Power Factor Improvement by Shunt Capacitor Bank at 33 KV Busbar in a Distribution Substation

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***Abstract*—Power factor (PF) is one of the important aspects affecting the performance of the electrical network. This phenomenon results from an increase in inductive loads, which leads to lower voltage, increase losses, and lower efficiency in the electrical network. Different types of shunt capacitor bank (SCB) configurations are installed in the distribution substation (DS), which can be grounded or ungrounded, fused or without fuses. These SCBs provide voltage support, power factor correction, power transport increment, loss reduction, and enhancement of system quality. This paper presents the evaluation of two fixed SCBs isolated by isolator at 33 kV busbar in DS for PFC. The work is simulated and analyzed using MATLAB.**

Keywords—33 kV busbar; distribution substation; power factor correction; shunt capacitor bank

I. INTRODUCTION

In electrical systems, connected loads with unalike types consume energy in different forms according to their physical structure and mode of operation. These loads are classified into resistive, inductive, and capacitive loads. One of the most important factors affecting the performance of the electrical network is the power factor (PF). As shown in Fig. 1, the apparent power delivered to an electrical load is much higher than active power consumed. This phenomenon results from an increase in inductive load, which leads to lower voltages, higher losses, and lower efficiency [1], [2].

The electrical system in various parts such as generation, transmission, and distribution contain electrical equipment with inductive action. Inductive loads kind is increasing rapidly with commercial and industrial load type. If an electrical equipment draws a higher current than the current rate given on nameplate at low PF, the supply cables and transformers must be oversized accordingly. PFC allows power distribution to operate efficiently [3]. PFC can be classified into active power factor correction (APFC), passive power factor correction (PPFC), hybrid power factor correction (HPFC). The capacitor bank (CB) is considered as a PPFC, which contains a few capacitors used to improve the power factor and increase the system efficiency. However, it is not as effective as APFC, but it is much cheaper than APFC [4].

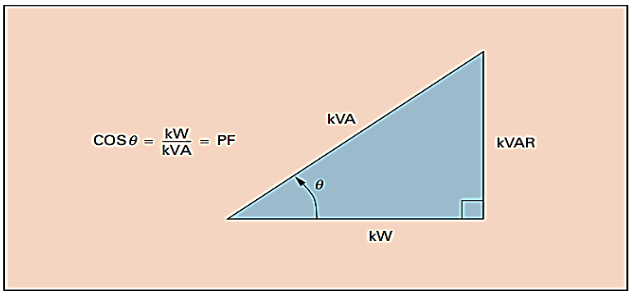

Fig. 1. Power triangle representation.

SCBs are mainly installed to provide capacitive compensation for PFC, the shunt capacitors are installed at a medium voltage level for voltage regulation, reducing power losses, increasing power transport, and improving power quality [5]. Power quality problem causes missing billions of dollars in revenue from electrical companies. They cause hours of interruption, lost efficiency, and the need to repair or replace network equipment prematurely. Consumers can also get higher energy bills. Poor power quality also hurts carbon emissions and energy efficiency [6].

II. THE CAPACITOR UNIT AND BANK CONFIGURATIONS

There are several types of capacitor bank configurations that are used to improve the overall performance of the electrical system which is illustrated in Fig. 2. The connection of capacitors in an SCB depends on the properties of the available voltage ratings of capacitor units, rated current, reactive power compensation, fusing, and protective relaying. In order not to exceed these limits, those capacitors are connected in series or parallel in one group or two as required. In general, most substation banks are Y-connected. Splitting the bank into two sections as a double-Y (Y-Y) with an isolator may be the preferred solution and may allow for a better-unbalanced detection scheme [7], [8].

The SCB Y-configuration is classified into five categories

- Ungrounded Y-configuration.
- Grounded Y-configuration.
- Double ungrounded Y-configuration.
- Double grounded Y-configuration.
- Double grounded Y with isolator configuration (two-stage SCB).

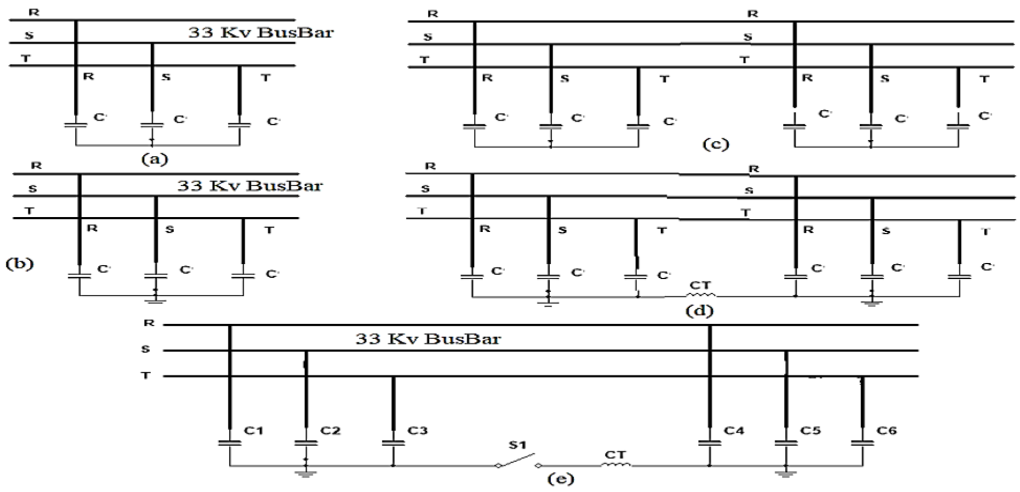

Fig. 2. Shunt capacitor bank (SCB) configurations. (a) Ungrounded Y, (b) grounded Y, (c) double ungrounded Y, (d) double grounded Y, and (e) double grounded Y with isolator.

III. Capacitor Bank Ingredients

A. Capacitor

Capacitor units must be operated for a long duration to withstand 110% of the rated RMS voltage. The capacitor should also be able to carry 135% of the rated current. Capacitors units through normal operation conditions should not exceed 115% of rated reactive power [9].

B. Series reactor

The reactor should be connected in series with the capacitors in CB. The purpose of the reactor is essential. The reactor must be used to restrict the short-circuit current and switching surge. Moreover, it is used as a filter to restrict high harmonics in a power network [10].

C. Neutral current transformer

A single-phase neutral current transformer is located between the star-point neutral connections for unbalance condition detection.

D. Instrument transformer

The instrument transformers, including voltage and current transformers, are utilized for high-voltage capacitor bank protection and metering. Three, single-phase, three-toroid current transformers with one core for capacitor bank protection and a second core for metering. An additional protection core must be included. Three, single-phase voltage transformers, or where available, existing busbar voltage transformers are utilized for abnormal voltage detection [11].

E. Surge diverters

The surge diverters utilized for protection of high voltage capacitor bank must conform to TasNetworks' Substation Lightning Protection and Earthing Standard, R522692.

F. High voltage power cables and conductors

High voltage power cables and conductors are utilized to transfer the electric power.

G. Earth-switch

The earth-switch is utilized for earthing the side of the high voltage capacitor, CB is provided with a solenoid interlocking to permit any access doors to the CB fence. Three-pole earth switch for effective capacitor bank discharge on de-energization [12].

IV. Results and Discussion

MATLAB/SIMULINK software model is shown in Fig. 3, which contains a 33 kV busbar in a distribution substation. The busbar provides power to the loads through four feeders (F1, F2, F3, and F4) as depicted in Table I.

TABLE I. Load Feeders in 33 Kv Busbar.

Feeder No.	MVA	PF
F1	5	0.84
F2	5	0.82
F3	4	0.85
F4	4	0.86
Total load	18	0.84

TABLE II. SCB Parameters.

Parameter	Value
Line voltage	33 kV
Rated voltage	9.3 kV
Rated current	175 A
Rated Capacity	450 kVAR
Rated Capacitance	35.27 μF
Ambient temperature	-10/+50
Frequency	50 Hz
Reactor	30 μH
No. of Capacitor	9

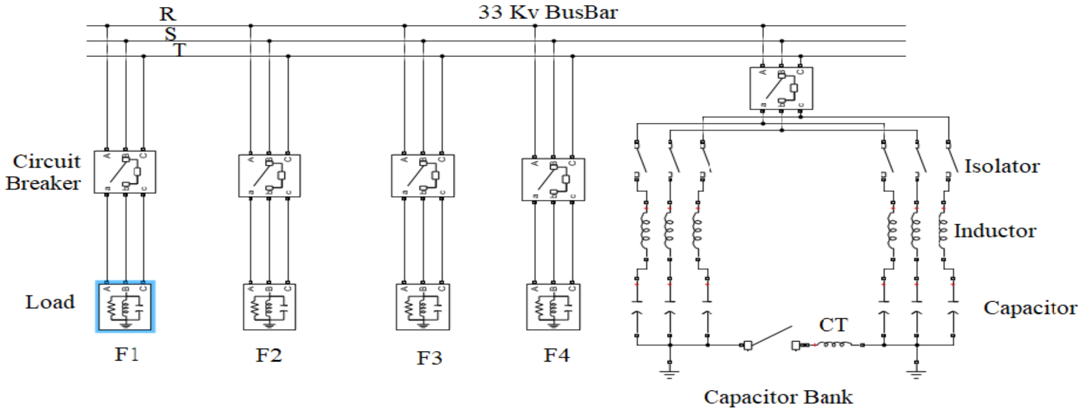

Fig. 3. 33 Kv Busbar with four feeders and two isolated SCBs.

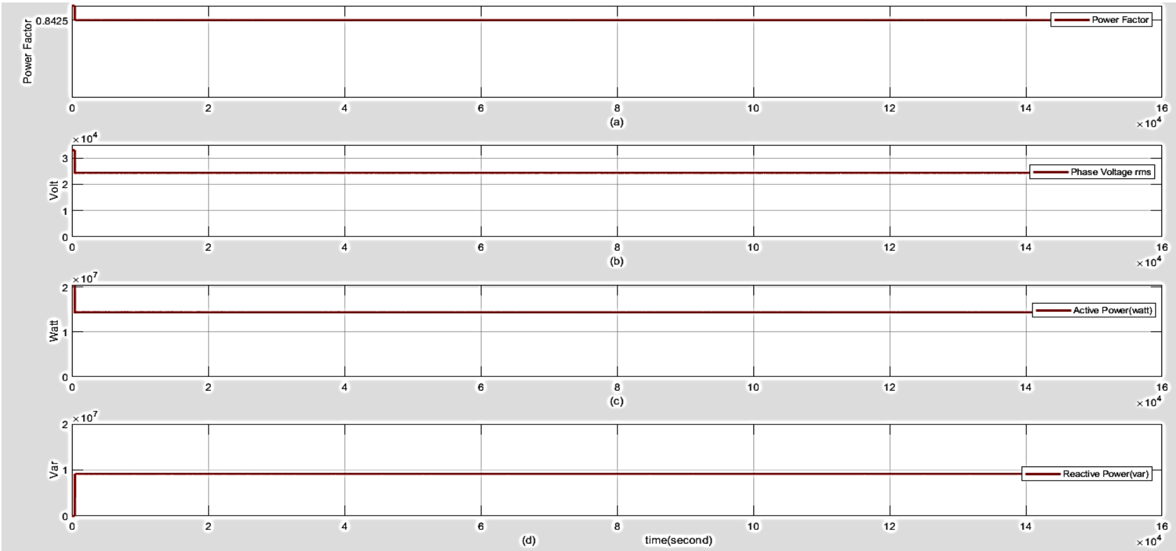

Fig. 4. PF, Kv, active power, and reactive power response without SCB.

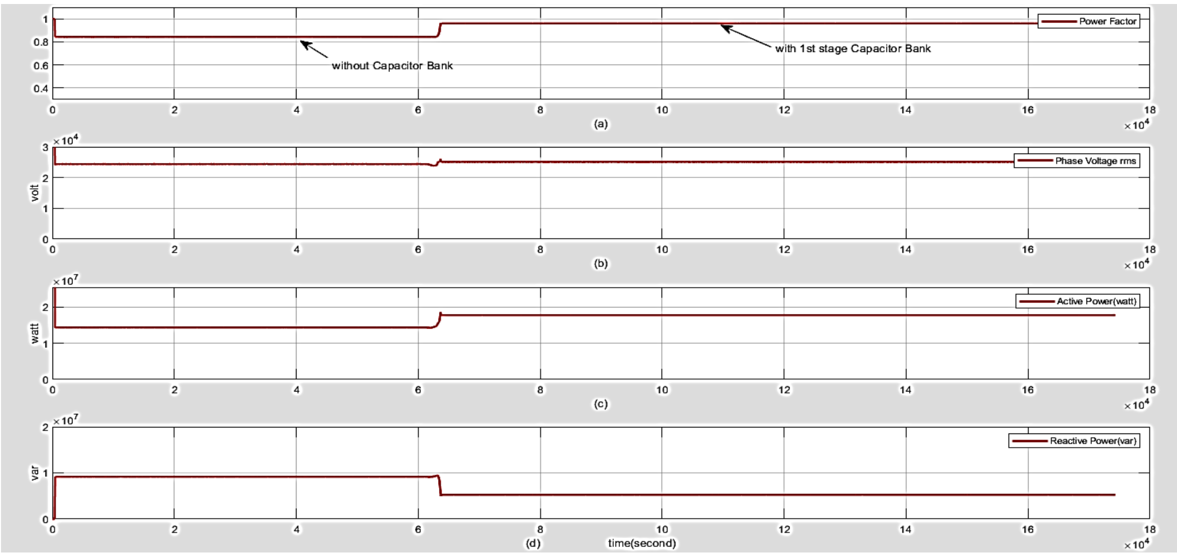

Fig. 5. PF, Kv, active power, and reactive power response with one-stage SCB.

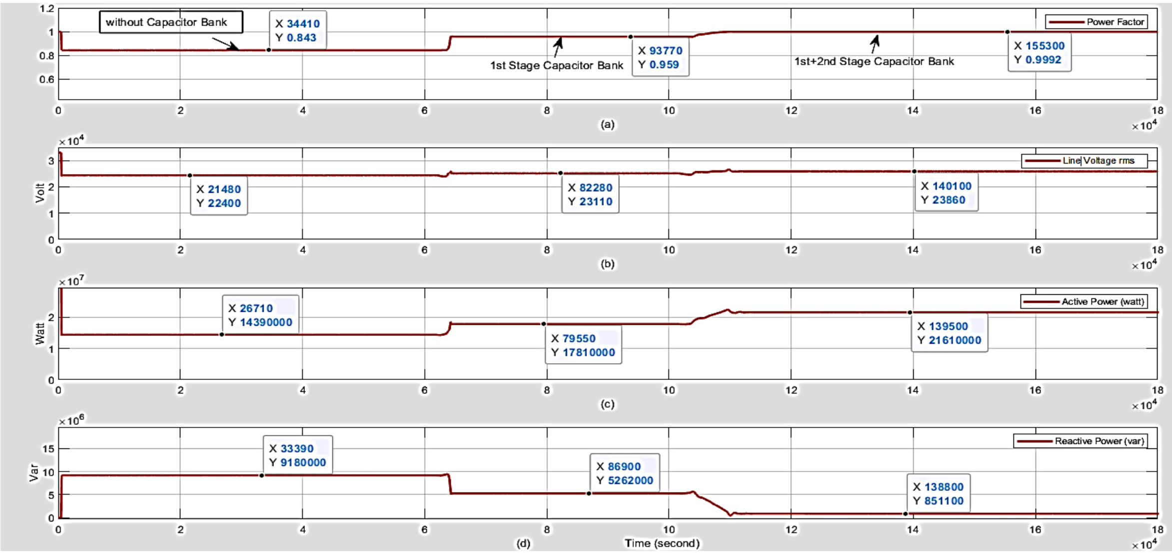

Fig. 6. PF, Kv, active power, and reactive power response with two-stage SCB.

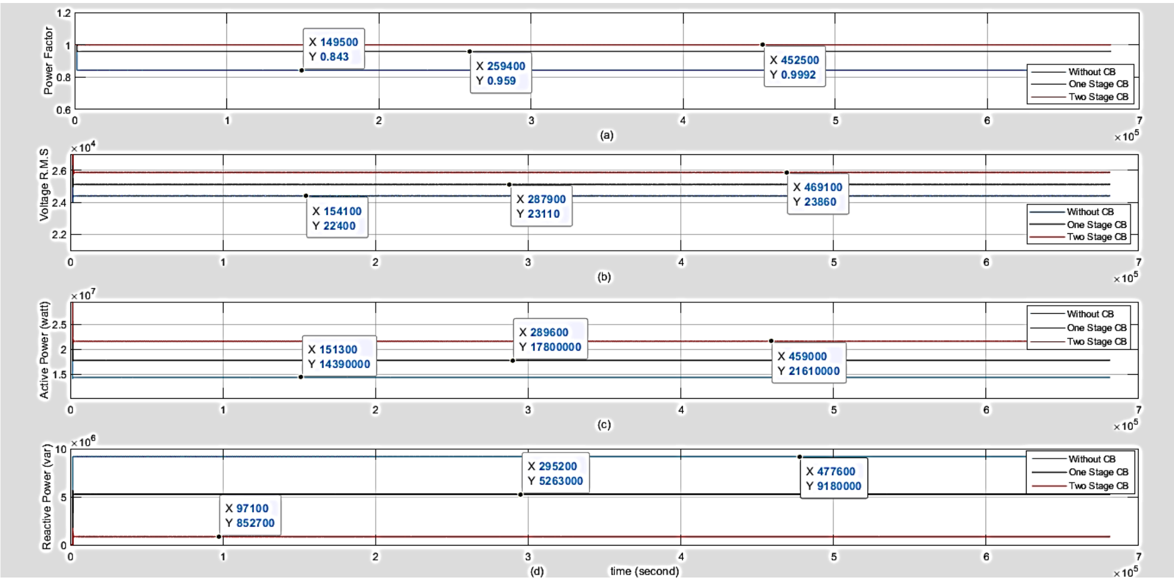

Fig. 7. PF, Kv, active power, and reactive power response for three cases.

Moreover, PFC is achieved by connecting one- or two-stage SCB to the busbar. Each stage has 4 MVAR with details given in Table II. In this paper, PF, voltage, active power, and reactive power response in the busbar for three different cases: without SCB, one-stage SCB, and two-stage SCB.

A. Operation without SCB

In this case, the busbar supplies all feeders without connecting to SCB. The response of PF, Kv, active power, and reactive power is shown in Fig. 4.

B. Operation with one-stage SCB

In this case, the busbar supplies feeders with 4 MVAR SCB for PFC. The response of PF, Kv, active power, and reactive power is shown in Fig. 5.

C. Operation with two-stage SCB

In this case, the busbar supplies feeders with 8 MVAR SCB (stage 1 and stage 2). The response is illustrated in Fig. 6.

The comparison among the three cases is shown in Fig. 7 and Table III. Clearly, it can be seen that the connection of two-stage SCB to the busbar improves the power system performance.

V. CONCLUSION

The main goal of utilizing a shunt capacitor at the busbar is to control the voltage level at a permissible range. SCB provides a capacitive load to compensate for the reactive power (VAR). The operation of the SCB with an isolator between two capacitor banks (CB1 and CB2) made it easy to operate stage-1 and stage-2 individually or together according to the compensation requirements of the power system. Such a technique results in a reduced number of switching times at the main circuit breaker. The simulation results have shown that when the two-stage SCBs enter the service, PF increases from 0.843 to 0.9992, the voltage rises about 5.4%, and active power transported through the busbar increases to 36.1 %. Moreover, the reactive power at the 33 Kv busbar decreased to 60%. Thus, the power system stability, efficiency, and reliability are improved substantially.

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