Outline of Work

For

Ph. D. Under Faculty of Engineering

**Topic of Research**: “Error Adaptive Schemes for: LT and HT Switched Capacitors and Microcontroller Based Static VAR Compensator at 11 KV Substations”

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INTRODUCTION

It is well documented in the literature and through public discussions at various levels that substantial power loss is taking place particularly in our low voltage distribution systems, on account of poor power factor loads, due to inadequate reactive power compensation facilities and their improper control. Switched capacitors in both LT and HT systems can directly supply the reactive power of loads, improve power factor, maintain good voltage profile, minimize equipment loading and reduce both power loss and KVA demand. The average cost involved for every MW by providing additional generation, transmission and a distribution facility is around Rs. 3-5 corers. On the other hand reactive power compensation at various levels facilities energy saving, better utilization of existing capacitors and improve the quality of supply at very low cost. Hence the Government of India insists on shunt capacitor installation in a massive way and is encouraging the state electricity boards through Rural Electrification Corporation (REC) and various other financing bodies.

The reactive power compensation and voltage control have been the most challenging tasks for power plants are interconnected through long EHV/HV lines and power is supplied to the consumers through distribution networks. It would be unwise to produce all the reactive power required from generating sources, as it would cause heavy losses and inefficient operation. Hence the practice adopted is to provide reactive power sources at load centers so as to meet the major portion of reactive power locally. Synchronous phase modifier is an ideal source for reactive power
compensation but it is costly, incurs large losses, requires foundation for installation, leads to stability problems during disturbances being low inertia synchronous machines and has maintenance problems. On the other hand, there have been a number of improvements over the years in the shunt capacitors manufacturing technology. Today shunt capacitor is a low cost static hardly any maintenance if installed with carefully designed ancillary equipment for protection. The capacitor units can be produced with standardized voltage/KVAR ratings and banks are formed to obtain the suitable ratings. It is possible to obtain required KVAR rating for 440 volts 3 phase LT applications and any MVAR capacitors in HT that is 11 KV to 132 KV systems. This thesis work deals with reactive power compensation schemes in both LT and HT systems.

**SCOPE OF THIS WORK**

It is envisaged to cover the following and their related aspects in this thesis work.

1. To make an indepth study of the existing practices in both LT and HT systems for reactive power compensation.
2. To critically review the present state of art for identifying the deficient areas so as to improve upon the existing schemes.
3. To find out the minimal requirements of ancillary equipment for protection and control.
4. To design the suitable inrush current limiting reactors necessary during the parallel switching of the bank steps.
5. To newly develop an error adaptive electronic controller based on KVAR sensing for switched capacitors in LT systems so as to provide reactive power compensation with smallest possible resolution.

6. To newly develop an error adaptive electronic controller based on bus voltage and load KVAR demand so as to provide reactive power compensation with minimum step variation at 11 KV substations.

7. To suggest a comprehensive microcontroller based control scheme for a static VAR compensator consisting of thyristor controlled reactor and switched capacitor banks in suitable steps so as to obtain continuously variable reactive power compensation as required at 11 KV substations.

8. To bring out the technical advantages of the above novel schemes and to carry out their cost benefit analysis so as to realize their practical implementation.

9. To suggest ways and means for practical implementation of the above schemes for LT and HT systems of electric supply undertakings and in industrial systems.

   The scope of the work as outlined in the section is described brief in the following paragraphs.

1] Study of Existing Practices:

   The shunt capacitors are widely used in both LT and HT systems for reactive power compensation by supply undertakings and other industrial utilities. At present their switching arrangement is through semiautomatic or manual control. In LT applications the capacitors are switched ON and OFF through contactors. In HT capacitors circuit breakers are used. Thus, the
capacitor banks are either ON or OFF giving raise to large step variation in reactive power. In actual practice the consumer demand varies continuously throughout the day and thereby the reactive power as well. Hence, the ideal control criterion has to be matching the reactive power requirement from time to time. The controllers employed in both LT and HT systems at present are nowhere close to this actual requirement.

The capacitors in LT systems require HRC fuses for protection, current limiting chokes, CTs, PTs and contactors. On the other hand the capacitor banks in HT requires lightning arrestor/metal oxide arrestors, isolators, circuit breakers/capacitor switches, inrush current limiting reactors, CTs, PTs and the protection is carried out through residual voltage transformer for single star banks and through neutral current transformer for double star banks.

2] Critical Review and Identification of Deficient Areas:

The size of individual capacitor units are standardized in both LT and HT systems. The bank sizes are fixed as per customer’s requirements and with limited switching facility in LT systems. The Rural Electrification Corporation of India has come out with a new specification in February 1992 for LT switched capacitors. They issued another specification for 11 KV automatically switched capacitor banks at substations in August 1992. Both these specifications have certain limitations which are dealt with in items 5 and 6 further on, such as inadequacy in reactive power capacitors and large step variation, through which it would not be possible to match the exact load KVAR requirement. The present thesis work is developed to overcome this lacuna in both LT and HT systems.
3] Ancillary Equipment for Protection and Control:

The capacitor bank requires adequate protection when used in both LT and HT systems. The banks are usually rated for 10% overvoltage as per ISS: 2834. The banks are protected by unbalanced detection in phase currents for LT, in the neutral displacement through RVT for single star banks and through neutral currents in double star banks for HT. These techniques are more or less standardized for protection of capacitor banks. However, specified measures are necessary when capacitor banks size is to be varied through switching operation. In LT a capacitor bank step cannot be switched ON again within two minutes time after switching OFF operation. Similarly HT capacitor banks cannot be switched ON again within five minutes time after switching OFF operation. Thus switching ON and OFF operations in both LT and HT require timers with appropriate delays.

In LT contactors are used to switch ON or OFF the capacitor bank steps. Standard sizes are available for this purpose. In HT vacuum circuit breakers or SF6 circuit breakers are used. When capacitor bank is to be provided with number of steps in HT it becomes costly to adopt these circuit breakers. Hence REC has suggested to adopt newly manufactured and indigenously available capacitor switches. For the schemes that are dealt with this thesis work, contactors are considered for LT applications and capacitors switches for HT applications which are cheaper. All other protective measures are as per the standard practices and within the guidelines of REC.

4] Inrush Current Limiting Reactor:

Capacitors require current limiting reactor when they have to be switched ON with mains. These reactors are to be carefully chosen so as to
avoid overstressing of contactors/circuit breakers/capacitor switches in both LT and HT schemes. The reactor size depends on the fault level at the point of common coupling and also the harmonics in the system. The inrush current problem is much savior when the banks are to be operated in parallel combination. This requires careful analysis and design for adapting suitable ratings for the series reactors. This aspect will be dealt in detail in the proposed work for the schemes in both LT and HT systems.

5] LT Switched Capacitors:

As per the specifications issued by REC in February 1992 the standard ratings of the capacitors and their step size variations are as follows.

<table>
<thead>
<tr>
<th>Transformer rating in KVA</th>
<th>Capacitor bank rating in KVAR</th>
<th>No. of steps</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>9</td>
<td>1</td>
</tr>
<tr>
<td>63</td>
<td>27</td>
<td>3</td>
</tr>
<tr>
<td>100</td>
<td>36</td>
<td>4</td>
</tr>
</tbody>
</table>

There exist two limitations, viz. only a step variation in reactive power compensation is possible and capacitors prescribed may be inadequate many a time under full load power factor conditions. To overcome these difficulties a completely new scheme is suggested which will be designed, fabricated and implemented in this thesis work.

The standard ratings of capacitors and number of steps to be used are as follows.
<table>
<thead>
<tr>
<th>Transformer rating in KVA</th>
<th>$Q_c$ in KVAR</th>
<th>Steps arrangement</th>
<th>Resolution in KVAR</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>15</td>
<td>$4(1+2+4+8)$</td>
<td>1</td>
</tr>
<tr>
<td>63</td>
<td>37.5</td>
<td>$4(2.5+5+10+20)$</td>
<td>2.5</td>
</tr>
<tr>
<td>100</td>
<td>60</td>
<td>$4(4+8+16+32)$</td>
<td>4</td>
</tr>
</tbody>
</table>

In the above schemes capacitors are switched in binary sequential steps which enables the matching of reactive power variation with reasonably good resolution. The automatic control unit to be designed is truly error adaptive. It means that whenever a change in KVAR sensed exceeds the least resolution value for respective rating of the transformer then capacitor steps are rearranged so that sensed KVAR remains within the least resolution specified. The automatic control unit will be able to sense the KVAR and generates the switching ON and OFF signals for capacitor banks. The scheme is as shown in figure 1 schematically.

6] Switched capacitors for 11 KV Substation :

Recently, in August 1992 REC has issued the specification for switched capacitor banks for 11 KV substation as follows.

<table>
<thead>
<tr>
<th>Transformer rating in MVA</th>
<th>Compensation steps by switched Capacitors in KVAR</th>
<th>Resolution</th>
</tr>
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</table>
Here also the same limitations exists. The minimum step of compensation is 600 KVAR and total compensation at full load 0.7 power factor is inadequate. To improve the situation an entirely new scheme is proposed will be as follows.

<table>
<thead>
<tr>
<th>Transformer rating in MVA</th>
<th>Compensation steps by switched Capacitors in KVAR</th>
<th>Resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.15</td>
<td>600+600=1200</td>
<td>600</td>
</tr>
<tr>
<td>5</td>
<td>600+1200=1800</td>
<td>600</td>
</tr>
</tbody>
</table>

This proposed scheme has a resolution of 120 and 200 KVAR respectively for the two transformers and adequate compensation capabilities. This scheme is totally error adaptive in the following sense; whenever KVAR error sensed is more than the resolution specified then capacitor switching will takes place so as to keep KVAR error within the resolution specified. While designing the error adaptive controller for this purpose, the line contingencies such as overvoltages, current imbalance in phase and capacitor banks as specified by REC will be taken care of. To develop such controller it seems that a dedicated microcontroller system will be more suitable, which will provide greater flexibility for control actions.
Also by providing additional peripheral devices such as displays, system parameters can be displayed. The overall schematic arrangement is as shown in figure 2.

7] Static VAR Compensator for 11 KV Substation:

The switched capacitor scheme for 11 KV substation dealt above is low cost but the compensation provided is varying in steps of 120 or 200 KVAR. To overcome this difficulty a thyristor controlled reactor can be used consisting of 40 KVAR and 67 KVAR per phase respectively. This will enable the smooth variation of reactive power through -120 to 1000 KVAR and -200 to 3000 KVAR for respective transformers. To control the conduction of thyristors in closed loop form and switching action of capacitors a dedicated microcontroller system will be used which will also takes care of line contingencies. For this purpose full software can be developed. The schematic arrangement is illustrated in figure 3. A reactive power output can be made to closely match with the load reactive power for maintaining the power factor at desire level.

8] Investigative Work :

The investigative work carried in this thesis essentially consists of three different stages:

i) Analytical study from theoretical considerations on a typical distribution system as present in the college campus. Six load cases have been considered.

ii) Simulation studies using MATLAB and SIMULINK for the purpose of evaluating the performance. Extensive studies have been carried out for making the switching operations transient field to arrive at
optimal value of inrush current limiting reactor with contactors and also with thyristor used as switches.

iii) Practical implementation of the scheme as proposed in the thesis work on a real system. The electronic controller, air cored reactors are designed and developed.

The various electronic devices such as microcontroller chips, thyristor for both switching and controlled have been assembled in the control panel and tested for its performance.

9] Cost Benefit Analysis:

The practical implementation of any scheme depends on its technical soundness and economic viability. In this thesis work, three distinct schemes will be dealt in detail which are technically sound compared to the existing practices in vogue. The cost benefit analysis based on capital investment, interest and depreciation charges and accrued gains will be carried out for all the schemes in both LT and HT applications.

10] Practical Implementation of New Schemes:

The new schemes dealt in the proposed plan of the thesis work have following attractive features.

a) The bank steps in LT switched capacitor are in binary sequential mode which yields optimum resolution, enabling good matching with reactive power demand of consumer loads.

b) The first scheme for HT provides four binary sequential steps so as to obtain good range of control with minimum possible step variation.
c) The second scheme for HT has been dealt with the static VAR compensation which yields smooth and continuously variable reactive power. This is an ideal scheme approaching the performance characteristics of a typical synchronous phase modifier. It is possible to provide voltage boost and buck through this arrangement as per the prevailing condition of operation during a time interval. However, this is somewhat costly scheme due to TCR, but it can be expected that the investment required is low as the cost of thyristors for phase control and switching is low.

It is expected that the schemes dealt in this thesis work will find wide application in future, both in electric supply undertakings and in industry due to their attractive features.

REFERENCES

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3. Microprocessor based static compensator of TSC and TCR type meeting A. C. System control requirements by U. Gudaru published in CAPACIT-86 by IEEMA.


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