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टेलीफोन / Tele : 2451200(PBX)
2450115 (DID)
Extn.: 42586
फैक्स / Fax : 91-0522-2465763

भारत सरकार – रेल मंत्रालय
अनुसंधान अभिकल्प और मानक संगठन
लखनऊ – 226 011
Government of India-Ministry of Railways
Research designs & Standards Organisation
Lucknow-226 011

No.TI/PSI/DRPC/DEV/07

Date: 03-04- 2007

REGD POST

Chief Electrical Engineer

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12- Western Railway, Churchgate, Mumbai-400 020
13- West Central Railway, DRM Office, Jabalpur
14- Central Organisation for Railway Electrification (CORE), Nawab Yusaf Road, Civil Line, Allahabad.

Sub : Instructions for use of Dynamic Reactive Power compensation.

Ref : This office letter No. TI/PSI/STATCON/DEV/06 dtd. 22.09.06

Vide reference to above please find enclosed herewith instruction No. TI/IN/0014 for use of dynamic reactive power compensation equipments.

Encls : as above

3.4.07
(Sumit Bhatnagar)
For Director General/TI

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Government of India

सत्यमेव जयते

Ministry of Railways
Research Designs & Standards Organisation
Manaknagar, Lucknow-226011

Instructions

For use Of Dynamic reactive Power compensation On IR

1.0 Scope

This Instruction stipulates the action to be taken by Zonal railways / CORE as applicable in case of providing dynamic power factor compensation equipment.

2.0 Objective and background

These guidelines will help in deciding the correct capacity of dynamic and fixed compensation to be provided for a particular TSS.

Traditionally fixed HT capacitors with 13% detuned reactor are being used for compensation of lagging reactive MVARs. However Railways may still end up having poor PF due to methodology adopted for calculation of PF i.e. addition of leading MVAR generated under over compensated situation arising due to light/no load conditions with fixed compensation method. Moreover the fixed capacitors connected to traction circuit with light load results into over voltages besides other limitations like generation of switching surges due to capacitor switching.

Railways shall have to interact with the respective supply authorities for getting the details of method for calculation of chargeable power factor being followed in their trivector meter. Proper study in terms of load variation pattern, harmonics content in the system, statutory requirement and tariff applicable etc. should be done at the time of considering installation of DRPC.

2.1 Limitations of fixed capacitor banks for PF Improvement

Although using fixed capacitor banks for PF improvement is the simplest and most cost effective method however it has got limitations e.g.

a. Provision of large size fixed capacitor banks for PF correction under no load or light load condition may create high voltages in the system. The over voltages generated due to switching in of capacitor banks under lightly loaded conditions should be recorded/ measured. Theoretically the rise in voltage on account of capacitor bank can be calculated by formula given below.

$$\% \Delta V = \frac{KVAR_{cap} \times Z_{tx}(\%)}{kVA_{tx}}$$

Where $\% \Delta V$ = percent voltage rise
$MVAR_{cap}$ = Capacitor bank rating
Z_{tx} = Traction Transformer Impedance (%)
kVA_{tx} = Traction Transformer rating

b. Under the no load/less load condition leading to over correction there will be losses due to flow of leading reactive current in the transformer windings.

c. Another disadvantage of using capacitor banks without proper series reactor is that the reactance of a capacitor bank decreases as the frequency increases, this causes the bank to act as a sink or trap for higher harmonic currents from the surrounding customer and/or utility system. The effect is increased current, increased heating and dielectric stresses that could lead to capacitor bank failure.

d. Switching on of HT capacitor banks results into over voltage switching transients of approximately 1.4 to 2.0 times the system voltage while switching off of capacitors puts stress on circuit breakers and possible damage to CB due to re-strike of arc.

In view of the above drawbacks it is difficult to achieve PF above 0.9 lagging using fixed capacitors. Recently in many states e.g. Orissa, West Bengal, Jharkhand, Tamilnadu, MP, Karnataka etc. rebate/incentive is being offered by electricity utilities for achieving PF above 0.9 up to unity. Due to the fast varying traction loads it is difficult to maintain this near unity PF simply using fixed capacitor banks hence to cater to this problem Dynamic reactive power compensation (DRPC) is the solution in such cases.

3.0 General instructions for adopting DRPC

The use of Dynamic Reactive Power Compensation shall be beneficial for Railways under following conditions

3.1 When tariff gives incentive/rebate for achieving PF above 0.9 upto unity, which is not advisable to achieve by using fixed capacitor banks due to problems of over correction in condition of light /no load (Such incentive is available in states like MPSEB, TNEB, and KSEB etc.)

3.2 As already pointed out above the fixed capacitor bank compensation leads to over compensation and leading PF under no/light load conditions, earlier the electricity boards were ignoring this leading MVAR and treated it as unity PF while calculating the PF and maximum demand energy charges and some of them were even subtracting the leading MVAR for calculating apparent power in the formula for chargeable PF. However in the year 2000 some utilities like MPSEB changed the calculation method to calculate the chargeable PF and started treating the leading MVAR similar to lagging MVAR for calculation of PF. This resulted in poor chargeable average PF and increase in MVA reading for Railways.

Although from 1.1.05, this problem was sorted out as MPSEB agreed not to consider the leading MVAR similar as lagging MVAR as a temporary measure, however they have advised railways to provide Dynamic reactive power compensation (DRPC) equipment at TSS to avoid the over compensation. Meanwhile as reported by S.Rly, ECoR other utilities like TNEB, CSEB have also adopted the similar stand of adding (and not neglecting) leading MVAR while calculating apparent power for chargeable PF.

3.3 When tariff is penalizing for values of PF lower than 0.9 or above which is difficult to maintain with fixed compensation under all load conditions especially at substations where variation in loads are more.

4.0 Reactive Compensation method

The reactive compensation Methods may be divided into following broad categories

(i) HT capacitors with 13% detuned reactors presently in use on IR. They also act as passive filters for filtering of harmonics but cannot fully eliminate all harmonics.

(ii) Static VAR compensators (SVC): The Static VAR compensators use power electronic switching devices to control capacitive or inductive energy into the power system. Commonly available SVC configurations are

- a. Thyristor switched capacitors (TSC).
- b. Thyristor controlled reactors with passive filters (TCR).
- c. TSC with TCR and passive filters to eliminate harmonics.

(iii) Self commutated VAR generators: The fast switching power electronic devices are used to act either as voltage or current fed inverter to inject required amount of leading/lagging reactive MVAR into the system. These are also known as active filters for power quality correction and are widely used in various configurations like shunt, series or combined use of shunt and series as UPQC.

At present two methods of dynamic PF correction are in use on Indian railway traction application namely:

a. Thyristor switched capacitors (TSC).
b. IGBT based STATCOM.

The calculation methodology for fixed and variable reactive compensation MVAR required to fully neutralize lagging MVAR to achieve near unity PF in both the above methods is explained in annexure IV with the two TSS sample data calculations.

4.1 Guidelines for deciding MVAR rating of dynamic and fixed compensation

4.1.1 The required reactive power compensation should be worked out based on typical load curve and the desired power factor improvement carefully as per RDSO instruction no. TI/IN/002 "Guidelines for shunt compensation for improving power factor at 25 Kv traction substation (September 96).

4.1.2 The energy parameters are to be recorded and tabulated every 15 minutes (or even less depending upon integration/window period followed by different utilities). The data obtained is to be utilized to make load distribution curves from fixed part which can cater to base load or minimum load on the TSS and additional variable / dynamic portion to compensate maximum load conditions. By providing variable compensation, the improvement in average power factor can be worked out by integrating the apparent and active powers during the various periods.

4.1.3 The load factor which is the ratio of summation of average kva-hr and maximum demand kva-hr be calculated for each TSS, generally load factor of a traction sub station varies from 25% to 45%. TSS with low load factor (i.e. wide variation of load) shall need more variable/dynamic compensation out of total reactive compensation required.

4.1.4 Average PF is measured on the basis of MVARh and MVAh for the period of 1 month and hence even if total lagging MVAR are not fully compensated for smaller period (less than window period adopted by utilities) it may not result in major deterioration of PF or MD however the exact tariff conditions may be verified in this regard.

4.1.5 While calculating total compensation MVAR required take into account tariff conditions for billing MD, CD e.g. In most of the states chargeable MD is taken as 70-80% of CD or recorded MD, whichever is higher.

4.1.6 The MVAR data collected for sufficient period should be used in determining following: -

1) The fixed compensation shall be used to maintain the p.f. of about 0.99 under no-load / minimum load condition. This is intended to take care of the base load of the sub-stations which also comprises of lighting / signaling transformers, no load magnetizing current of main transformer and DRPC's transformers etc.

   Summarily install LT/HT fixed capacitors of required capacity to cater the base load and rest compensation capacity by providing DRPC. The minimum requirement of fixed compensation for a typical TSS may be of the order of 600-1200 kVAR.

2) Rating of total reactive compensation required is to be based on maximum MVAR requirement occurred. Hence while calculating total MVAR compensation required as well as base load requirement of MVAR compensation, short duration peaks for maximum or minimum can be ignored. After study of such peaks for 1-2 months decide about MVAR requirement taking into account long duration uncompensated lagging MVAR which may increase MD. During the calculation the seasonal variations may also be taken into account in the load pattern and it will be better if load variation detail of different seasons are analyzed.

4.2 As already explained that presently two methods are being used for Dynamic Reactive Power Compensation.

1) If the compensation is done by Thyristor Switched capacitor Bank, the capacity of fixed capacitors will be equal to minimum required MVAR to compensate the base load. And as TSC type compensation generates capacitive MVAR only and not lagging reactive MVAR, the required variable compensation will be

= Total required max. MVAR compensation - Required min. MVAR compensation to be provided by fixed HT capacitor banks.

2) If the compensation is done by STATCOM, the capacity of fixed HT capacitors will be sum of 50% capacity of total required variable compensation and minimum required MVAR compensation. Moreover as STATCOM type compensation can generate capacitive as well as reactive MVAR, thus the required variable compensation will be equal to 50% capacity of total required variable compensation.

(i) Required capacity of fixed HT capacitor = Minimum required MVAR (Base load) + 50% capacity of total required variable compensation

(ii) Required capacity of variable compensation through STATCOM= 50% capacity of total required variable compensation

The case studies of two TSS having different load pattern is given in Annexure III as example. For the sake of simplicity, MVA, MVAR, and PF variation only for 24 hours has been shown. The Railways may take help of reputed outside agencies to undertake recording of energy/load measurements for calculating the total reactive compensation requirement.

5.0 The design considerations of Sub-components of complete DRPC system

5.1 Calculation For Fixed Cap with 13% detuned reactor.

Fixed compensation capacity requirement will be available in kVAR as described above.

Thus Required Capacitive reactance, **A** = $KV^2 x1000/kVAR$

In order to limit the over voltages limit the inrush current and to avoid resonance at all odd harmonics a series reactor is provided in series with capacitor bank. The reactor provided shall be 13% of the value of capacitor bank rating. In no case the value of X_L/X_C should be 11.1% as this is the resonance frequency for the third harmonics. Similarly ratio of X_L/X_C = 4% and 2% should be avoided to over come any resonance at 5th or 7th harmonics.

The value of inductive reactance of the series reactor can be given by the following expression:-

$$X_L = 0.13 X_C$$

However $$(X_C - X_L) = \mathbf{A}$$

$$\therefore X_C - 0.13\, X_C = \mathbf{A}$$

thus $$X_C = \mathbf{A} / (1 - 0.13)$$

Required capacitive reactance X_C = 1.149A

and Rating of series reactor -:

$$X_L = 0.13\, X_C$$
$$= \mathbf{0.13 \times 1.149A}$$

Required inductive reactance X_L = 0.149A

(For more details please refer this office Instruction No. IN 0002 Rev. 1)

5.2 Calculation For TSC and STATCOM sub-components

5.2.1 *Rating of LT Capacitor*

The capacitor should be capable to take care of the voltage 1.6 times of system voltage. As the voltage across the capacitor at fundamental frequency may be 1.29 times the rated system voltage and there will be voltage rise due to harmonic current also.

5.2.2 *Rating of Series Reactor for each arm of LT capacitor*

The ratio of the inductor reactance to the capacitor reactance at network frequency should be 13%

5.2.3 *Rating of Transformer*

Required Rating of reactive compensation = **X** MVAR at **27 kV**.

Consider 10% extra for future addition on account of increase in load.
Thus revised Rating of reactive compensation will be=**1.1 X** MVAR at **27 kV**.

As it is desired that capacitor shall satisfactorily operate continuously at rated Voltage and shall withstand 30% over current due to over voltages, harmonics and transient over current

Thus required new reactive compensation = **1.1 X** x **1.3** MVAR
The new MVAR rating will be = **1.43 X** MVAR

Thus required rating of transformer will be = 1.43 x **X** kVA
$\cong$ 1.50 x **X** kVA

For IGBT based STATCOM system also same methodology for rating of step down transformer may be adopted.

5.2.4 General guidelines for Rating of Thyristor & IGBT Modules

The selection of power modules for any application is subject to the considerations of:

- Voltage capacitance,
- Current carrying capacity under realizable cooling conditions and with reference to the switching frequency
- Safe operating areas (SOA) and
- Critical rate of rise of on-state current (di/dt)

The most important characteristics of power modules will deteriorate when the temperature rises. For this and few other reasons, the determination of the maximum operating temperature is critical.

Under no circumstances, the maximum ratings for blocking voltage, peak current, junction temperature and safe operating area as indicated in the datasheets be exceeded, which might occur during any static or dynamic operation. The same goes for the limit values of module case parameters (e.g. isolation voltage, vibration strength, climate persistence, assembly instructions).
It must be ensured that the specific semiconductor module approved by RDSO prior to type testing should only be used, at the time of supply and commissioning of the system.
The selection of a suitable power electronic device for a specific application is a complex exercise however now various websites like www.semisel.semikron.com offer online solutions for selection of correct rating and type of module, which can also be explored.
The design of the complete dynamic compensation system shall be modular. There are different capacity semiconductor power modules available, hence capacity of each module should be verified as per the design drawings approved by RDSO prior to type testing. The

rating of each module or step in the existing TSC based DRPC systems is 100 KVAR. Similarly, existing IGBT based STATCOM, each module is of 150 KVAR.

5.2.5 Features of APFC relays/ controllers

In TSC systems microprocessor DSP based APFC relays controls the power factor of the installation by giving signals to switch ON or OFF power factor correction capacitors. It is the brain of control circuit and controls firing of thyristors to switch on/off the capacitors based on zero differential voltage switching.

Calculation of power parameters is based on stored sampled data of voltage and current inputs using a fast sampling rate ADC. The fundamental component of voltage and current is extracted using fast Fourier transform techniques. Generally the APFC are capable of displaying various power parameters like true RMS values of V & I, power, Energy, MD and harmonics etc. These are also provided with different serial communication ports, data loggers, soft touch control keypads, self-check and protection features

When the power factor falls below setting, the capacitors are switched on either First in First out (FIFO) or First in Last Out (FILO) sequence. The capacitors controlled by the APFC must be switched on/off in linear sequence. To prevent over correction hunting, a dead band is provided. This setting determines the range of phase angle over which the controller does not respond; only when the PF goes beyond this range, the controller acts. When the load is low, the effect of the capacitors is more pronounced and may lead to hunting. Under current blocking (low current cut out) shuts off the controller, switching off all capacitors one by one in sequence, when load current is below setting. Special timing sequences ensure that capacitors are fully discharged before they are switched in. This avoids dangerous over voltage transient. The solid state LCD displays various functions that the operator should know and also indicate each capacitor switching stage.

5.3 In addition to above, the following design calculations may be verified with the supplier at the time of commissioning of DRPC system.

- Reactive power compensation requirement for various load patterns.
- Parallel resonance frequencies and inrush current calculation for each combination of capacitor arm in TSC system.
- Data of harmonic measurement carried out by supplier before and after installation of DRPC.
- Selection of Switchgear based on above calculations.
- Design of panel cooling system.
- Calculation for transformer terminal voltage at leading PF.
- Calculation for short circuit effect (Electro Dynamic forces developed) on Bus bars.
- Voltage drop calculation of Bus Ducts.
- Protection for Transformer, IGBT/Thyristor panel, IGBT/Thyristor module etc.
- Structure design for Transformer & IGBT/Thyristor panel.
- Foundation design calculation.

Effects of harmonics and lagging MVAR drawn by load needs to be studied separately for deciding on dynamic compensation because adoption of modern power quality correction techniques can simultaneously act for PF and harmonics corrections. Moreover it must be ensured that DRPC system does not increase the existing harmonics level due to switching of its own power electronic devices.

At present only few systems of dynamic reactive compensation are working on Indian Railways namely TSC systems at Bhadli (CR) and Makshi (under commissioning) and STACON based systems at Lasalgaon , Pimperkheda (CR), while some more systems are either in planning stage or under commissioning hence performance of the systems installed need to be evaluated by Railways in terms of initial cost, losses, system output and maintainability of the systems as per the Para 14.0 of RDSO specification no. TI/SPC/PSI/DRPC/0050 regarding Capitalization of losses & benefits.

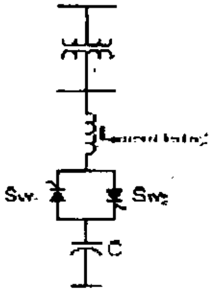
Annexure-I

Operating principal Thyristor-Switched Capacitors

It is a well known fact that conventional contactor or breaker switching systems are not suitable for improving p.f at places where the load is of fast variable nature. Therefore, electric traction always faces the problem of low p.f. Since frequent switching of H.T. capacitors is not possible, hence it is necessary to inject the required amount of capacitive current through thyristor switched LT capacitors at 433 V. Static compensators of the TSC type have the features of stepwise control, average delay of one half a cycle (maximum one cycle), and no generation of harmonics since current transient component can be attenuated effectively.

The basic scheme of a static compensator of the thyristor-switched capacitor (TSC) is as below:

25 kV single phase traction supply is stepped down to 433 volts through step down transformer. On the LT side of the transformer; the capacitors, which are split up into appropriately small steps, are connected and individually switched in and out using bi-directional thyristor switches. Switching of these thyristors is controlled by an automatic power factor correction relay. This relay is fed with current and voltage inputs through proper CTs and PTs for p.f. sensing of the load. the relay will determine the correct amount of capacitors required at any time for maintaining target p.f. by switching in and out the capacitors accordingly.



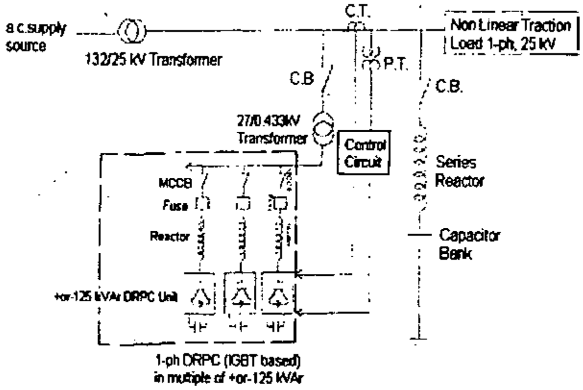
The thyristor-switched capacitor configuration.

Each single-phase branch consists of two major parts, the capacitor C and the thyristor switches. In addition, there is an inductor L, whose purpose is to limit the rate of rise of the current through the thyristor, to prevent resonance with the network and to prevent any inrush current produced by a firing pulse out of time. To connect each branch, a firing pulse is applied at the thyristor gate, when the capacitor voltage and the network voltage have the same value (this Zero differential voltage is sensed using a comparator circuit connected across the thyristor). In this way, a soft connection is obtained. The voltage across the capacitor will increase starting from zero without distortion, following a sinusoidal waveform, and after the half cycle is completed, the capacitor voltage will have the reverse voltage, and the thyristor automatically will block. In this form of operation, both connection and disconnection of the branch will be soft, and without distortion. If the firing pulses, and the voltage *at zero value* are properly adjusted, neither harmonics nor inrush currents are generated,

Annexure-II

Operating principle of IGBT based Self-commutated VAR compensator

The Self-commutated VAR compensator is basically meant for stepless (smooth) and dynamic reactive compensation of a given load reactive power demand and is hence used in shunt with the load. Self-commutated VAR compensators capable of generating or absorbing reactive power without requiring large banks of capacitors or reactors ,instead it uses a capacitor with a regulated dc voltage. Self-commutated compensators are used to improve voltage regulation, correct power factor. The compensator uses pulse width modulated (PWM) voltage source converters (VSCs) based on IGBTs as the self-commutated power device.



GENERAL SCHEME OF IGBT Based
DYNAMIC REACTIVE POWER COMPENSATION

The VSC is a boost converter with output DC voltage greater than peak of the supply voltage. The fundamental component of PWM voltage reacts with the input supply voltage to produce the desired capacitive or inductive current. The load current feed back from a load CT is given to the VSC, which calculates the reactive current component. The fundamental component of the PWM voltage is dynamically adjusted to offer exact compensation for the calculated reactive current component of the load current. This relieves the source from supplying any reactive current/VAR. Neglecting the internal power losses of the overall converter, the control of the reactive power is done by adjusting the amplitude of the fundamental component of the voltage.

Its principle of operation is similar to the synchronous machine. The concept of STATCOM is very simple but it is difficult to implement.

The IGBT based VSC generates an AC voltage, which is in phase with the network voltage. This VSC & network, they are connected through a series reactor or transformer leakage reactance. The current flows through the reactor lags/leads the network voltage, depending on the direction of current. When the voltage generated by VSC is greater than the network voltage, leading reactive current is drawn from the network and then STATCOM acts as a capacitor and when the network voltage is greater than the VSC voltage, a lagging current is drawn from the network and then STATCOM acts as a reactor.

Annexure-III

Typical load variation pattern of Heavy Loaded TSS

Time	MVARh	PF	MVAh
00:15	2.3458363	0.838	4.299
00:30	3.4078002	0.851	6.489
00:45	6.3998779	0.818	11.126
01:00	4.2943325	0.85	8.152
01:15	5.394757	0.825	9.546
01:30	4.3760727	0.847	8.232
01:45	7.3840135	0.796	12.199
02:00	4.9714153	0.828	8.866
02:15	6.3291812	0.812	10.844
02:30	5.5472464	0.827	9.867
02:45	5.7106662	0.825	10.105
03:00	4.6015037	0.841	8.505
03:15	4.77218	0.832	8.602
03:30	6.0799161	0.819	10.596
03:45	4.2676948	0.823	7.513
04:00	4.3508587	0.845	8.136
04:15	5.55666	0.826	9.858
04:30	5.5702418	0.82	9.732
04:45	5.3201414	0.814	9.159
05:00	5.5123522	0.824	9.729
05:15	5.3183965	0.813	9.134
05:30	4.2648638	0.827	7.586
05:45	4.1949238	0.829	7.501
06:00	3.8746684	0.826	6.874
06:15	4.9008476	0.821	8.584
06:30	4.3070339	0.822	7.563
06:45	3.8700324	0.848	7.302
07:00	4.4385524	0.825	7.854
07:15	2.996323	0.82	5.235
07:30	3.7428601	0.828	6.675
07:45	4.1336344	0.797	6.844
08:00	2.5722506	0.809	4.376
08:15	5.6715357	0.791	9.27
08:30	4.581787	0.797	7.586
08:45	6.3235338	0.796	10.447
09:00	7.4711027	0.783	12.011
09:15	4.6897468	0.806	7.923
09:30	6.4945895	0.797	10.753
09:45	5.401078	0.813	9.276
10:00	6.4126622	0.808	10.884
10:15	4.7743053	0.829	8.537
10:30	5.0149553	0.819	8.74
10:45	3.7377122	0.823	6.58
11:00	3.565543	0.832	6.427
11:15	2.4249243	0.832	4.371
11:30	3.803296	0.827	6.765
11:45	4.2995051	0.823	7.569
12:00	3.7674313	0.832	6.791
12:15	5.3852475	0.806	9.098
12:30	4.8031519	0.815	8.289
12:45	2.9926536	0.833	5.409
13:00	2.9239967	0.825	5.174
13:15	2.4365635	0.852	4.654
13:30	1.7601286	0.834	3.19
13:45	2.8769704	0.856	5.565
14:00	2.0387891	0.816	3.527
14:15	1.6080685	0.847	3.025
14:30	1.148476	0.846	2.154
14:45	0.8205915	0.898	1.865
15:00	1.5360452	0.819	2.677
15:15	3.0392116	0.843	5.65
15:30	3.467876	0.799	5.767
15:45	1.9621979	0.861	3.858
16:00:00	2.1814162	0.779	3.479
16:15:00	1.5403252	0.855	2.97
16:30	2.2639931	0.833	4.092
16:45	2.5943315	0.848	4.895
17:00	3.7601884	0.81	6.412
17:15	1.3194306	0.838	2.418
17:30	5.0688917	0.802	8.486
17:45	3.1743505	0.825	5.617
18:00	4.7858748	0.792	7.839
18:15	6.3934782	0.79	10.428
18:30	5.4848224	0.793	9.003
18:45	6.557607	0.792	10.741
19:00	4.2406413	0.82	7.409
19:15	5.718658	0.799	9.51
19:30	5.0953294	0.812	8.73
19:45	6.6111056	0.794	10.875
20:00	4.1410501	0.82	7.235
20:15	4.9688777	0.815	8.575
20:30	5.4773307	0.822	9.618
20:45	3.5195403	0.846	6.601
21:00	4.8067499	0.831	8.641
21:15	3.9336432	0.816	6.805
21:30	5.7763793	0.819	10.067
21:45	5.4569138	0.82	9.534
22:00	4.3470473	0.821	7.614
22:15	3.461088	0.818	6.017
22:30	3.9654488	0.805	6.684
22:45	4.8402805	0.823	8.521
23:00	5.4260616	0.809	9.231
23:15	4.55496	0.827	8.102
23:30	5.0464795	0.823	8.884
23:45	3.9393287	0.836	7.179
00:00	4.4624911	0.838	8.178
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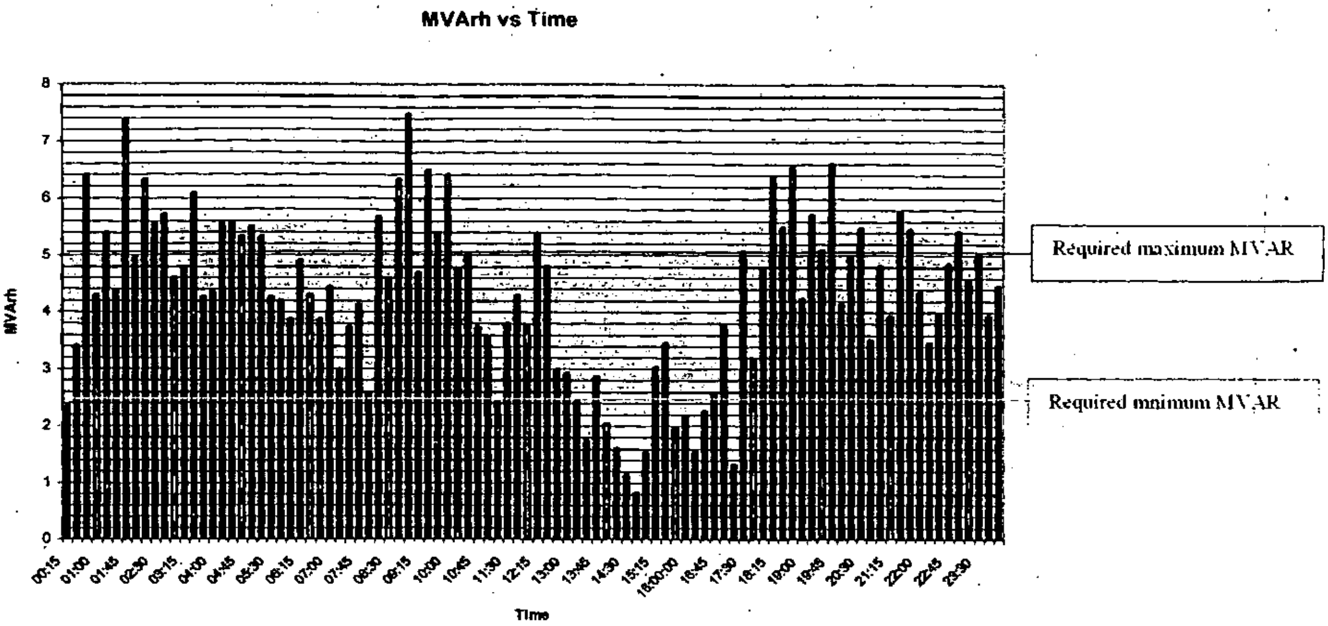
min=	0.8205915	Average=	4.3016143



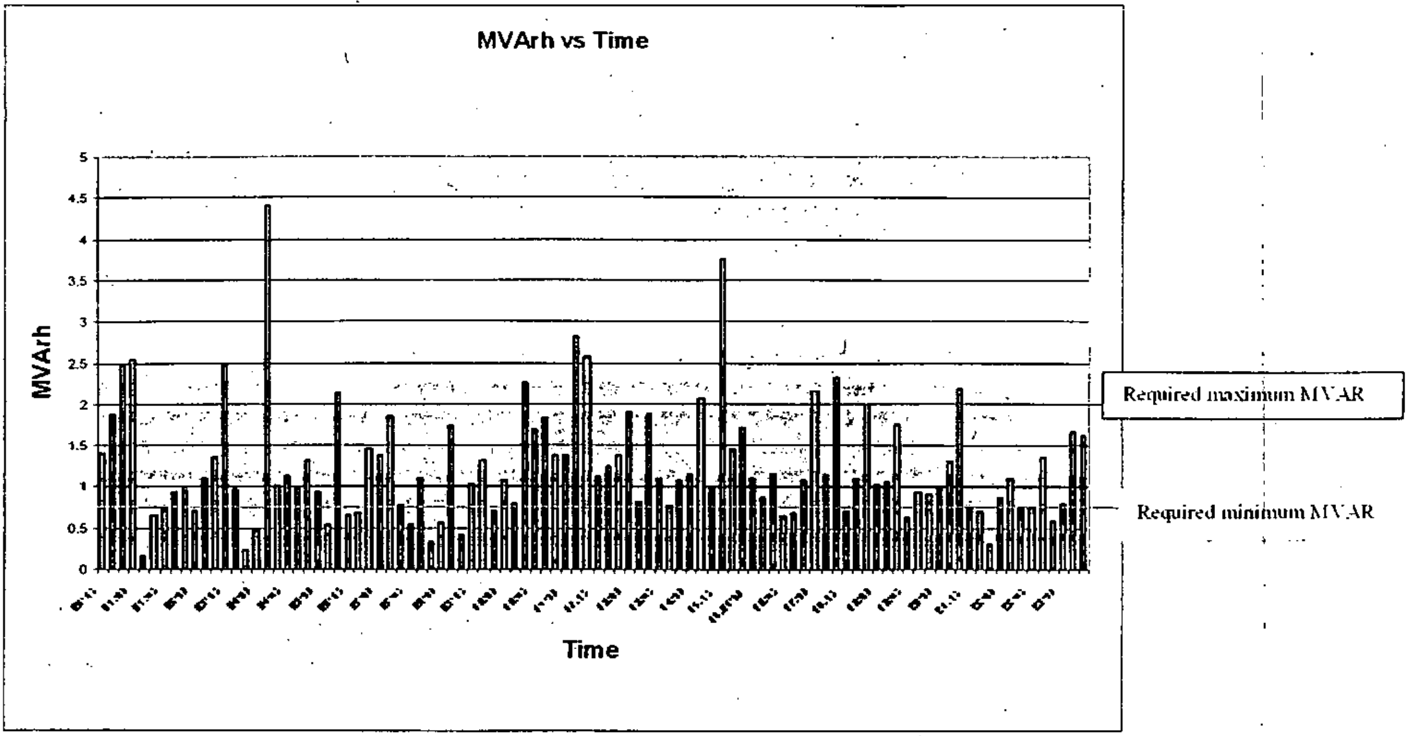
As the total required compensation for this particular TSS is approx. 5.7 MVAR and the minimum required compensation (base load) is 2.4 MVAR.

Case-I : If we adopt TSC type compensation method, the capacity of Fixed HT capacitor will be 2.4 MVAR and capacity of Thyristor switched LT capacitor will be 3.3 MVAR.

Case-II : If we adopt STATCOM type compensation method, the capacity of Fixed HT capacitor will be {(2.4 + 50% of 3.3 MVAR) = 4.05 MVAR} and capacity of STATCOM will be 50% of 3.3 MVAR = ± 1.65 MVAR. Because when STATCOM generate lagging reactive MVAR of its total capacity the total compensation will be equal to (4.05- 1.65)=2.4 MVAR and when it generates leading/capacitive MVAR of its total capacity the total compensation will be equal to (4.05 + 1.65)=5.7 MVAR, thus total variable compensation is for 3.3 MVAR i.e. from 2.4 MVAR to 5.7 MVAR.

Typical load variation pattern of Lightly Loaded TSS

Time	MVARh	PF	MVAh	12:30	1.2328822	0.809524	2.1
00:15	1.4177447	0.9142857	3.5	12:45	1.3964218	0.911765	3.4
00:30	1.8761663	0.9130435	4.6	13:00	1.8973657	0.818182	3.3
00:45	2.4718414	0.5666667	3	13:15	0.8306562	0.971429	3.5
01:00	2.5455844	0.6363636	3.3	13:30	1.8761712	0.913043	4.6
01:15	0.1732051	0.5	0.2	13:45	1.0954441	0.935484	3.1
01:30	0.6557438	0.9545455	2.2	14:00	0.7745967	0.875	1.6
01:45	0.7416199	0.9642857	2.8	14:15	1.0816649	0.857143	2.1
02:00	0.9380832	0.9130435	2.3	14:30	1.161895	0.6875	1.6
02:15	0.9591663	0.9166667	2.4	14:45	2.0566975	0.678571	2.8
02:30	0.7141428	0.9615385	2.6	15:00	0.9797959	0.92	2.5
02:45	1.0954451	0.9354839	3.1	15:15	3.7456641	0.452381	4.2
03:00	1.3527749	0.90625	3.2	15:30	1.4496662	0.8915	3.2
03:15	2.4959968	0.8541667	4.8	15:45	1.7175564	0.84375	3.2
03:30	0.9643651	0.8235294	1.7	16:00:00	1.0954441	0.935484	3.1
03:45	0.2236068	0.6666667	0.3	16:15:00	0.8717798	0.9	2
04:00	0.4795832	0.9166667	1.2	16:30	1.148917	0.941176	3.4
04:15	4.4215382	0.7424242	6.6	16:45	0.6557471	0.954545	2.2
04:30	1.0198039	0.9259259	2.7	17:00	0.6855681	0.958333	2.4
04:45	1.1313709	0.9393939	3.3	17:15	1.0770356	0.933333	3
05:00	0.9797959	0.92	2.5	17:30	2.1563877	0.897959	4.9
05:15	1.3228757	0.75	2	17:45	1.161895	0.875	2.4
05:30	0.9380832	0.9130435	2.3	18:00	2.3345197	0.912281	5.7
05:45	0.5385165	0.9333333	1.5	18:15	0.714147	0.961538	2.6
06:00	2.1330761	0.895833	4.8	18:30	1.1135529	0.9375	3.2
06:15	0.6557471	0.954545	2.2	18:45	1.9899767	0.833333	3.6
06:30	0.6855681	0.958333	2.4	19:00	1.0392335	0.928571	2.8
06:45	1.4594513	0.918919	3.7	19:15	1.0583041	0.931034	2.9
07:00	1.3964218	0.911765	3.4	19:30	1.7663524	0.902439	4.1
07:15	1.8520259	0.75	2.8	19:45	0.6244998	0.95	2
07:30	0.7745967	0.875	1.6	20:00	0.9380856	0.913043	2.3
07:45	0.5385178	0.933333	1.5	20:15	0.9110524	0.97619	4.2
08:00	1.0954449	0.764706	1.7	20:30	0.9797898	0.71429	1.4
08:15	0.3316628	0.833333	0.6	20:45	1.3228757	0.75	2
08:30	0.5567764	0.9375	1.6	21:00	2.1908901	0.304348	2.3
08:45	1.7435596	0.9	4	21:15	0.7416169	0.964286	2.8
09:00	0.4123104	0.888889	0.9	21:30	0.7	0.96	2.5
09:15	1.0392335	0.928571	2.8	21:45	0.3	0.8	0.5
09:30	1.3048274	0.8235	2.3	22:00	0.8717798	0.9	2
09:45	0.714147	0.961538	2.6	22:15	1.0954441	0.935484	3.1
10:00	1.0816649	0.857143	2.1	22:30	0.754986	0.965517	2.9
10:15	0.8062254	0.969697	3.3	22:45	0.7483306	0.866667	1.5
10:30	2.2449918	0.866667	4.5	23:00	1.3527749	0.90625	3.2
10:45	1.6970551	0.894737	3.8	23:15	0.5916103	0.944444	1.8
11:00	1.8330294	0.909091	4.4	23:30	0.8062254	0.969697	3.3
11:15	1.3747721	0.909091	3.3	23:45	1.6733193	0.891892	3.7
11:30	1.3964218	0.911765	3.4	00:00	1.6248096	0.885714	3.5
11:45	2.8284258	0.851852	5.4				
12:00	2.5690433	0.896552	5.8	max=	4.4215382		
12:15	1.1313703	0.939394	3.3	min=	0.1732051	Average=	1.2656963



As the total required compensation for this particular TSS is approx. 2.0 MVAR and the minimum required compensation (base load) is 0.75 MVAR.

Case-I : If we adopt TSC type compensation method, the capacity of Fixed HT capacitor will be 0.75 MVAR and capacity of Thyristor switched LT capacitor will be 1.25 MVAR.

Case-II : If we adopt STATCOM type compensation method, the capacity of Fixed HT capacitor will be {(0.75 + 50% of 1.25 MVAR) = 1.375 MVAR} and capacity of STATCOM will be 50% of 1.25 MVAR = ± 0.625 MVAR. Because when STATCOM generate lagging reactive MVAR of its total capacity the total compensation will be equal to (1.375- 0.625)=0.75 MVAR and when it generates leading/capacitive MVAR of its total capacity the total compensation will be equal to (1.375 + 0.625)=2.0 MVAR, thus total variable compensation is for 1.25 MVAR i.e. from 0.75 MVAR to 2.0 MVAR.