THE EFFECT OF SHUNT COMPENSATORS ON OPTIMIZATION OF AN ELECTRIC POWER DISTRIBUTION NETWORK

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ABSTRACT

In this research, shunt compensation technique of power system enhancement is used for optimizing theperformance of a radial distribution feeder. The system initial performance was tested by simulating the network in power world software. The bus with high loss sensitivity factor was selected for placing the capacitor bank and the size determined by mathematical analysis.
The performance of the proposed compensator in the system was verified by comparing the power loss, voltage profile of buses and power factor before and after the compensator was installed. Finally, the performance of the compensator was checked when fault and dynamic load variations are occurred on the selected system.

Key words: *- bus voltage, loss sensitivity, power loss, power factor, power world*

1. INTRODUCTION

1.1. VOLTAGE CONTROL

The steady state voltage and reactive power control in distribution systems can be properly controlled by coordinating the available voltage and reactive power control equipment, such as on-load tap-changers, substation shunt capacitors and feeder shunt capacitors. In order to achieve efficient and reliable operation of power system, the control of voltage and reactive power should satisfy the following objectives [1]:

Voltages at all terminals of all equipment in the system are within acceptable limits. System stability is enhanced to maximize utilization of the transmission system. The reactive power flow is minimized so as to reduce $R I^2$ and $X I^2$ losses.

1.1.1. VOLTAGE CONTROL METHODS IN POWER SYSTEM

The task of voltage control is closely associated with fluctuating load conditions and corresponding requirements of reactive power compensation. Therefore several voltage control methods are employed in power system to keep the voltage levels within the desirable limits.Some of the voltage control methods in power system areShunt capacitors, Series capacitors Shunt reactors, Synchronous condensers, SVC and STATCOM. In this research, Shunt capacitor type voltage control or reactive power source was used to control the voltage level of a practical distribution feeder.

1.2. POWER LOSSES

The transmission and distribution system delivers electricity from the generating site (electric power plant) to residential, commercial, and industrial facilities. These distribution networks comprise overhead lines, cables, transformers, switchgear and other equipment to facilitate the transfer of electricity. However, power losses are inevitable in power system analysis. Hence, these losses will create several consequences in the power system.

1.3. OPTIMAL LOCATION OF CAPACITOR BANK

The capacitor location or placement for low voltage systems determines capacitor type, size, location and control schemes. The optimal capacitor placement is generally a hard combinatorial optimization problem that can be formulated as a nonlinear/search minimization problem [2] [3].

When capacitors of appropriate size are added to the appropriate locations, the power losses can then be minimized by reducing the reactive power component in , thereby reducing the observed power demand. Indeed, there are many aspects to this compensation and its effects, depending on where capacitors get to be located, what are the optimal sizes, and the details of the distribution circuit. Obviously properly switched capacitors located at appropriate locations along distribution feeders provide great financial benefits to the utility. In addition, if there is to be only one capacitor bank on a uniformly loaded feeder, the usual two-thirds, two-thirds rule gives optimum loss and demand reduction. This means that the bank kVArsize should be two-thirds of the heavy load kVAr as measured at the substation, and the bank should be located two-thirds the length of the feeder from the substation. If the objective is voltage control the bank should be farther from the substation. With several banks on a uniformly loaded feeder, the total capacitor kVAr can more closely match the total load kVAr. Depending on the type of the switching control used, multiple banks on a feeder can lead to 'pumping' as the controls affect the operating points of each other.

Usually no more than three or four banks are used per feeder. In fact, in the case of concentrated industrial loads, there should be a bank, sized to almost equal the reactive load current, located as close to each load as possible [2][3].

2. METHODOLOGY

Required data's has been collected from a practical distribution system in Bahirdar city –Ethiopia from feeder 2 distribution system called ''Bata feeder'' having 40 buses with 31 different type of loads connected on it [2].

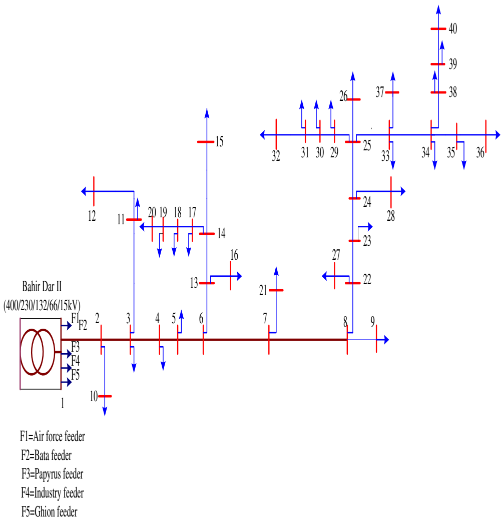

Fig 2.1. Feeder Two Distribution System Line Layout Diagram

2.1. SIZING OF THE REACTIVE POWER DEMAND

To improve the power factor of the system and for having good voltage profile, capacitor bank placement and sizing is required and this can be done by using sensitivity analysis and the amount of power to be injected to distribution system should be sized with proper design mechanism.

2.2. LOAD FLOW ANALYSIS OF THE SELECTED FEEDER

The initial system condition of the selected feeder was analyzed by doing load flow analysis in power world software.

2.3. IMPACT OF CAPACITOR BANK CONNECTION

After having initial load flow results (bus voltage Profile, Active &reactive power flow, line losses and power factor) properly designed capacitor banks on the selected buses are connected for showing the impact of the capacitor bank connection to the system [6].

2.4. TRANSIENT BEHAVIOR ANALYSIS OF THE SYSTEM

The performance of the feeder is tested again in case of a heavy load change on the feeder. For solving the system performance back to stable state the amount of reactive power to be injected in this state is also analyzed.

3. RESULT AND DISCUSSIONS

3.1. LOAD POWER FACTOR CALCULATION

The calculated power factor for the buses is summarized as shown in the following table below

TABLE 3.1. Initial power factor for the system

Bus	Power factor(CosØ)	Bus	Power factor(CosØ)
1	0.75	20	0.79
2	0.74	21	0.71
3	0.75	22	0.71
4	0.77	23	0.77
5	0.772	26	0.78
6	0.771	27	0.78
7	0.767	28	0.817
8	0.778	29	0.76
9	0.805	30	0.76
10	0.764	31	0.78
11	0.724	32	0.77
12	0.79	33	0.78
13	0.79	34	0.82
14	0.795	35	0.77
15	0.82	36	0.77
16	0.77	37	0.77
17	0.78	38	0.76
18	0.78	39	0.8
19	0.77	40	0.77
Total			**0.77**

3.2. BASIC CALCULATION FOR CAPACITOR BANKS

According to the result of the loss sensitivity factor obtained from Power World Simulator Software , at Bus 12, 38, 39, and 40 capacitor bank can be placed for controlling the voltage level, improve the Power factor and reduce the Power loss of the system. The required injected reactive power at these buses is computed as:

1. At Bus 12 the required consumable reactive power is computed as follows:

$I_{line} = Q/\sqrt{3}\ V$
P=0.1348MW
The Line current that obtained from Power World Simulator is I_l=6.7202A

$Q = \sqrt{3}\ VI_l$, before calculating Q we should calculate the voltage that flow over bus 12, so.
P=VI
$V = P/I = (0.1348MW) / (6.7202 * 10^{-6}MA) = 20058.92V$

$Q = \sqrt{3}\ VI_l$= desired reactive power $= \sqrt{3}\ (0.02006MV)\ (6.7202*10^{-6}MA)$
= 0.233MVar

2. Bus 38 the required consumable reactive power is computed as follows:

$I_{line} = Q/\sqrt{3}\ V$
P= 0.2461MW, I_l=12.5164A
P=VI
V=P/I
$= (0.2461MW)/(12.5164*10^{-6}MA)$
V=19662.2v

$Q = \sqrt{3}\ VI_l$ = desired reactive power
$= \sqrt{3}\ (0.01966MV)\ (12.5164*10^{6}MA) = 0.4257MVar$

3. Bus 39 the required consumable reactive power is computed as follows

$I_{line} = Q/\sqrt{3}\ V$
P=0.1792MW I_l=9.276A
P=VI
V=19337.4v

$Q = \sqrt{3}\ VI_l$= desired reactive power
$= \sqrt{3}(0.019337MV)\ (9.276*10^{-6}M)$
= 0.310016MVar

4. Bus 39 the required consumable reactive power is computed as follows

$I_{line} = Q/\sqrt{3}\ V$
P=0.0925MW I_l=4.99A
P=VI
V=18537.074v

$Q = \sqrt{3}\ VI_l$= desired reactive power
$= \sqrt{3}\ (0.018537MV)\ (4.99*10^{-6}M)$
=0.160025MVar

There were a total of 1 Generator, 40 Buses and Transformers and 31 Loads involved in the constructing of electrical network

TABLE3.2Rating of the power equipment

Bus	device	MVA rating	Voltage
1	Generator	2.49MW	15KV

Total system data before shunt compensation in the system is installed

TABLE 3.3. Power factor of the selected feeder before compensator connected to the system

Bus No	Loss MW	Powerfactor before compensation	Loss Mvar
1	0	0.75	0
2	-0.0225	0.74	-0.0199
3	-0.0238	0.75	-0.0210
4	-0.0240	0.77	-0.0212
5	-0.0240	0.772	-0.0212
6	-0.0243	0.771	-0.0214
7	-0.0254	0.767	-0.0224
8	-0.0261	0.778	-0.0230
9	-0.0261	0.805	-0.0230
10	-0.0226	0.764	-0.0200
11	-0.0271	0.724	-0.0242
12	-0.0277	0.79	-0.0246
13	-0.0247	0.79	-0.0218
14	-0.0249	0.795	-0.0219
15	-0.0250	0.82	-0.0220
16	-0.0247	0.77	-0.0218
17	-0.0249	0.78	-0.0219
18	-0.0250	0.78	-0.0220
19	-0.0251	0.77	-0.0221
20	-0.0253	0.79	-0.0222
21	-0.0255	0.71	-0.0225
22	-0.0266	0.71	-0.0234
23	-0.0269	0.77	-0.0236
24	-0.0269	0.78	-0.0236
25	-0.0271	0.78	-0.0238
26	-0.0271	0.817	-0.0238
27	-0.0267	0.76	-0.0234
28	-0.0269	0.76	-0.0236
29	-0.0271	0.78	-0.0238
30	-0.0272	0.77	-0.0239
31	-0.0273	0.78	-0.024
32	-0.0273	0.82	-0.0240

33	-0.0273	0.77	-0.0240
34	-0.0274	0.77	-0.0240
35	-0.0275	0.77	-0.0241
36	-0.0275	0.76	-0.0241
37	-0.0276	0.8	-0.0242
38	-0.0276	0.77	-0.0242
39	-0.0278	0.76	-0.0244
40	-0.0280	0.736	-0.0246

After Shunt Compensator Installed**:** The constructed electrical network then modified by adding of shunt capacitors at Bus 12, Bus 38, Bus 39, and Bus 40. The purpose of this action is to increase the receiving end voltage at each bus, power factor of the load and to reduce active and reactive power loss at each bus.

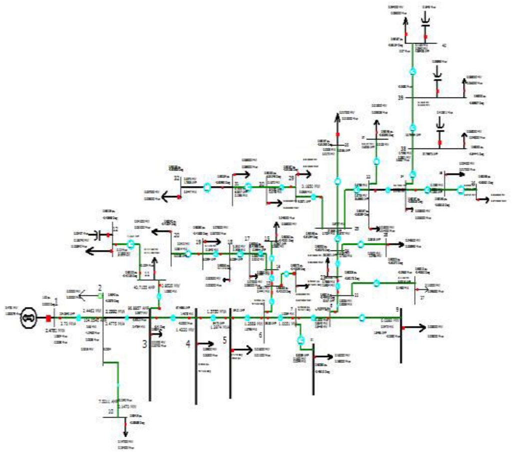

Fig 3.1 A 40 bus Bata feeder connected with shunt capacitor.

From this system, it was observed that, the total generation of power from the generator after the network was compensated with capacitor banks has dropped significantly. The generators produced 2.478 MW and 1.0803 MVAR, instead of 2.49 MW and 2.182 MVAR as before. It is good to produce less power because this can save up the cost of generation. Another important thing to be observed from this condition is the reduction of reactive power produced from the generators. Logically with only 1.0803 MVAR, the loads could not operate, as the reactive power needed by the loads in overall is 1.443 MVAR. The remaining 1.1071MVAR was actually supplied by the shunt capacitors installed near the loads. This explains why the reactive power from the generators had decreased. Although the presence of reactive power can harm the health of a power system, a little amount of it is needed to drive the power across the entire system. Another good thing about the compensation of the network is the improvement of the voltage regulation, power factor and power loss.

As seen from the simulation, the receiving end voltage at each bus has increased by a lot after compensation. This happens because the reactive power that flows from the generators has been cut down by the shunt capacitors, thus allowing the bus to meet near its rated voltage. As the result, voltage regulation at each bus drops to below 1%. Low voltage regulation means that the bus can provide enough voltage to the loads.

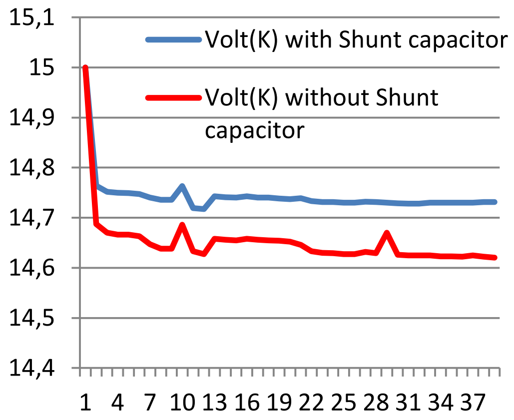

Fig.3.2. Voltage controls before and after compensator connected.

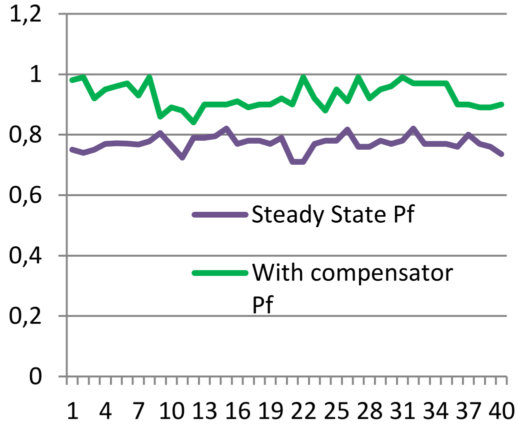

Fig.3.3 power factors before and after compensator connected.

As you can see the above graph the green color is the power factor after compensator connected so it is improved very well because all load power factor values are above 0.85. The red color is before the compensator connected the loads of the power factor values are under 0.85.

Reduction of power losses:Reactive power in power system could not be avoided by any means. The only thing that can be done is to limit the reactive power so that the performance of the system can be enhanced. Reactive power comes in the form of heat loss to the

surroundings. By installing the shunt capacitor, the reactive power flowing from the generator could be reduced. The capacitor shares the role of supplying reactive power to the load, making the generator to supply less reactive power. Real power or the active power generation can be reduced since reactive power has decreased.
Before connected capacitor bank the power loss of the system 1.01881MW and 0.9938Mvar but after connected capacitor the power loss of the system become decrease by 0.02501MW and 0.7916Mvar.
As you can see in fig 3.4 MW loss is improved with some change and also the Mvar loss improved with a big change because capacitor basically generate reactive power.

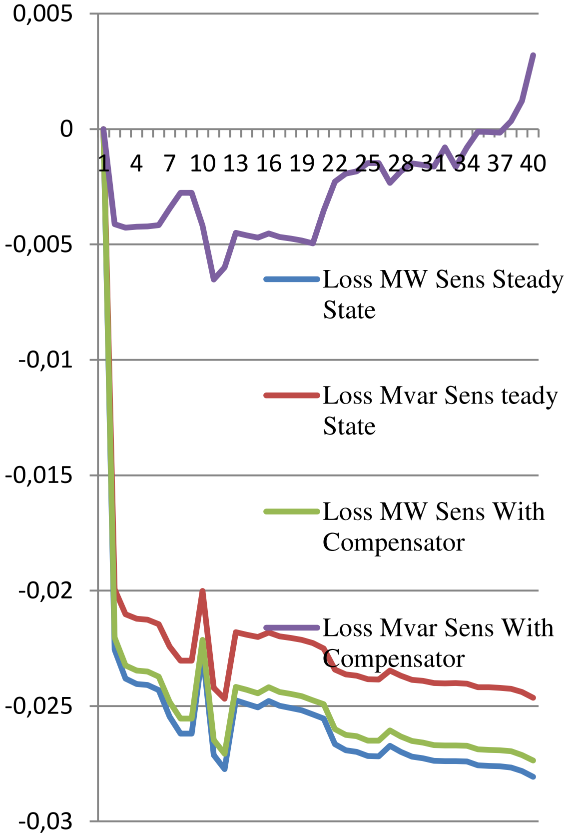

Fig 3.4.Power Loss before and after Compensator connected

Finally, the system performance is tested by having dynamic load change and fault before and after shunt compensator connected as shown in fig.3.5 below. the dynamic load change and the steady state PU before compensator connected the values are under 0.98 but after compensator connected the dynamic load change, fault happen and steady PU values improved and also above 0.98. Good PU value between 0.98 up to 1.1.

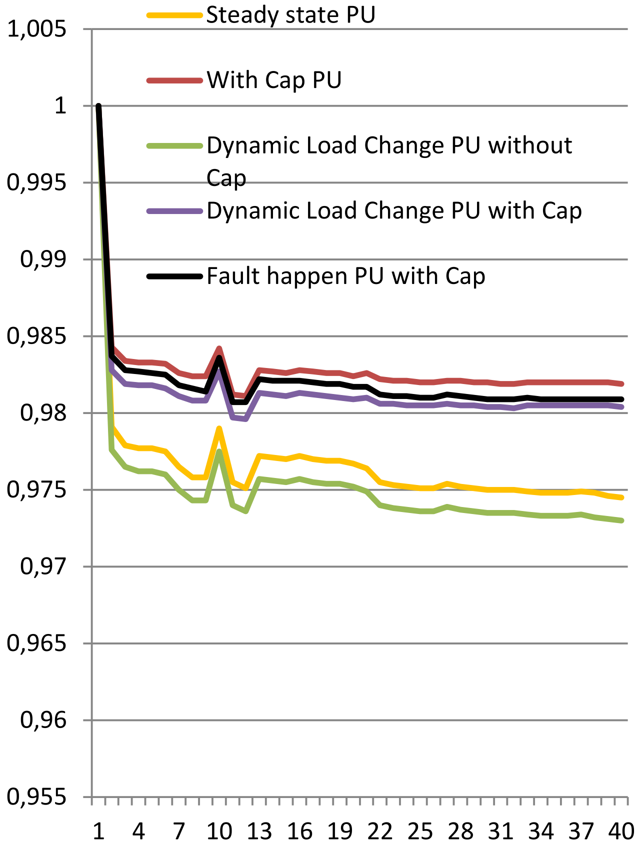

Fig.3.5 the effect of capacitor bank with dynamic load change and in case of fault

4. CONCLUSION

As shown in section 3 of this research, addition of shunt capacitors to a 40 bus radial distribution feeder on selected bus improves the per unit voltage profile of all the buses, with improved power factor.
The power loss is reduced when capacitor bank is connected to the feeder. In case of dynamic load change and fault in the feeder, the voltage profile of all the buses was better when capacitor bank was connected.
Therefore, the distribution system performance can be optimized by having a capacitor bank connected to the selected feeder for improved voltage profile and power factor and power loss reduction at steady state and in time of transient.

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