Research Article

SVC Based Voltage Stabilization for Sensitive Agricultural Loads

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Abstract | Agricultural loads involving machinery and other processing units are generally inductive in nature. The power required by agricultural industry is broadly categorized into shaft power and process heat power, and could be used for planting, cultivating, pumping, harvesting, drying, cooking, baking, woodworking, forging and smelting etc. This results in lagging Volt-Ampere-Reactive (VARs), which must be balanced by the same number of leading VARs in order to ensure unity power factor, thus avoiding penalties on agricultural industry. Switched Capacitors and Voltage Regulators are used to cope with such a situation. Regulators results in higher line currents thus resulting in excessive losses in addition to voltage sag problems. On the other hand, static capacitors can tackle the reactive VARs, but in steps only. Thus, a real time solution is required for sensing, controlling, and injection of VARs based on the actual requirement. Such a solution is proposed in this paper along with simulation results. This would help agriculture-based industries in avoiding paneities, which would in turn lower the production cost of agricultural products. Also, sensitive equipment would not be encountering voltage fluctuations anymore.

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Introduction

Individual power consumption is increasing with each passing day. Power generated at generation centers is transmitted to far long areas, as the load centers are often situated at a fair distance. The distribution grid stations step down the voltage level and feed the required consumers according to the requirement. Pakistan is an agriculture-based economy, relying mostly on agricultural products. Machines used in agricultural industry are generally inductive in nature. At times agricultural machinery is very sensitive and required stable and streamlined power requirements. Thus, it is mandatory to keep the voltage between permissible limits according to the tolerance levels of machines. In case of inductive agricultural loads, the power factor along with the voltage profile are quite poor. Poor power factor results in penalties from the utilities upon agricultural industry, which directly affects the production cost. In order to improve voltage profile and power factor, such consumers take the help of voltage regulators thus stepping up the voltage which results in high line currents and increased power loss (Schipman and Dalincé, 2018). Industries have employed step-wise capacitor banks that can only improve the power factor in pre-defined steps. A real time PFI device is required that can cope linearly with load changes and VAR requirement

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(Marlar and Cho, 2008; Tey et al., 2005). Static VAR Compensator (SVC) can be used for real time VARs injection based on thyristor or Insulated Gate Bipolar Junction Transistors (IGBTs) controlled switching of Capacitors (Pradhan et al., 2014; Saito et al., 2013). This would allow agriculturists to avoid penalties thus helping in boosting their agricultural production. In addition to this the equipment life would increase because of stabilized voltage and power requirements due to balanced VAR's.

Materials and Methods

Static Var Compensator (SVC)

Static VAR compensators were introduced in the last decades of the 20th century and are compensation devices connected in parallel. They can both provide voltage support as well as improve the power factor (Das et al., 2016). It has three basic configurations: they consist of Silicon controlled rectifiers, controlled switched capacitor and controlled switched inductor. Each valve consists of two anti-parallel thyristors that helps in controlling the Reactive Volt Amperes injection. Unlike the Thyristor switched capacitors, the Thyristor switched inductors generates high harmonics. Filters could be added to minimize harmonics (Reid, 1996).

SVC can be used both for regulating transmission voltage and improvement of power quality. In case of lightly loading conditions, thyristor switched reactors are incorporated to consumer VARs from the system so as to bring the voltage level down; thus, avoiding power flow problems. Similarly, under heavily loaded conditions, the capacitors are switched to balance the lagging VARs produced due to inductive load and raise the power factor (Manan and Jamnani, 2016).

A model of SVC was introduced that had TSC with TCR. Results showed remarkable improvement compared to ordinary switched capacitors. The introduction of fully controlled switch (GTO) added to the controllability of bidirectional switches (Khan et al., 2018).

Thyristor Switched Capacitor (TSC)

The Thyristor switched capacitors includes bidirectional power electronic based switches, capacitors and reactors to limit the current (Ohtake et al., 2014). Thyristor valves are added in series to withstand the line voltage. Thyristor switched capacitors are capable of injecting number of reactive Volt Amperes with a fair bit of control. Switching is possible with the help of valves but phase control in not possible. Thus, the amount of VAR injection is always in pre-defined steps.

Thyristor Switched Inductor (TSI)

It consists of bidirectional valves and inductive reactance. They can be helpful in light loading conditions when the grids are not over-stressed. If for some reason the power factor is leading, Thyristor switched inductors because of its ability can absorb reactive power to bring the power factor back to unity. They can be controlled by controlling the firing angles of Power Electronic switches.

Thyristor Switched Capacitors (TSC) with Thyristor Switched Inductors (TSI)

In order to introduce flexibility Thyristor Switched Inductors can be used in connection with Thyristor Switched Capacitors for power factor improvement. This is known as Static VAR Compensator, which has the ability to cope with varying reactive power requirements. They are coupled to the Alternating Current system through coupling transformers.

Mathematical Design of TSC and TCR

The value of capacitance in TSC branch can be computed using Equation (6):

$$Ic = \frac{V}{Xc} \quad \ldots\ldots\ldots\ldots (1)$$

$$Xc = \frac{1}{2\pi fC} \quad \ldots\ldots\ldots (2)$$

Putting value of Equation (2) in Equation (1) we get,

$$Ic = 2 \times V\pi fC \quad \ldots..(3)$$

$$Also\ kVAR = \frac{VIc}{1000} \quad \ldots\ldots (4)$$

Putting the Equation (3) in Equation (4) we get,

$$kVAR = \frac{(V^2\pi fC)}{1000} \quad \ldots\ldots (5)$$

Here, V is the line to line voltage; f is the system frequency, *50 HZ*; C is the Capacitance and kVAC is the capacitive reactance.

Alternatively, we can write,

$$C = \frac{(kVAR \times 1000)}{(2\pi f V^2)} \quad \ldots\ldots(6)$$

Similarly, Inductance can be computed using Equation (11):

$$I_L = \frac{V}{X_L} \quad \ldots\ldots\ldots(7)$$

$$I_L = \frac{V}{2\pi f L} \quad \ldots\ldots(8)$$

$$kVARL = \frac{V I_L}{1000} \quad \ldots.(9)$$

$$kVARL = \frac{V^2}{(1000 \times 2\pi f L)} \quad \ldots..(10)$$

$$L = \frac{V^2}{(1000 \times 2\pi f \times KVARL)} \quad \ldots..(11)$$

Here; *V* is the line to line voltage; I_L is the inductor current; *f* is the system frequency, *50 HZ*; *L* is the Inductance; *kVARL* is the inductive reactance.

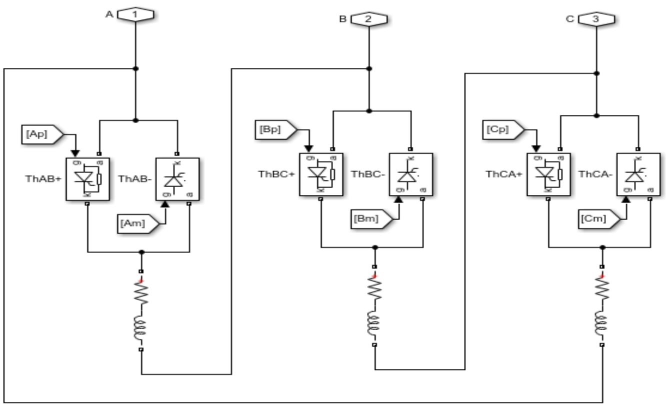

Figure 1: *three phase thyristor switched capacitors with added line inductance.*

Static VAR compensator is the combination of TSI and TSC. Figure 1 shows TCS with added line inductances. The delta connected TSC consists of capacitor, inductor and anti-parallel thyristors. Thyristor valve controls reactive power injection with the help of control circuits (Zemerick, 2002). Capacitance is strictly linked to power demand. The equation (Sumangala, 2013) which relates reactive power with capacitance is given by Equation (12):

$$Q_c = V_L^2\, 2\pi f C \quad \ldots\ldots\ldots\ldots.(12)$$

Where;

Q_C is reactive power supplied by capacitor; VL is the line voltage; f reflects frequency of line and C indicates capacitance. Reactive Power Support = 30 MVAR Leading Capacitance = 0.2 Farad and Current Limiting Reactor = 0.3 micro-H.

Figure 2 represent the model of TSI connected in delta fashion (three-phase). Figure 3 displays controller for SVC. The controller computes reactive VARs (Q) of the system. The decision of turning on and off depends on the value of Q. A single unit can provide up to 30 MVAR. If the requirement is higher than the capacity of a single unit, a second unit may turn on. In case of both units meeting the Q requirement the sharing is supposed to be strictly equal.

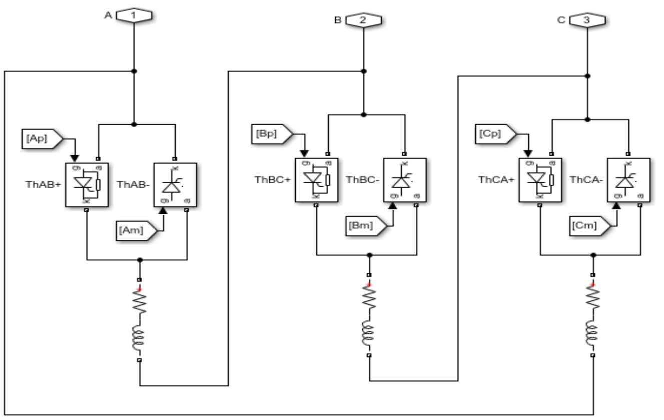

Figure 2: *Three phase thyristor controlled reactors.*

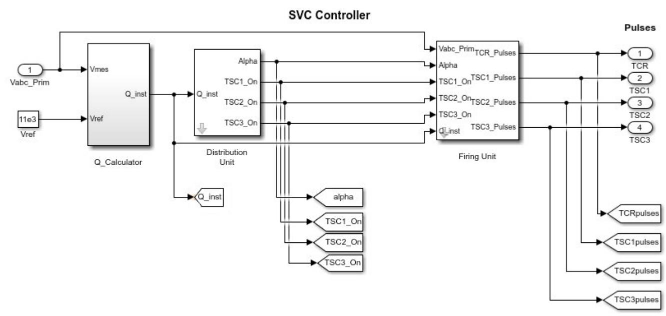

Figure 3: *SVC Controller.*

When a Gate Turn Off (GTO) thyristor is used instead of SCR, a control over the turn-off can also be achieved. Figure 4 shows the gating pulses.

Results and Discussion

Simulations were carried out at PhD Simulation Lab, Department of electrical engineering. Agricultural machinery sensitivity data was collected at department of Agricultural Loads. Voltage and currents before compensation and after compensation were plotted

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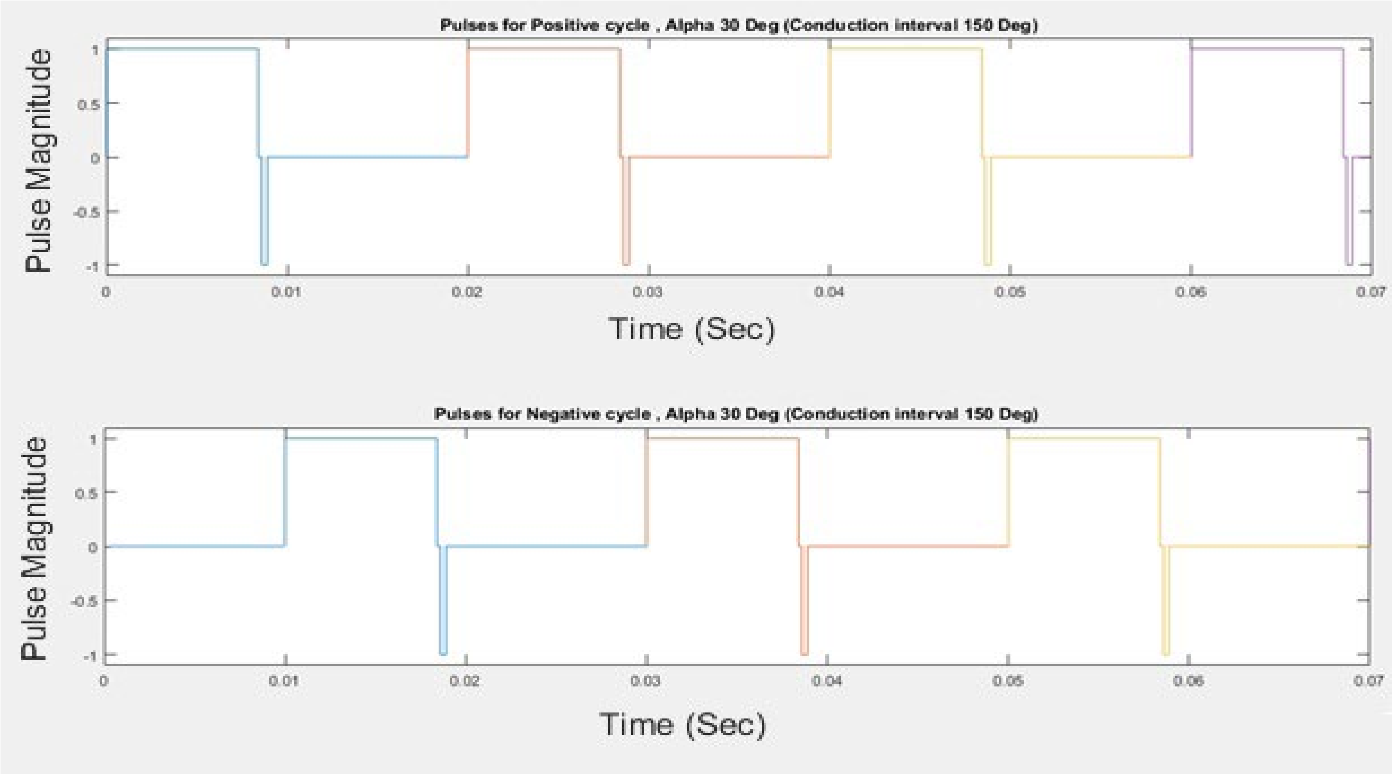

Figure 4: *Gating Signals for GTO.*

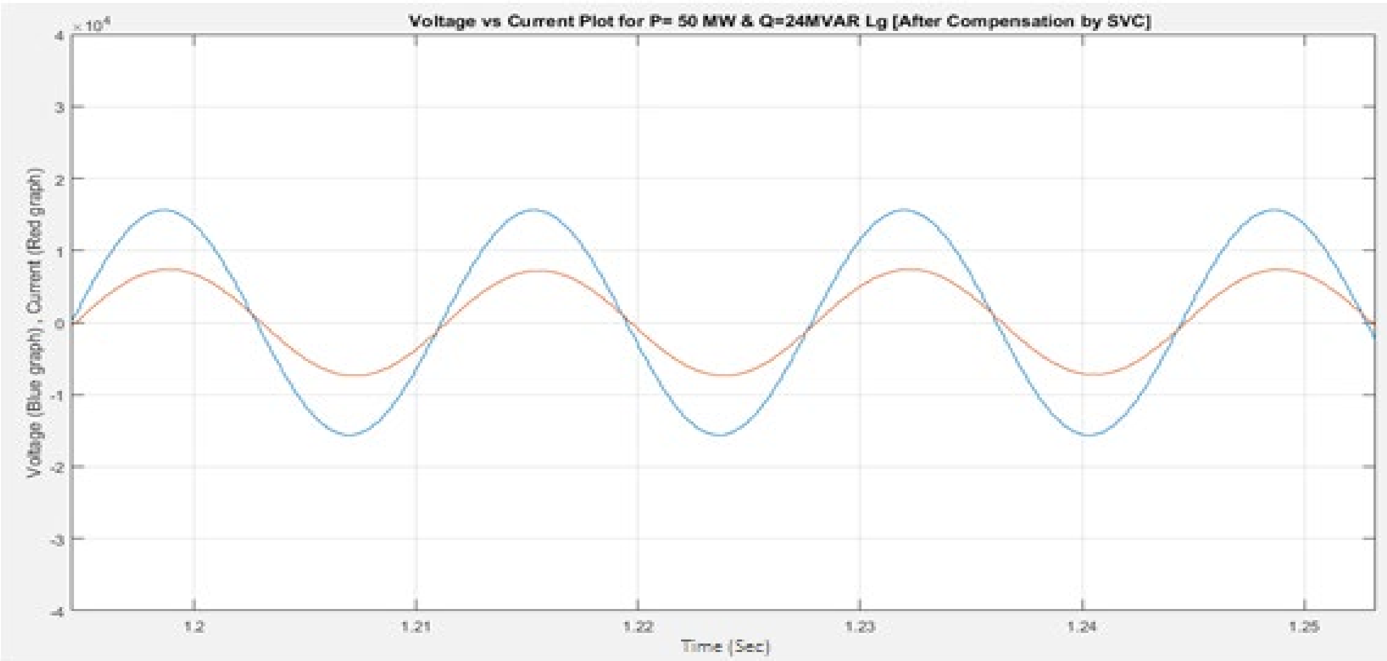

Figure 5: *Voltage vs current graph (Before Compensation).*

in the following figures (for same loading conditions). The effect of SVC on PQI is then observed for all conditions. Results showed considerable improvement. In Table 1, the first two columns show active and reactive loads (before simulation). Column 3 and 4 represents Power Factor before and after correction. Subsequent figures show voltage and current waveforms for loading conditions for 50MW active load and 24MVAR lagging reactive load. In case if harmonic filters were employed, harmonic distortion would further reduce, and power quality will improve.

Figure 5 shows voltage and current graphs for 50 MW, 24 MVAR system before reactive VAR compensation/ power factor correction. Voltage is shown in blue, and current is shown in red. It can be observed that the voltage and current is not in phase thus resulting in a phase shift between the two. This

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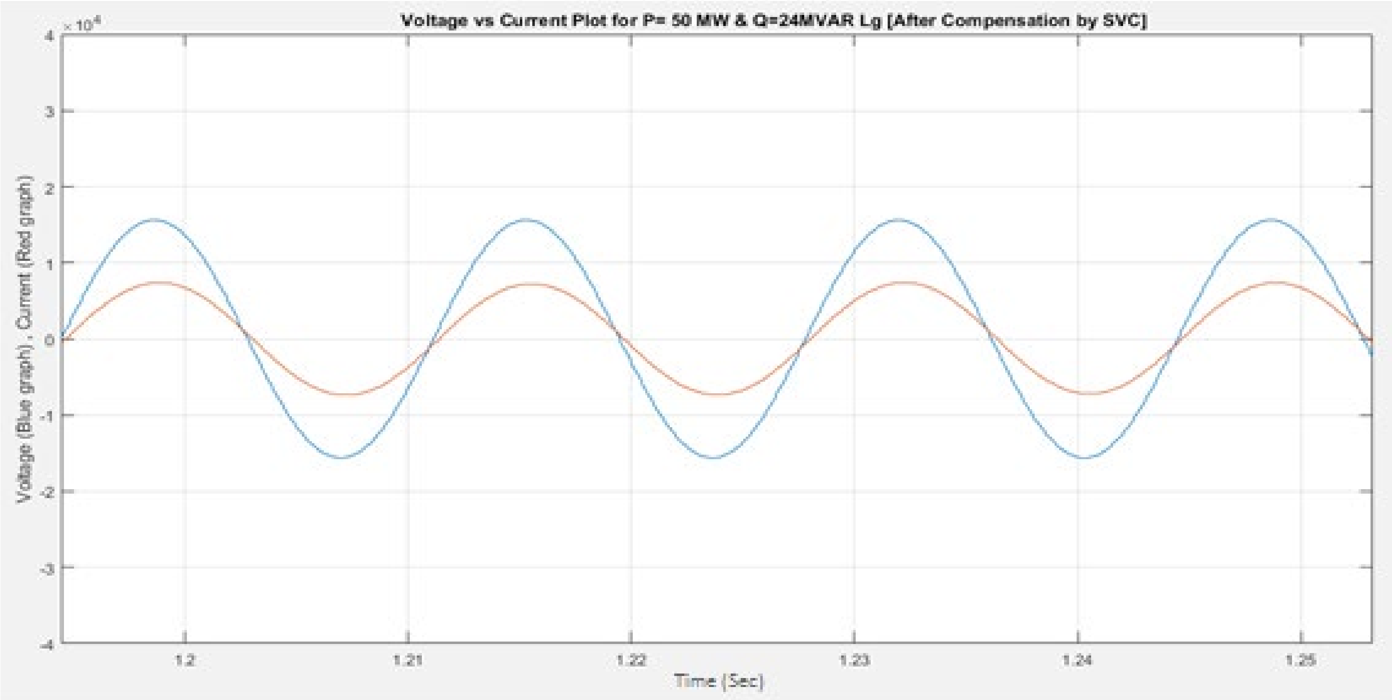

Figure 6: *Voltage vs current graph (After Compensation).*

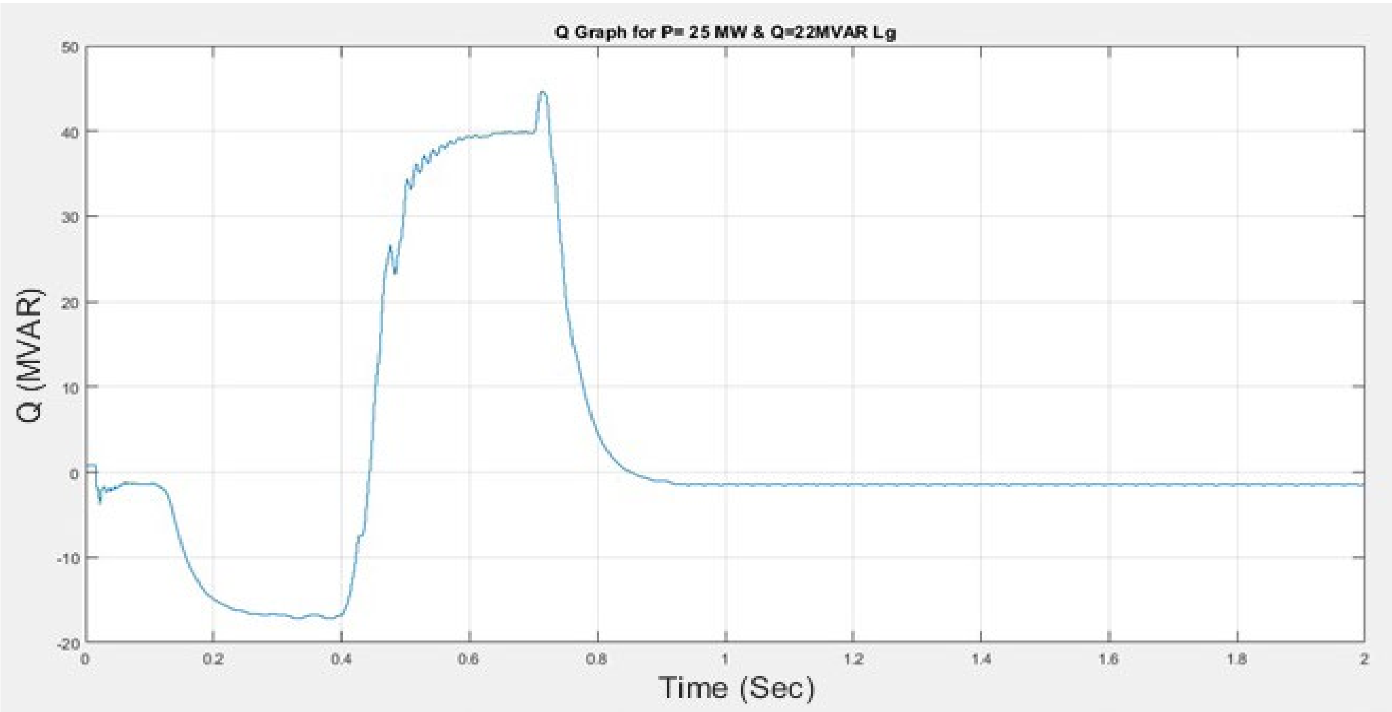

Figure 7: *System Q graph.*

situation worsens the displacement power factor, thus making the sensitive loads vulnerable to the disturbances in system parameters. Figure 6 shows the voltage and current graphs (voltage shown in blue and current shown in red) for 50 MW, 24 MVAR after compensation by SVC. It is clear that the voltage and current is in line with a phase difference of zero degrees, thus making the power factor close to unity. As a result, the voltage profile as well as the power factor are in permissible limits ruling out any damages to the sensitive equipment. Figure 7 reflects the system response for Q (MVAR) against Time (seconds). Results of simulations show that after initial transients due to switching of thyristors SVC compensates within 0.8 seconds for system reactive power. After which the system response becomes stable and power factor is improved to unity.

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Table 1: *Power factor before and after compensation.*

Active Load (MW)	Reactive Load Before Simulation (MVAR Lg)	Power Factor Before Simulation (Lg)	Power Factor After Simulation (Lg)	Compensated (MVAR)
25	12	0.9	0.94	3
25	15.5	0.85	0.96	8.5
50	24.2	0.9	1	24.02
50	37.5	0.8	0.98	28.8
50	45	0.75	0.96	31.2
100	62	0.85	0.96	34
100	75	0.8	0.96	39.5

Conclusions

From the above results, I conclude that voltages are compensated, and power quality is improved with the help of static VAR compensators using TSC, TSI, and Power Electronic Switches. This would ensure operation at high power factor for agricultural loads, thus avoiding any paneities. In addition, it would reinforce machine life and safe operations. The production cost could be cut down via savings in energy production costs. Model was developed in SIMSCAPE (MATLAB). Real time power factor improvement can be achieved using TSC and TSI. Fast electronic Switches were added to control the firing delays and hence the capacitance of capacitors. Harmonics can be negated by using appropriate firing delays and the use of harmonic filters. This relieves the weak grid and consequently improves the power quality.

Recommendations

It is recommended that in order to make further improvements, press packed IGBTS should be introduced to the system model. Currently IGBTs have some shortcoming, as a result it cannot be incorporated though they are superior switches in terms of control and current carrying as well as voltage withstanding capabilities. Researchers are working on press packed IGBTs which would overcome its shortcomings and thus would improve the system further. In additions to this, control systems could be employed for real-time measurements of reactive power, based on which control signals would be initiated for controlling firing of controlled switches.

Author's Contribution

This research work was supervised by Mu-hammad Naeem Arbab and co supervised by Abdul Basit. Modelling and Simulations were done by Faheem Ali and Muhammad Kashif Khan. Data collection was the responsibility of Muhammad Amir and was analysed by Gulzar Ahmad.

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