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Asset Optimization & Switching Time Optimization in Fixed Shunt Capacitor Switching System in Electricity Distribution Utility

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***Abstract*—In this advanced digital world, Reactive power improvement plays vital role in electricity distribution utility. It has major benefits such as improved grid stability, decrease in losses, improved equipment life etc. Fixed shunt capacitor bank switching method widely used in distribution utility for reactive power management. We studied capacitors bank optimization and switching time in this paper. Asset optimization benefits financially and switching time management reduces technical & financial losses.**

***Keywords*—Asset optimazation;Swicthing time; reactive power improvement etc**

I. INTRODUCTION

Mumbai's leading Power distribution utility operates an extensive network that covers over 400sq.kM, serving the region from Bandra to Mira-Bhayander in the west and Sion to Mankhurd in the east. We are committed to delivering reliable electricity to more than three million households, achieving a Peak demand of 2300 MW in June 2024, supported by an installed capacity of 4,517 MVA. The management of Reactive power is crucial for the efficient and reliability functioning of electrical systems. Enhancements in Reactive power offer several significant advantages, including improved system and voltage stability, reduced energy losses, optimized power factors, excessive overheating, extended equipment lifespan, and increased grid capacity.

In our distribution system, we have implemented a Fixed Shunt Capacitor Switching strategy for effective reactive power management. This paper focuses on the optimization of capacitor bank assets and the manual switching times of capacitors.

In our system, a total of 244 Nos. Power Transformers with a rated voltage of 33/11kV & 22/11kV are installed. Power Transformers have different capacities such as 10MVA& 20MVA. The low power factor (PF) leads to increased distribution losses. When the power factor is low, the current drawn increases for a given load. Since losses are proportional to the square of the current, this results in higher losses. To mitigate the losses associated with a poor power factor, it is beneficial to improve the power factor, which can be achieved through the use of shunt capacitors. These capacitors can be installed on the secondary side (11 kV side) of 33/11 kV power transformers in substations. As per the practice Fixed Capacitor banks having capacity ranging from 2.7 MVAR to 5.5 MVAR are installed and connected to 11kV Bus for injecting the Reactive power into the system. Capacitor switching done by Operator remotely through SCADA system considering parameters such as power factor, voltage profile, Transmission network requirement, type of consumer load etc. We have selected 14 Power transformers for this study as per following table 1.

For analysis purposes, we have categorized Capacitor banks in the following category.

1. Asset Optimization
2. Switching Time Optimization

We collected data & analyzed parameters such as percentage loading in peak month, Average power factor & existing switching operations (ON/OFF) at load dispatch center for selected capacitors in Table I.

TABLE I. LIST OF CAPACITORS INSTALLED IN SUBSTAIONS

Sr no.	Distribution Substation	Transformer Capacity	Installed Capacitor (KVAr)
1	CHEMBUR-1	10MVA-1	2780
2	CHEMBUR-2	10MVA-1	2720
3	CHEMBUR-3	20MVA-1	5440
4	MALAD-1	20MVA-1	2780
5	MALAD-2	20MVA-1	5440
6	MALAD-3	20MVA-2	5440
7	BANDRA-1	20MVA-1	5440
8	BANDRA-2	20MVA-2	5440
9	BANDRA-3	10MVA-1	2720
10	BANDRA-4	20MVA-1	5440
11	BANDRA-5	20MVA-2	5440
12	MIRA BHAYANDAR-1	20MVA-1	5500
13	MIRA BHAYANDAR-2	20MVA-2	5500
14	MIRA BHAYANDAR-3	20MVA-3	5500

II. ASSET OPTIMIZATION

We gathered historical data and made the following observations.

1) Eleven Power transformers exhibit monthly peak loading levels below 40%, as illustrated in Figure I. Only three transformers, namely Mira Bhayandar-1, Mira Bhayandar-2, and Mira Bhayandar-3, experience peak load levels exceeding 40% in the system, as explained in Fig (1).

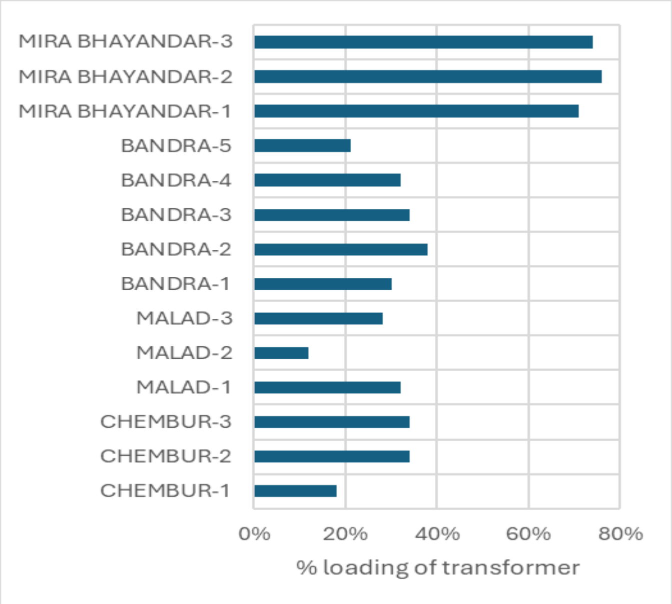

Fig.1. Percentage Transformer loading of 14 selected cases

2). The average power factor for 11 cases out of 14 is 0.99 and these capacitors were not operated (ON/OFF) for reactive power improvement throughout the peak month. For the remaining 3 cases, i.e. distribution substations at Mira Bhayandar-1, Mira Bhayandar-2 and Mira Bhayandar-3 have very poor power factors.

3) The data on capacitor switching operations has been analyzed, revealing that, in accordance with current practices at the control center, no capacitor switching occurred in the 11 specified cases over the course of the year. However, daily capacitor switching is consistently performed for the remaining three distribution substations: Mira Bhayandar-1, Mira Bhayandar-2, and Mira Bhayandar-3.

Most of the premium Consumers in some area has their own Automatic power factor control units. Also, there are already installed APFC units at various Consumer substations (11kV/430V).

Hence considering the above statistics, we recommend to consider these 11 cases under asset optimization category & advised to decommission capacitor banks from existing respective locations. The remaining three cases will be considered under Switching time optimization (ON/OFF time).

Here are the Key benefits of Asset optimization.

- Space saving in congested Metro city: - There is space requirement of 8.8 meters by 4.75 meter i.e. 41.8m^2 including fencing in distribution substation. So approximately 450 sq feet will be saved by decommissioning these capacitor banks at single substation. Ready reckoner rate in Bandra area is more than 300000 rupees per square meters approximately. So saved space cost of one case will be more than 12.5 million rupees approximately.
- Cost saving can be done by utilizing decommissioned capacitor banks units and utilization at other locations where it is required. After the decommissioning of the capacitor bank, large space will be empty at existing distribution substations.
  This space can be utilized for
1) For commissioning a new distribution feeder which will improve reliability in open ring distribution system.
2) Commissioning of new Unitized Compact Consumer substation as per network requirement.
- Reduction in operation and periodic maintenance cost of capacitor bank.
- Capacitor banks can lead to power quality issues, including elevated steady-state voltages, switching transients during operation, and the potential for harmonic resonance. These issues are avoided.
- Capacitor banks may experience failures due to factors such as resonance effects, inadequate maintenance, sudden fluctuations in load, and the presence of harmonics. The risk of fire & explosion hazards due to capacitor has also been eliminated.

III. CAPACITOR SWITCHING TIME OPTIMAZATION.

Now out of 14 cases, 3 Nos. of cases are considered for switching time optimization. There are various small-scale industries in Mira-Bhayandar east area and consumers don’t have their own automatic power factor control system. It is very clear that MVAR requirement is very high in these 3 cases. Manual capacitor switching at control center through SCADA is done on basis of

- Transformer loading,
- Reactive power requirement by System,
- Improvement of voltage at 33kV level

TABLE II. CAPACITOR SWITCHINHG DATA

Before switching ON		After switching ON		Switching Time (hh:mm)
Power Factor	Transformer Load	Power Factor	Transformer Load	
0.97	383	0.99	375	08:36
0.94	417	0.98	398	08:50
0.94	421	0.99	406	08:53
0.94	420	0.97	407	08:55
0.95	527	0.99	495	09:02
0.95	453	0.98	431	09:04
0.94	441	0.98	401	09:08
0.89	571	0.99	503	09:33
0.92	497	0.99	448	09:43

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The data in Table II is gathered for various switching times and different transformer load conditions at Mira Bhayandar-3..It is very clear that , power factor improved after switching ON capacitor. Table II presents data comparing the conditions before and after the manual capacitor switching at the Mira Bhayandar-3 power transformer.

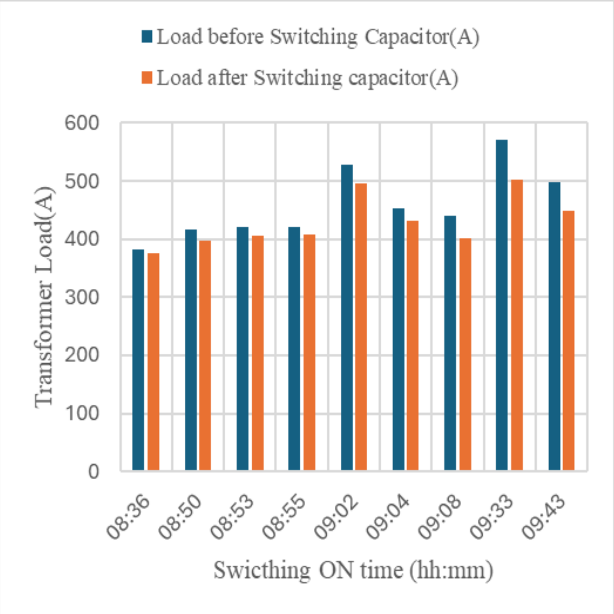

Fig. II. Transformer load (11kV) before & after switching ON capacitor vs Switching ON Time at Mira-Bhayandar-3

As an example, Mira Bhayandar-3 before and after transformer loading with respect to switching time shown in Fig-II. After switching ON the capacitor, there is an immediate decrease in transformer loading which varies as per switching time. Delays in capacitor switching can primarily impact transformer loading.

Fig III shows that percentage reduction in transformer loading with respect to time due to capacitor switching. So, capacitor Switching "ON" must be done on proper time. Transformer efficiency varies between 96 to 99 respectively. This efficiency is influenced by both the design of the transformer and the actual operating load it experiences.

Transformer losses are classified into two categories: No-load losses and Load losses. Manufacturers typically provide specific values for both No-load loss ($P_{NO\text{-}LOAD}$) and Load loss (P_{Load}) for each transformer. The total power loss (P_{Total}) in the Transformer at any given load level can be determined using the following formula:

$$P_{TOTAL} = P_{NO\text{-}LOAD} + (\%\ Load/100)^2 * P_{LOAD}. \quad (1)$$

From Figure IV, we can observe that as the switching time of capacitors is delayed, there are more significant variations in the power factor. This indicates that timing plays a crucial role in maintaining an optimal power factor. If we delay the switching of capacitors, the system may experience increased reactive power demand, which can lead to lower power factor levels. A lower power factor can result in inefficiencies in the power system, causing increased current flow and additional strain on transformers and other equipment.

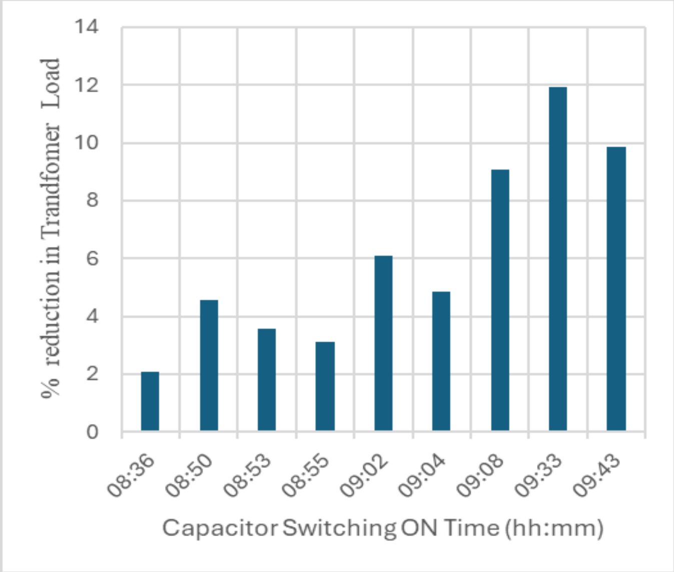

Fig.III. Percentage Reduction in transformer load (11kV) after switching ON capacitor at Mira-Bhayandar-3

Furthermore, as illustrated in Figure II & IV, the delay in switching capacitors directly affects transformer loading. When the power factor is poor due to untimely capacitor switching, Transformers operate under heavier loads than necessary, leading to increased losses both Technical (in the form of heat and energy loss in the transformer windings) and Financial (due to higher energy costs and potential penalties from utility companies for low power factors). Data indicates that capacitor switching impacts transformer loading by over 10%.

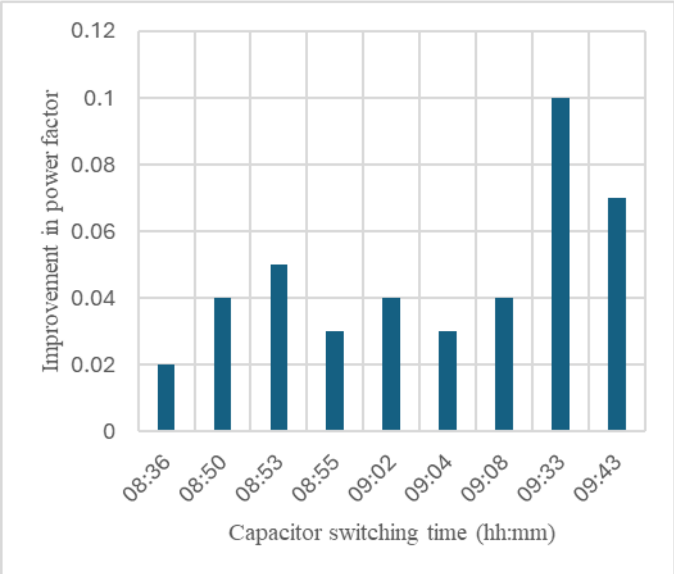

Fig IV. Improvement in Power factor after switching ON capacitors at Mira Bhayandar-3.

To mitigate these issues, it is essential to strategically schedule the switching of capacitors. By activating these reactive power compensators at the proper time, we can stabilize the power factor, minimize transformer loading, and ultimately reduce both technical and financial losses.

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We recommend revising the criteria outlined in Table II regarding the loading of transformers, power factor, and switching time. This updated criterion is also applied to automate capacitor switching using the SCADA system. Implementing this automation will contribute to a reduction in transformer losses.

TABLE III. CRITERIA FOR CAPACITOR SWITCHING ON

Revised Criteria for switching ON capacitor			
Criteria	Mira Bhayandar-1	Mira Bhayandar-2	Mira Bhayandar-3
Switching time (ON) range	08:15 - 08:30 am	08:15 - 08:30 am	08:15 - 08:35 am
Transformer load at 11KV side (A)	380-400	350-380	340-380
Power Factor	<0.98	<0.98	<0.98

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SUMMARY

We analyzed 14 existing cases of fixed shunt capacitor banks installed at distribution substations in an electricity distribution utility to improve reactive power. However, upon evaluation, we found that there was no requirement for fixed shunt capacitor banks at 11 of these locations. Consequently, we removed the installed capacitor banks from these sites to optimize their usage.

The remaining 3 cases still require the switching ON of capacitor units to improve reactive power. To further optimize the capacitor switching, we studied these 3 cases using historical data on power factors, transformer loading, and other relevant parameters.

Based on this analysis, we derived new criteria for switching on the capacitor units. These criteria consider factors such as transformer loading, power factor, and switching time to ensure optimal capacitor bank operation. We implemented the new switching criteria to enable automatic capacitor switching at these three locations. This optimization is expected to improve the overall performance and efficiency of the distribution network.

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