CHAPTER 7

PERFORMANCE EVALUATION OF SVC
7.1 Introduction:

The aggregate behaviour of typical load at a substation / on a distribution transformer is somewhat unpredictable since the load changes in its nature, composition, and magnitude from time to time during the day.

A comprehensive microcontroller is designed & developed for analyzing the performance of Static Var Compensator. The SVC consists of capacitor bank in five binary sequential steps being operated in conjunction with a TCR of lowest step size capacity. It is an error adaptive controller based on KVAR sensing for switched capacitor bank operation and to fix the TCR level. The logic and control techniques employed are unique and comprehensive incorporating number of features. This compact integrated controller will be tested on a distribution transformer to establish its functional feasibility and technical features envisaged. This chapter deals with theoretical performance evaluation prior to verification with the experimental setup on the mains transformer.

7.2 Capacitor bank in five binary sequential steps.

The automatic power factor controllers available at present in the market do not offer exact matching with reactive power required by the load during specified interval which leads to inaccuracies in power factor control and reactive power compensation. In order to overcome these limitations and to ensure precise control, the bank is arranged in five binary sequential steps to enable reactive power variation with least possible resolution. A TCR of lowest step size is operated in conjunction
with capacitor bank so as to achieve a continuously variable reactive power, in a stepless way.

A three phase 50 Hz, 11KV/433 Volts Dy11, 125 KVA distribution transformer is employed for experimental setup. The total Q value for compensation chosen is 77.5 KVAR, arranged in the following five binary sequential steps with values and corresponding signals that are given from controller to the respective contactors are as follows. (Fig.7.1)

Step-1- \( Q_0 = 2.5 \text{ KVAR} \) - \( S_0 \) to Contactor ‘0’
Step-2- \( Q_1 = 5.0 \text{ KVAR} \) - \( S_1 \) to Contactor ‘1’
Step-3 – \( Q_2 = 10.0 \text{ KVAR} \) - \( S_2 \) to Contactor ‘2’
Step -4- \( Q_3 = 20.0 \text{ KVAR} \) - \( S_3 \) to Contactor ‘3’
Step-5 – \( Q_4 = 40.0 \text{ KVAR} \) - \( S_4 \) to Contactor ‘4’

An innovative error adaptive controller is designed, developed and tested for switching operations of the capacitor bank as required in the system under consideration. It has the following features:

i) The control strategy is error activated to match with the load reactive power for a chosen time interval.

ii) It eliminates the scope for over compensation.

iii) It is flexible to choose appropriate number of steps as per the required compensation depending on the loading condition.

iv) Resolution is small.
v) Simple in principle, elegant in operation and of low cost.

vi) Possible to extend the idea presented in the controller for large size transformer at high voltages.

The controller receives both current and voltage signals through CT and PT, performs necessary calculations through an in built program and generates the activating signals $S_0, S_1, S_2, S_3$ and $S_4$ so as to match the reactive power from the compensator with the prevailing load demand. There are 32 possibilities arising from the controller output starting from 00000 to 11111.

### 7.3 System data for case study.

Walchand College of Engineering, Sangli is getting supply from MSEDL through 11 KV feeder and there are two transformers feeding various loads in the campus. Their ratings are as follows:

- 11 KV feeder of length 5 km Vishrambag Substation to college premises have the following parameters:
  - H.T. Supply: 11 KV over head feeder:
    - Mink 7/3.66 mm ACSR conductor,
    - Resistance per Km. distance: 0.49 $\Omega$,
    - Reactance per Km. distance: 0.365 $\Omega$,
    - Transformer rating: 125KVA, 11KV/433V, 50 Hz. Dy11
    - Percentage impedance: 4.25 ohms
Capacitor bank rating: 77.5 KVAR

No. of steps: 5 steps

Steps in KVAR: 2.5, 5, 10, 20, 40 KVAR

7.4 Control Strategy:

The objective here is to effectively utilize transformer capacity and maintain power factor close to unity always, for all load levels during the day. For this purpose the thyristor controlled reactor of 2.5 KVAR is used in the setup. The capacitor bank in five binary sequential steps when operated in-conjunction with the TCR, it is possible to get stepless variation of reactive power in the range of -2.5 KVAR to 77.5 KVAR. The current and voltage / KVAR are sensed and fed to a dedicated
microcontroller to perform necessary calculations and arrive at the number of steps and the level of TCR operation [3]. This will enable close matching of the compensator reactive power output with the prevailing load reactive KVAR appearing across the secondary winding of the transformer. The periodicity of feedback control is timed at every two minutes, to scan and initiate the signals for ON/OFF control of capacitor bank steps and application of gate signals to the thyristor blocks. The reason for choice of two minutes time is to ensure that every capacitor bank discharges when switched OFF to below 50 volts. This is the standard practice followed for LT capacitors switching operation. [4]

The sequential steps are given below for calculation purpose. MATLAB Program has been used for calculating the the compensated and uncompensated data.

```matlab
ic=[30;60;90;110;135;165];
pf=[.7;.72;.74;.76;.78;.8]
phase=acos(pf)
pf=cos(phase)
e=250;
r=.16;
x=.123;
dv=r*ic.*cos(phase)+x*ic.*sin(phase);
deltav=x*ic.*cos(phase)-r*ic.*sin(phase);
pang=asin(deltav/e);
vr=e*cos(pang)-dv
preg=((e-vr)./vr)*100
losses=3*ic.^2*r
p=3*vr.*ic.*cos(phase)
```
\[ q = 3vr \cdot ic \cdot \sin(\text{phase}) \]
\[ s = \sqrt{p^2 + q^2} \]
\[ \text{eff} = \frac{p}{(p + \text{losses})} \times 100 \]
\[ \text{icomp} = \frac{p}{vr} \]
\[ \text{icomp} = \frac{\text{icomp}}{3} \]
\[ dv = r \cdot \text{icomp} \]
\[ \text{deltav} = x \cdot \text{icomp} \]
\[ \text{pang} = \arcsin(\frac{\text{deltav}}{e}) \]
\[ \text{vrcomp} = e \cdot \cos(\text{pang}) - dv \]
\[ \text{pregcomp} = (e - \text{vrcomp}) / \text{vrcomp} \times 100 \]
\[ \text{lossesreduced} = 3r \cdot \text{icomp} \cdot \text{icomp} \]
\[ \text{peffcomp} = \frac{p}{(p + \text{lossesreduced})} \times 100 \]
\[ \text{savingwatt} = (\text{losses} - \text{lossesreduced}) \]
\[ \text{savingcurrent} = ic - \text{icomp} \]

A revised schematic diagram shown in Fig.7.1 illustrates the operating principle employed for experimental setup. As explained in the earlier chapter 5, it basically generates required signals to operate both capacitor bank in five binary sequential steps and the TCR.

In order to get requisite KVR level from the thyristor controlled reactor, the duration of conduction is to be permitted as needed. The main supply voltage is taken as a reference potential from the potential transformer, the instant at which it is passing through zero and positive going is detected by zero crossing detector for the each phases and the signals are produced to apply for the thyristor gates.
7.5 Analytical results.

An attempt has been made to establish the technical soundness by closely matching compensator reactive power with the load value continuously & automatically. The adaption of binary sequential steps has reduced the resolution and when operated in conjunction with TCR, stepless control has been possible. The entire assembly consisting of capacitors, contactors, controller, thyristor controlled reactors, has been made as compact as possible. In particular the controller part is in modular form and can be made applicable for different ratings of compensators and even for high voltage application. Air cored coils are employed to avoid saturation and large losses.

The total losses taking place in capacitors and TCR are subtracted from the reduction in losses that has occurred in the transformer & feeder for calculating the net gain.

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Load Current Amp.</th>
<th>Power Factor PF.</th>
<th>Power KW</th>
<th>Reactive Power KVAR</th>
<th>Apparent Power KVA</th>
<th>Receiving End Voltage Volts</th>
<th>Losses Watts</th>
<th>% Voltage Regulator</th>
<th>% Feeder Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>01</td>
<td>30.00</td>
<td>0.70</td>
<td>15.6</td>
<td>15.9</td>
<td>022.3</td>
<td>430.10</td>
<td>48.6</td>
<td>0.68</td>
<td>99.69</td>
</tr>
<tr>
<td>02</td>
<td>60.00</td>
<td>0.72</td>
<td>31.9</td>
<td>30.8</td>
<td>044.4</td>
<td>427.25</td>
<td>194.4</td>
<td>1.34</td>
<td>99.39</td>
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<tr>
<td>03</td>
<td>90.00</td>
<td>0.74</td>
<td>48.9</td>
<td>44.5</td>
<td>066.1</td>
<td>424.9</td>
<td>437.4</td>
<td>2.00</td>
<td>99.11</td>
</tr>
<tr>
<td>04</td>
<td>110.0</td>
<td>0.76</td>
<td>61.2</td>
<td>52.3</td>
<td>080.5</td>
<td>422.78</td>
<td>653.4</td>
<td>2.41</td>
<td>98.94</td>
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<tr>
<td>05</td>
<td>135.0</td>
<td>0.78</td>
<td>76.7</td>
<td>61.5</td>
<td>098.3</td>
<td>420.69</td>
<td>984.1</td>
<td>2.92</td>
<td>98.73</td>
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<tr>
<td>06</td>
<td>165.0</td>
<td>0.80</td>
<td>95.6</td>
<td>71.7</td>
<td>119.5</td>
<td>418.27</td>
<td>1470.1</td>
<td>3.52</td>
<td>98.48</td>
</tr>
</tbody>
</table>

TABLE 7.1
DISTRIBUTION FEEDER PERFORMANCE WITHOUT COMPENSATOR

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Compensated Reactive Power KVAR in Binary sequential Steps</th>
<th>TCR Value KVAR</th>
<th>Reduced Current Amp.</th>
<th>Reduced Losses Watts</th>
<th>TCR + Capacitor Losses Watts</th>
<th>Net Losses TCR+Capacitor+Feeder losses Watts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q5</td>
<td>Q4</td>
<td>Q3</td>
<td>Q2</td>
<td>Q1</td>
<td>Lag</td>
<td>1</td>
</tr>
<tr>
<td>01</td>
<td>-</td>
<td>-</td>
<td>10</td>
<td>5</td>
<td>2.5</td>
<td>1.6</td>
</tr>
<tr>
<td>02</td>
<td>-</td>
<td>20</td>
<td>10</td>
<td>-</td>
<td>2.5</td>
<td>1.7</td>
</tr>
<tr>
<td>03</td>
<td>40</td>
<td>-</td>
<td>-</td>
<td>5</td>
<td>-</td>
<td>0.0</td>
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<tr>
<td>04</td>
<td>40</td>
<td>-</td>
<td>10</td>
<td>-</td>
<td>2.5</td>
<td>0.2</td>
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<tr>
<td>05</td>
<td>40</td>
<td>20</td>
<td>-</td>
<td>-</td>
<td>2.5</td>
<td>1.0</td>
</tr>
<tr>
<td>06</td>
<td>40</td>
<td>20</td>
<td>10</td>
<td>-</td>
<td>2.5</td>
<td>0.8</td>
</tr>
</tbody>
</table>

TABLE 7.2
KVAR COMPENSATION IN BINARY SEQUENTIAL STEPS FOR THE CASES REFERRED IN TABLE 1
<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Receiving End Volts</th>
<th>% Voltage Reg.</th>
<th>% Feeder Eff.</th>
<th>Increased Load Current Capability Amp</th>
<th>Net Saving in Loss. Watts</th>
<th>Relief in KVA</th>
</tr>
</thead>
<tbody>
<tr>
<td>01</td>
<td>432.3</td>
<td>0.15</td>
<td>99.84</td>
<td>9.00</td>
<td>-23</td>
<td>6.7</td>
</tr>
<tr>
<td>02</td>
<td>431.6</td>
<td>0.31</td>
<td>99.68</td>
<td>16.80</td>
<td>38</td>
<td>12.5</td>
</tr>
<tr>
<td>03</td>
<td>430.9</td>
<td>0.49</td>
<td>99.51</td>
<td>23.40</td>
<td>194</td>
<td>17.2</td>
</tr>
<tr>
<td>04</td>
<td>430.2</td>
<td>0.62</td>
<td>99.38</td>
<td>26.40</td>
<td>271</td>
<td>19.3</td>
</tr>
<tr>
<td>05</td>
<td>429.6</td>
<td>0.79</td>
<td>99.22</td>
<td>29.70</td>
<td>361</td>
<td>21.6</td>
</tr>
<tr>
<td>06</td>
<td>428.7</td>
<td>1.01</td>
<td>99.02</td>
<td>33.00</td>
<td>511</td>
<td>24.0</td>
</tr>
</tbody>
</table>

**TABLE 7.3**

RESULTS AFTER COMPENSATION FOR THE RESPECTIVE CASES OF TABLES I & II

Various load levels covering the entire range of the transformer chosen are covered at different power factors. The feeder parameters & transformer equivalent values are referred to LT side and the compensator performance is investigated. The results given in table I, II & III indicate the improvements brought out with the application of continuous control. The notable features are:

- Maintaining the power factor at unity.
- Minimum feeder current and loss reduction.
- Improvement in distribution feeder efficiency.
- Improvement in the voltage at load end.
- Relief in maximum demand and effective utilization of transformer capacity.
- Saving in monthly bill due to reduction in penalty on account of poor power factor, and reduction in maximum demand charges.
- Conservation of energy takes place.

(All these features are shown with graphical representation in Fig.7.2, 7.3, 7.4 and 7.5)

There are some specific technical advantages of the static VAR compensator consisting of contactor switched capacitor banks in binary sequential steps and thyristor controlled reactor as outlined below:
• It is possible to get stepless control of $Q$ closely matching with load requirements.
• The combination offers greater flexibility in control.
• There is substantial reduction in harmonics generated due to small size of reactor employed in the static VAR compensator.

The load current v/s receiving end voltage, load current v/s percentage voltage regulation, load current v/s feeder efficiency and load current v/s enhancement in feeder current carrying capacity are shown in Fig. 7.2, 7.3, 7.4 and 7.5. All these graphical characteristics bring out the technical advantages of SVC through the microcontroller. The analytical results obtained in this chapter will be verified with experimental results in the ensuing chapters.

The economic benefits that can be derived from the installation of SVC scheme as proposed in this work can be under the following heads:

1. Released generation capacity; transmission capacity and distribution substation capacity.
2. Reduced energy losses and conservation of energy.
3. Reduced voltage drop and improvement in voltage.
4. Increasing the revenue due to voltage improvements.
Fig 7.2 Plot of load current v/s receiving end voltage,

Fig.7.3 The plot of Load current v/s voltage regulation
Fig. 7.4. The plot of Load current v/s feeder efficiency.

Fig. 7.5. The plot of Load current v/s increase in current capability.
Fig. 7.6 The plot of Load current v/s KVA relief
7.6 Result Analysis:

Six specific loading cases for the distribution systems have been reported in the earlier chapters are taken up for performance evaluation. The results obtained from the study carried out clearly bring out the enhancement in receiving end voltage, reduction in percentage voltage regulation, increase in the feeder efficiency, enhancement in load current capability and relief in KVA demand as depicted in figures 7.2, 7.3, 7.4, 7.5 and 7.6 respectively. All these improvements could be realized through close matching of load reactive power with compensator reactive power in the entire range of operation. Tables 7.1, 7.2 and 7.3 gives the numerical values for all the six cases considered with and without compensators on the distribution feeder.

7.7 Conclusions:

The performance evaluation of Static Var Compensator consisting of capacitor bank in five binary sequential steps operated in conjunction with a TCR is carried out. A schematic diagram is given with a micro controller for switching and control operations; and a MATLAB program is presented with the sequential steps for the operations to be carried out. All the six cases are considered for performance evaluation and improvements brought out with compensator in receiving voltage, its regulation, feeder efficiency, enhancement in load current capability and relief in load KVA demand are presented in various graphs. Finally economic justification is given by considering the capital investment, interest and depreciation charges and the payback period. Thus it is established that the proposed scheme is technically sound and economically beneficial for the college.