International Journal of
Scientific Engineering and Technology Research

ISSN 2319-8885
Vol.03,Issue.15
July-2014,
Pages:3259-3263

www.semargroup.org,
www.ijsetr.com

Design and Calculation of 5 MVAR Shunt Capacitor Bank at 33 kV Bus in Distribution Substation

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Abstract: Shunt capacitor bank improves the power factor, increases voltage level on the load and reduces current flow through the transmission lines. The main reason of installing a capacitor bank is to reduce electricity costs. This inappropriate installation without enough study gives rise to a great variety of technical problems. Therefore, the fact that capacitor banks are designed for long-term use should be considered. Capacitor have no moving parts, initial cost is low, upkeep costs are minimal, and they are compact, reliable, and highly efficient and can be installed basically three possibilities to correct loads individually, in groups or centrally. In this paper, model of 5 MVAR rating of shunt capacitor bank is designed installation for 33 kV busbar is Aung Chan Thar 132/33/11 kV substation in Myanmar.

Keywords: Power Factor Improvement, Reduce Electricity Cost, Reactive Power Stability, Shunt Capacitor Bank, Voltage Control.

I. INTRODUCTION

An electrical power system consists mainly of the components are generators, transformers and transmission lines. The transmission system consists of all the equipment from the generating-end, switchyard lines, switching stations, equipment at the receiving-end till the entrance to sub-transmission networks, and distribution networks. A large number of distribution systems have run into problems such as poor voltage regulation, poor power factor, high losses and poor efficiency, overloading and less reliability for continuity of supply. It is necessary to improve the working of the power distribution systems to reduce the unfavorable conditions and reduce losses, improve voltage regulation, etc. On a power line, besides the active power, the reactive power must also be available for inductive loads. An alternator can produce the reactive power for the line, but the reactive power can be supplied from any source that can be either an alternator or capacitor groups connected near the load. The reactive power source must be very close to the load for efficient operation of the system. If the reactive power of any load is supplied from a synchronous motor or a group of capacitors rather than the power line, this system is called reactive power compensation.

So, the power factor of the system can be kept at a required value. The voltage control is achieved by regulating the reactive output of the generating plants, tap changing on the transformers and switching on or out reactors or capacitors to achieve target system voltages. The system improvement has to be planned properly with the four objectives: (1) to reduce losses in the distribution and sub-transmission system, (2) to improve the voltage regulation so as to bring it within the prescribed limit, (3) to improve the continuity of supply, (4) to improve the power factor in the sub-transmission and distribution system so as to get optimum utilization of generation, sub-transmission and distribution capacities. Therefore, the capacitor banks were used in transmission and distribution system to improve the power factor and voltage regulation.

II. SPECIFICATIONS OF POWER CAPACITOR USED IN 33 KV LINE

When applied on a power system for the reduction if inductive current (power, factor correction), capacitors can be grouped into either transmission or distribution classes. In either case, they should be installed electrically as near to the load as possible for maximum effectiveness. When applied properly, capacitors balance out most of the inductive component of current to the load. The result is a reduction in size of the conductor required to serve a given load and reduction in I^2R losses. Static capacitors may be used at any voltage, but practical considerations impose an upper limit of a few kilovolts per unit, therefore, high-voltage banks must be composed of many units connects in series and parallel.

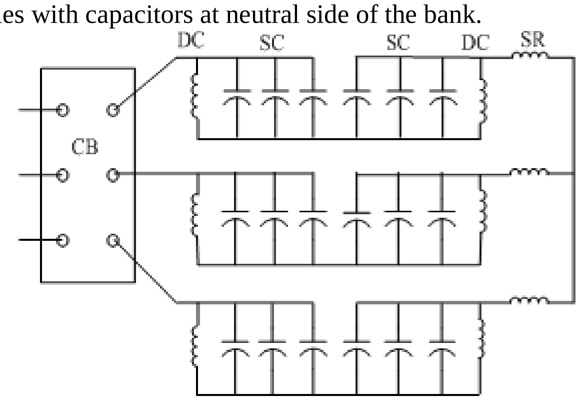
High capacity transmission capacitor banks should be protected by a high-side circuit breaker and its associated protective relays. Small distribution capacitor may be vault or pole-top-mounded and protected by fuses. In this substation, at 33 kV bus, capacitors are grouped into the distribution classes. As industrial loads occasionally require very large amounts of power factor correction, varying with time and industrial process cycle. There are 6 capacitor units in series and 3 group of units. If one capacitor element fails, the element is shortened and the voltage on the remaining elements is 17 or about 2.8% increase in the voltage. The capacitor bank continues in service; however, successive failures of elements will lead to the removal of the bank.

TABLE I: Data for Proposed Power Capacitor AT 33 Kv Bus

Parameter	Value
Line voltage	33 kV
Rated voltage	9.5 kV
Rated current	87.8 A
Weight	6030 lb
No. of phase	Single phase
Frequency	50 Hz
Rated capacity	834 kVAR
Insulation Level	No. 30
Test voltage T-T AC	19000 V
Test voltage T-E AC	70000 V
Manufactured Co. Ltd.	Nissin Electric Co. ltd, Kyoto. Japan

III. SHUNT CAPACITOR FOR VOLTAGE REGULATION

The capacitors used in the transmission systems for the purpose of voltage regulation, act to improve power factor. In these installations, reactive output rating of a unit capacitor is chosen at 834 kVAR and two groups are connected in series, and three of these groups in star connection with floating neutral make a three phase bank. The single phase discharge coil is connected so as to bridge each phase leg of a capacitor bank. The secondary windings of the discharge coil are used for protecting relay system. The series reactor is connected in series with capacitors at neutral side of the bank.



SC = Capacitor Unit   SR = Series Reactor

CB = Circuit Breaker   DC = Discharge Coil

Fig.1. Capacitor bank configuration of 33 kV line for 45 MVA power transformer No.(2).

Once the list of additional reactive power requirements is finalized, determinations are made about the placement of each bank. The value of the kVAR connected to kVA per feeder, the position on the feeder of existing capacitor banks, and any concentration of present or future load are all considered in determining the position of the new capacitor banks. Aung Chan Thar substation is connected 132 kV to the 33 kV distribution network which applied 45 MVA transformer from 132 kV step down to 33 kV. This line is radial line system as shown in fig.1.

IV. ANALYSIS OF LOAD DATA WITH RESPECT TO POWER FACTOR CHANGES

Table II is to illustrate some variables obtained from power factor changes. Capacitor rating added to improve power factor can be determined. Capacitor rating is the difference between MVAR ratings of original power factor and desired power factor (fig.2).

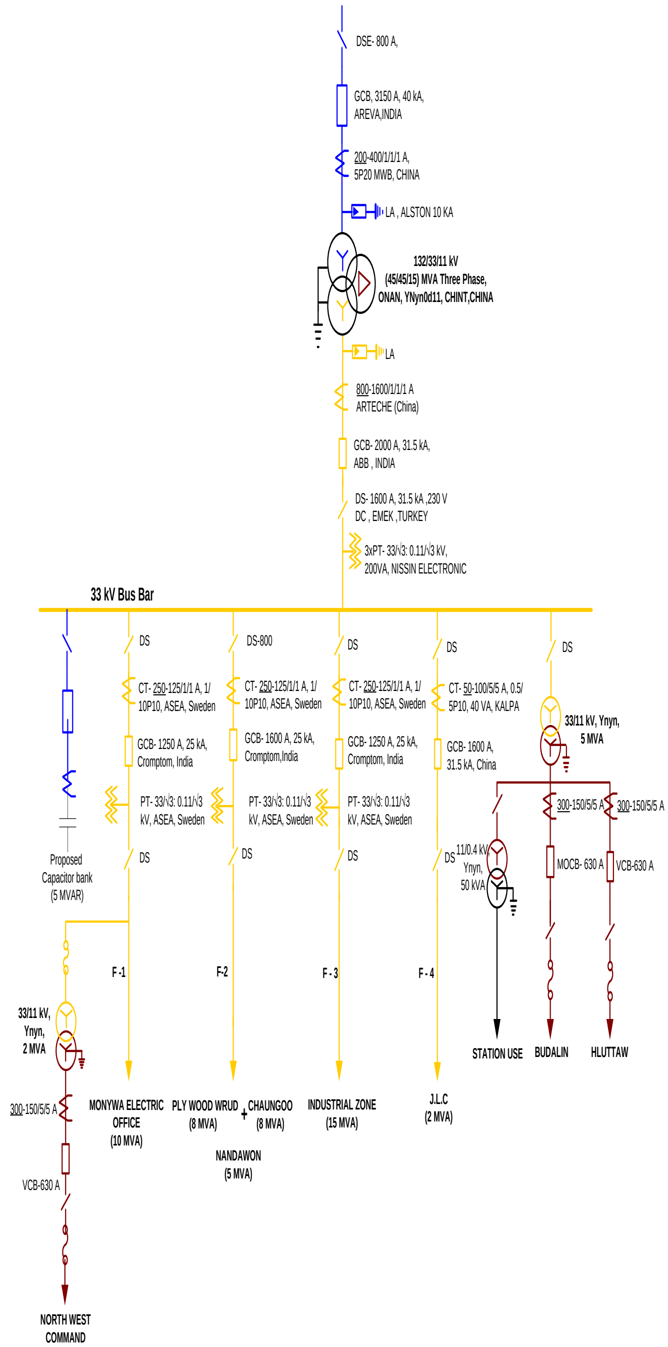


Fig.2. Proposed 5 MVAR capacitor bank installed at 33 kV main 45 MVA (2).

From Table II, 5 MVAR capacitor bank would be needed for 45 MVA power transformer to improve power factor.

TABLE II: 33 kV MAIN 45 MVA NO.(2) Log Sheet Data

33 kV Main 45 MVA No.(2) Log Sheet					
Time	**kV**	**A**	**MVA**	**MW**	**p.f**
1:00	32.3	197	11.072	9.8	0.8851
2:00	32.4	122	6.878	6.1	0.8869
3:00	32.5	162	9.161	8.1	0.8841
4:00	32.8	203	11.585	10.2	0.8804
5:00	32.2	250	14.007	12.5	0.8924
6:00	32.1	317	17.706	15.8	0.8923
7:00	31.1	364	19.698	17.4	0.8833
8:00	31.2	325	17.644	16.2	0.9181
9:00	31.4	218	11.911	10.9	0.9151
10:00	32.2	227	12.718	11.2	0.8806
11:00	32.6	150	8.5086	7.4	0.8697
12:00	32.2	207	11.598	10.6	0.914
13:00	32.9	146	8.358	7.3	0.8734
14:00	32.1	251	14.019	12.5	0.8916
15:00	32.1	228	12.735	11.4	0.8952
16:00	32.6	196	11.118	9.8	0.8814
17:00	32.3	300	16.861	14.8	0.8777
18:00	31.7	342	18.864	16.8	0.8906
19:00	31.1	412	22.245	19.5	0.8766
20:00	32.1	360	20.11	17.1	0.8503
21:00	32.3	314	17.648	15.7	0.8814
22:00	32.1	270	15.081	13.5	0.8952
23:00	32.7	205	11.664	10.2	0.8744
24:00	32.8	202	11.529	10.1	0.876

V. DESIGN CALCULATION OF CAPACITOR BANK SIZE

The following data are obtained from Aung Chan Thar Substation to design capacitor bank for power factor correction.

Transformer rating	=	45 MVA
Transformer reactance	=	15 %
Voltage	=	33 kV
Present maximum load	=	19.5 MW
Present maximum MVA	=	22.245 MVA
Power factor (maximum load)	=	87.66 %
Desired power factor	=	95 %

If the power factor is raised to 95 %,

$$\text{Desired MVA Demand} = \frac{\text{Present Load}}{\text{Desired Power Factor}} \quad (1)$$

$$= \frac{19.5}{0.95} = 20.526 \text{ MVA}$$

The size of the capacitor required to accomplish this is determined from the MVAR at the two values of power factor as follows:

$$\text{MVAR} = \sqrt{\text{MVA}^2 - \text{MW}^2} \quad (2)$$

MVAR_1 at 87.66 % power factor $= \sqrt{22.245^2 - 19.5^2}$

$= 10.704$ MVAR

MVAR_2 at 95 % power factor $= \sqrt{20.526^2 - 19.5^2}$

$= 6.408$ MVAR

Capacitor rating=MVAR_1(Uncorrect) –MVAR_2 (Corrected)

$= 10.704 - 6.408$

$= 4.296$ MVAR

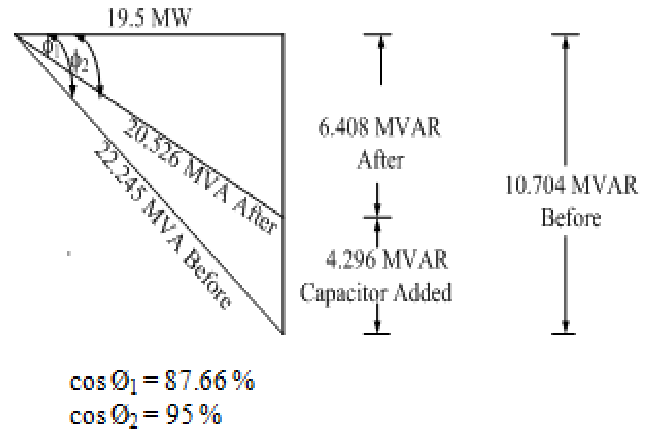


Fig.3. Required apparent power before and after adding capacitors (At 95 % Power Factor).

Fig.3 presents this power triangle shows apparent power demands on a system before and after adding capacitors. By installing power capacitors and increasing power factor to 95 %, apparent power is reduced from 22.245 MVA to 20.526 MVA (reduction of 7.73 %). Theoretically, capacitors could provide 100 % of needed reactive power. In practical usage, however, power factor correction to approximately 95 % provides maximum benefit.

Multiplying factor = 0.238

Capacitor Rating = Multiplying Factor × MW Demand

$= 0.238 \times 19.5$

$= 4.641$

≈ 5 MVAR

95 % is a good economic power factor for industrial purposes. In this thesis, this power factor is corrected from 87.66 %. Therefore the installation of 5 MVAR capacitor bank is determined for achieving power factor of 95 % while providing the same productive power of 19.5 MW.

VI. CHECK CALCULATION FOR AFTER INSTALLATION OF 5 MVAR CAPACITOR BANK

For maximum load condition,

MVAR_2 (Corrected)=MVAR_1 (Uncorrect) – Capacitor rating

$= 10.704 - 5$

$= 5.704$ MVAR

$$\text{MVA}_2 = \sqrt{\text{MW}^2 + \text{MVAR}_2^2} \quad (3)$$

$$= \sqrt{19.5^2 + 5.704^2} = 20.317 \text{ MVA}$$

$$\text{Power Factor} = \frac{\text{Present Load}}{\text{MVA Demand}} = \frac{19.5}{20.317} = 0.9598$$

TABLE III: Power Factor Data After Isstalling Capacitor Bank

Time	Power Factor	Time	Power Factor
1:00	0.9998	13:00	0.9919
2:00	0.9582	14:00	0.9942
3:00	0.9961	15:00	0.9982
4:00	0.9988	16:00	0.9996
5:00	0.9944	17:00	0.9791
6:00	0.9825	18:00	0.978
7:00	0.9716	19:00	0.9597
8:00	0.9925	20:00	0.9506
9:00	0.9998	21:00	0.9815
10:00	0.9958	22:00	0.9915
11:00	0.9942	23:00	0.9979
12:00	0.9996	24:00	0.9984

VII. VOLTAGE RISE

The approximate voltage change due to capacitors at a transformer secondary bus is determined by using the following equation:

$$\%\,\text{Voltage rise} = \frac{\text{Capacitor MVAR} \times \%\,\text{Transformer Reactance}}{\text{Transformer MVA}} \quad (4)$$

Capacitor Rating = 5 MVAR
Transformer Reactance = 15 %
Transformer MVA = 45 MVA

% Voltage Rise $= \frac{5}{45} \times 15\% = 1.67\ \%$

The voltage regulation of a system from no-load to full-load is practically unaffected by the amount of capacitors, unless the capacitors are switch. However, the addition of capacitors can raise the voltage level. The voltage rise due to capacitors in most industrial plants with modern power distribution system and a single transformation is rarely more than a few percent.

TABLE IV: Voltage Data after Installing Capacitor Bank

Time	Voltage (kV)	Time	Voltage (kV)
1:00	32.839	13:00	33.449
2:00	32.941	14:00	32.636
3:00	33.043	15:00	32.636
4:00	33.348	16:00	33.144
5:00	32.738	17:00	32.839
6:00	32.636	18:00	32.229
7:00	31.619	19:00	31.619
8:00	31.721	20:00	32.636
9:00	31.924	21:00	32.839
10:00	32.738	22:00	32.636
11:00	33.144	23:00	33.246
12:00	32.738	24:00	33.348

For maximum load condition,
Present voltage = 31.1 kV
% Voltage rise = 1.67 %

Therefore, improved voltage $= 31.1 + \frac{31.1 \times 1.67}{100}$
$= 31.1 + 0.519$
$= 31.619$ kV

VIII. LINE CURRENT REDUCTION

The percent line current reduction may be approximated from this equation.

$$\%\,\text{Line current reduction} = 100\left[1 - \frac{\text{Present Power Factor}}{\text{Improved Power Factor}}\right] \quad (5)$$

$$= 100\left[1 - \frac{0.8766}{0.95}\right] = 7.726\ \%$$

For maximum load condition,
Present current = 412 A
Present power factor = 0.8766
Improved power factor = 0.9597

$$\%\,\text{Line current reduction} = 100\left[1 - \frac{\text{Present Power Factor}}{\text{Improved Power Factor}}\right]$$

$$= 100\left[1 - \frac{0.8766}{0.9597}\right] = 8.658\ \%$$

Reduced current $= 412 - \frac{412 \times 8.658}{100}$
$= 376.3$ A

TABLE V: Line Current Data after Installing Capacitor Bank

Time	Line Current (A)	Time	Line Current (A)
1:00	174.4	13:00	128.5
2:00	112.9	14:00	225.1
3:00	143.7	15:00	204.4
4:00	178.9	16:00	172.8
5:00	224.3	17:00	268.9
6:00	287.8	18:00	311.4
7:00	330.9	19:00	376.3
8:00	300.6	20:00	322
9:00	199.5	21:00	281.9
10:00	200.7	22:00	243.6
11:00	131.2	23:00	179.6
12:00	189.2	24:00	177.2

A. Lower Losses

An estimate of reduction of power losses can be made using following equations.

$$\%\,\text{Power losses} = 100\left[\frac{\text{Present Power Factor}}{\text{Improved Power Factor}}\right]^2 \quad (6)$$

$$\%\,\text{Loss reduction} = 100\left[1 - \left[\frac{\text{Present Power Factor}}{\text{Improved Power Factor}}\right]^2\right] \quad (7)$$

$$= 100\left[1 - \left[\frac{0.8766}{0.95}\right]^2\right] = 14.855\ \%$$

There is 14.855 % reduction in power losses.

IX. CONCLUSIONS

Having low power factor does not cause a piece of machinery to shut down, but high power factor is important for the overall health of the power system. Operating in a high power factor environment ensures that the power system is functioning efficiently. It also makes economic sense. As the demand for electrical energy continues to grow and the resources for producing the energy become less and less available, the idea of not using more than what we need takes on more relevance. In this paper 5 MVAR shunt capacitor bank is installed at 33 kV bus for reactive power compensation in Aung Chan Thar 132/33/11 kV substation. In this substation have 5-outgoing lines of 33 kV bus for available loads. Distribution line voltage 33 kV has decrease to 31.1 kV at present maximum load 19.5 MW and decrease to 32.4 kV at present minimum load 6.1 MW. This voltage 31.1 kV is out of -5% range. So, a shunt capacitor bank (5 MVAR) has proposed installed for better voltage regulation, reduce transformer loading and improve the power factors of various loads.

X. ACKNOWLEDGEMENT

The author wishes to express her deepest gratitude to her teachers, Department of Electrical Power Engineering, Mandalay Technological University. The author also wishes to extend special thanks to her parent, her friends for their supports and help. Similar thanks to all for their instructions and willingness to share their ideas throughout all those years of study.

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