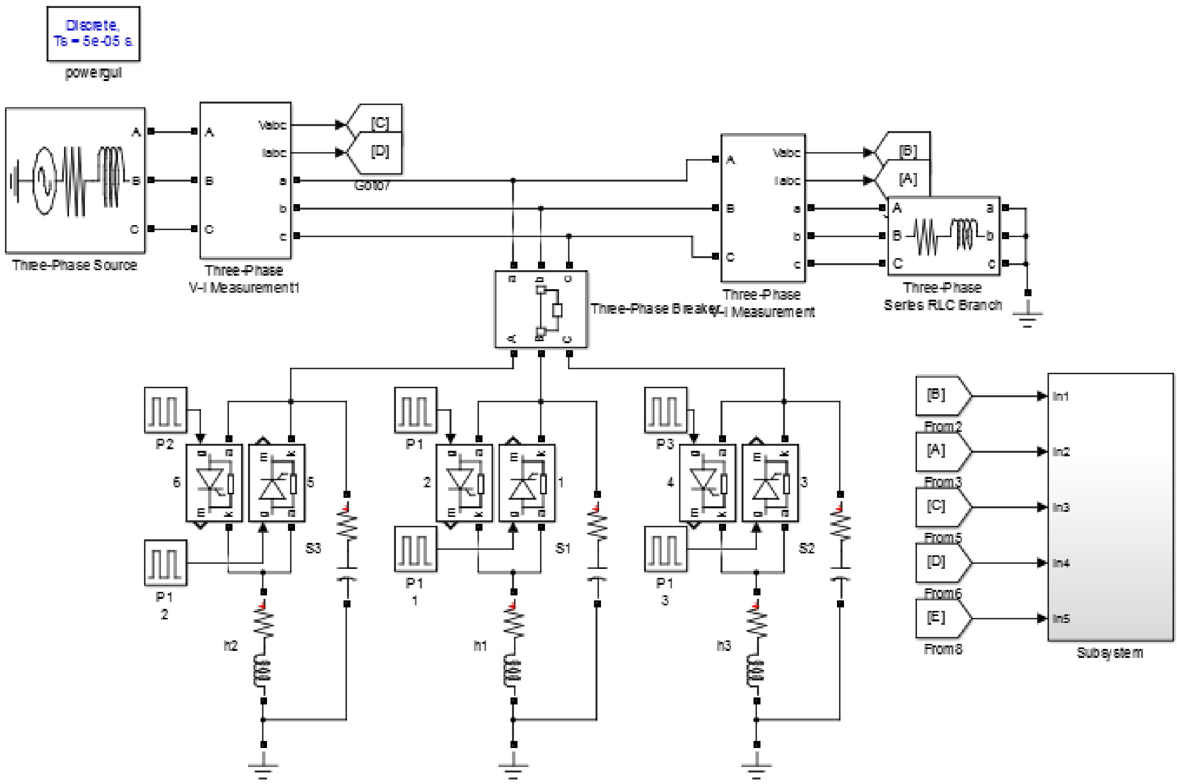


Fig.5 Simulink model of Three Phase FC-TCR

Table no 4: Variation of α followed by other independent and dependent variables in 3 phase

Alpha (α)	Ps (Watts)	Qs (Var)	Power Factor
Without SVC	1041	2124	0.4309
90º	3857	3223	0.8416
110º	3764	2872	0.7726

IV. Control Strategy for Thyristors

The change in the reactive power is function of firing angle being controlled by firing scheme. The scheme may be closed loop system or it may be open loop system. For open loop, it functions for a fixed value of admittance while in closed loop continuous variations are possible. Here the system utilizes different control strategies explained as follws:

- **Analog firing scheme**

In this scheme, the firing pulses are being generated by cascaded connection of comparators, integrators. The pulses are synchronized at 50 Hz by using IC555 timer pulses. The pulses are controlled by pot variation.

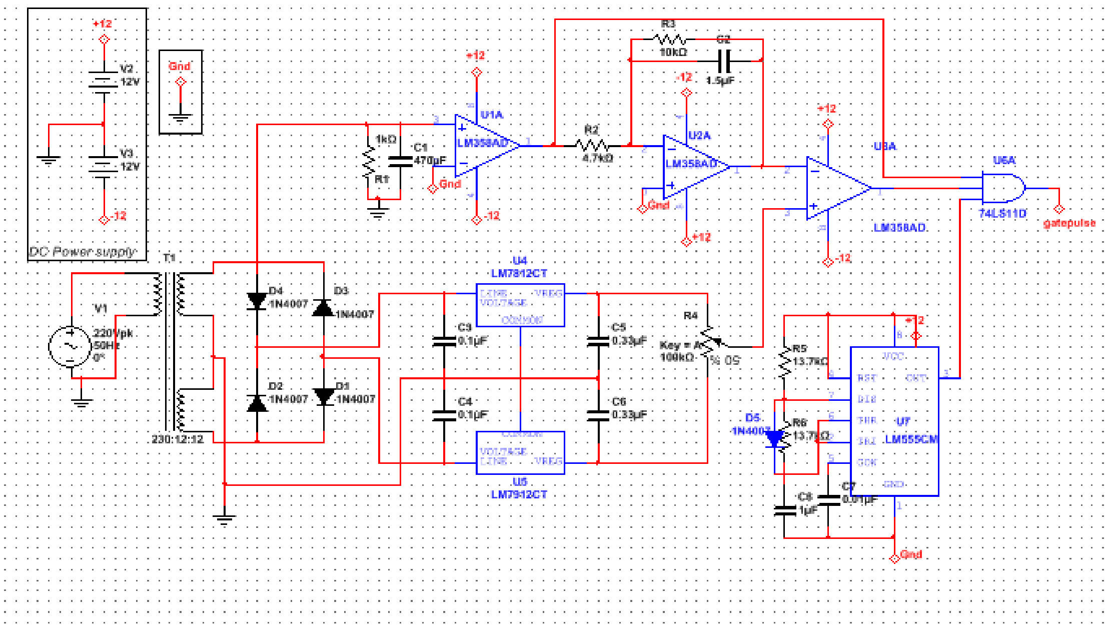
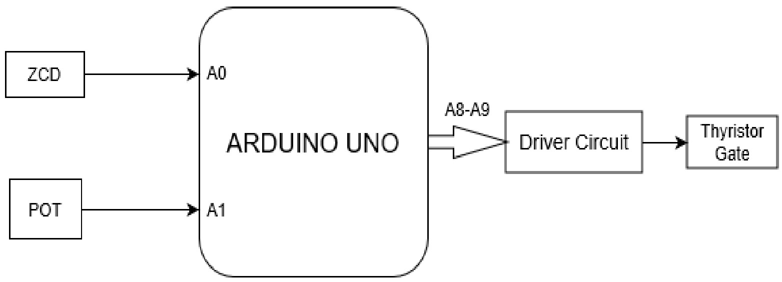


Fig.6 Simulink model of Analog firing scheme

- **Arduino based firing scheme**

At any time when zero crossing (rising edge of square wave) is detected on the AC mains, Arduino is interrupted and the latest values of ADC is used to manipulate firing delay which is used to determine firing angle. ADC output is 0-1023 which is used to control firing angle 0-180 degrees. Let ADC is the output from analog to digital converter and alpha is the firing angle. So, alpha is calculated using the following equation:
alpha = ADC / 5.68

The delay as per the firing angle which is based on the ADC output and ADC output is based on the analog voltage (0-5V). AC supply is 50Hz it has the time period of 20ms and for positive half cycle time period is 10ms, ADC reading is converted into a delay after which firing pulse is to be generated. If ADC is output of ADC and d is the delay in microseconds, then
d = (ADC * 5) * 1.955
1.955 here is the scaling up factor for the ADC reading and 5 is the reference voltage.
ZCD is the output of zero crossing detector connected to pin A0 of Arduino.



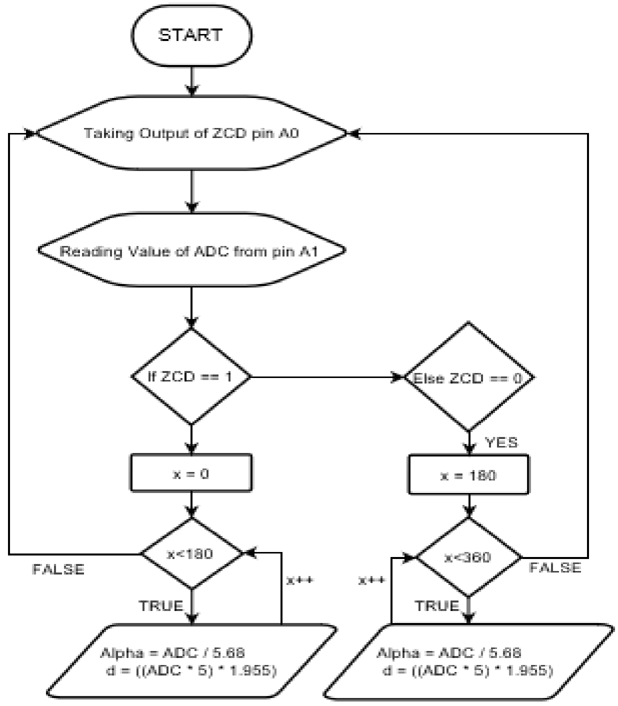


Fig.7 Flowchart of Arduino firing pulse generation

V. Conclusion

In proposed scheme, SVC successfully controls the variation in reactive power of the system by varying the firing angle. From the simulation it is perceived that, FC-TCR system adds necessary phase lag or lead to the system. The range of reactive power control can be increased by using different combinations in parallel.

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