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OPTIMAL LOCATION FOR LOSS REDUCTION ON A 7-BUS BAR POWER GRID SYSTEM BY CAPACITOR PLACEMENT

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Abstract — Reduction of power loss in transmission and distribution system is key to improve the efficiency of power system. This paper presents a method of minimizing the loss associated with the reactive component of the branch current by optimal placement of shunt capacitor on an IEEE seven Bus-bar system by Power-World Simulator. The project started by drawing the one-line diagram of the 7-bus power grid system with rated values suggested by the simulator tool. Upon completion, all the data regarding the Voltage per unit, mega volt-ampere reactive losses, megawatt and mega volt-ampere at each buss were recorded. Analysis was done on the system using the power world simulator.

From the simulation results, the original system recorded a low power factor of 0.79 and a mega volt-ampere reactive loss of eighteen percent (18%). After analyzing the system and installing the capacitor bank at the optimal location, the power factor improved to 0.98 and the system's mega volt-ampere reactive reduced to 6.4%. The optimal location for the capacitor bank was identified as the bus that injects more reactive power to the system. The bus also has a low voltage per unit value and high conductance as compared to all other buses.

Keywords- Power loss, 7-Bus bar, Power grid, Power world simulator, mega volt-ampere reactive

I. INTRODUCTION

Transmission and distribution losses are a major concern in Ghana. An article published by Lawrence Quartey (2015) in the Africa report on Ghana energy crisis, in May 2015 placed Ghana on top of the top 30 countries in the world that loose most of its electrical energy transmitted and distributed. Ghana loses 26% of its electrical energy transmitted and distributed.

The level of reported losses in a year is influenced by, both technical and operational losses. Studies have indicated that as much as 13% of total power generated is consumed as loss due to the heating of conductors at the distribution level **[1].** [2] were able to reduce losses on power lines using Compensation devices. In their work, it was noted that, if surge impedance loading of the line corresponds to the line loading, then a flat voltage profile can be achieved. The compensation device was chosen bearing in mind, the above-mentioned idea. However, if the appropriate compensation device is installed in line, the effective surge impedance will yield a virtual natural load canceling the actual load of the line. But in the practical system, the demand curve is not smooth, it varies with time. To have surge impedance loading equal to the natural loading of the line, compensation device should be operated according to the variable load condition.

[3] implemented shunt capacitive in his work. In his work, the capacitor was connected at the substation or at the midpoint of the line. It was not uniformly distributed throughout the line and automatic control of the shunt capacitive compensation was used to maintain the voltage at a constant level. The effect of shunt capacitive compensation is continuously distributed throughout the line. [4] commented on the shunt capacitive compensation that it is required when the alternator active power output is greater than the surge impedance loading of the line. Huge amount of power can be transmitted by doing shunt compensation. But in the practical system, it requires large number of capacitors.

A. Capacitor Allocation and Network Reconfiguration

This micro level objective can be approached by doing capacitor allocation at the sensitive load buses with optimum value [5]. Optimal capacitor placement of the network balances the conglomerated load. If there is a lump of load at a certain bus, then by shifting the load efficiently to another light load bus can reduce the active power loss. It also stabilizes the system and maintains the nominal voltage at the buses. Though with the prevailing condition of Power System, capacitor allocation and network reconfiguration are very much tough and cumbersome approach to reduce the line loss, but it is a useful and less hazardous way to minimize the line loss economically. However physically it is a well understood fact that capacitor allocation and network reconfiguration is necessary for loss minimization [6].

B. Power Factor Improvement

The importance of installing the capacitor is to improve the power factor. In the solution to improve the power factor by [7], power factor correction capacitors were added to the plant power distribution system to act as reactive power generators and provide the needed reactive power to accomplish kW of work. In his work, KVAR was not considered. However, [3] argued that One should consider the average value of the active power as well as the average power factor in the system. Using these two values, one can

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calculate the capacitor bank for the average operating condition needed to improve the overall power factor.

C. Optimization Strategies for minimizing Power Losses

Analytical approach, genetic algorithm approach, ant colony approach, particle swamp and heuristic approach were adopted for power loss minimization by capacitor placement and network reconfiguration in [8].

Loss reduction by installing capacitors on primary feeders was studied in [9]. In his work, capacitor installation at the load end was beneficial rather than placing it in the substation. However, a method proposed by [8] differ from [9]. he argued that for optimum size and location of shunt capacitors for reduction of losses in distribution feeder, the capacitor should be placed on the distribution feeder by doing power factor correction. By this approach, the power quality was also improved.

Particle Swarm Optimization (PSO) has been implemented for optimal capacitor placement by [10]. in their work, AC load flow calculation and harmonic load flow calculations were done. The type of capacitor is tested in every compensation and if the iteration number reaches the maximum number of iterations, then the computation procedure is stopped, and the best solution or particle is considered as the optimal solution. Otherwise, computation procedure continues until the iteration number reaches the maximum iteration number. PSO has not proven to solve the problem of power loss due to its deficiency in a number of iterations needed to be performed.

Heuristics Search Strategies for capacitor placement has been studied in the distribution system by [11]. In their approach, cost saving was given more importance than loss reduction. The computation time and the complexity of the simulation procedure were significantly reduced by this heuristic approach. The test system which is considered for simulation is a balanced three phase network with balanced three phase voltages though the effect of harmonics was not considered in their work, but they realized that if the peak power loss for the test system is computed and it is checked for each bus to find out the largest effect of reactive power compensation, then the sensitive bus or node is selected on the basis of highest impact or change in loss and the capacitor should be placed at that particular node to reduce the real power loss.

II. SYSTEM DESIGN

A. Designing the One-Line Diagram of the Power flow System

The one-line diagram used in this project work was created with the Power World Simulator software tool, the software provides all the necessary quantities required by a typical power grid system for the purpose of analyzing the power system. The quantities include generators, buses, circuit breakers, transmission lines, filters, and three phase loads. The modeled power system for this work is as shown in Figure1. The system consists of seven 138 kV buses, five generators, eleven transmission lines with circuit breakers, 6 static loads and one power factor correction capacitor (PFC). The software allows changes to be made on the quantities to display actual electrical quantities on the one-line diagram. For instance, the per unit (PU) voltages and phase angles in degrees are provided for each voltage bus. The actual power outputs in real and imaginary are displayed for each of the generators. The actual power flows in real and imaginary are provided for all transmission lines. The ratings of the connected load and PFC are included on the one-line as well. The power system one-line diagram created using the software is then used as the main work for the project. Figure 1 shows the one-line diagram of the power flow system.

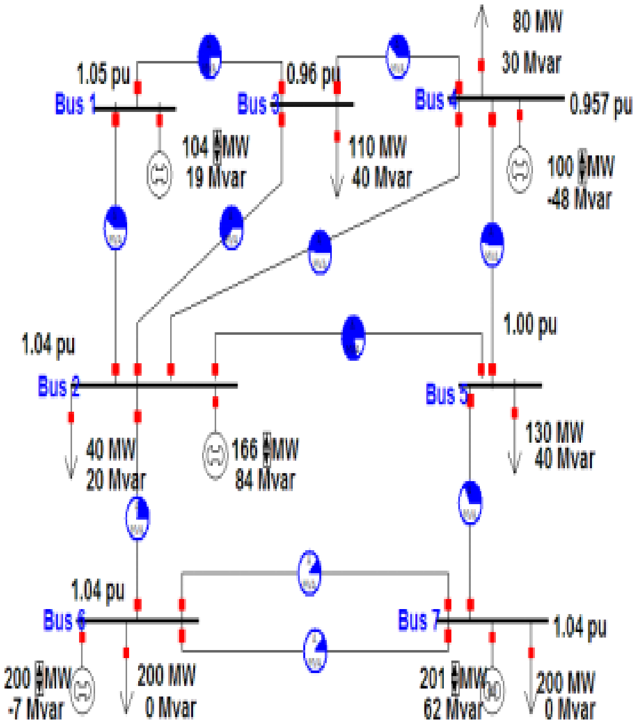
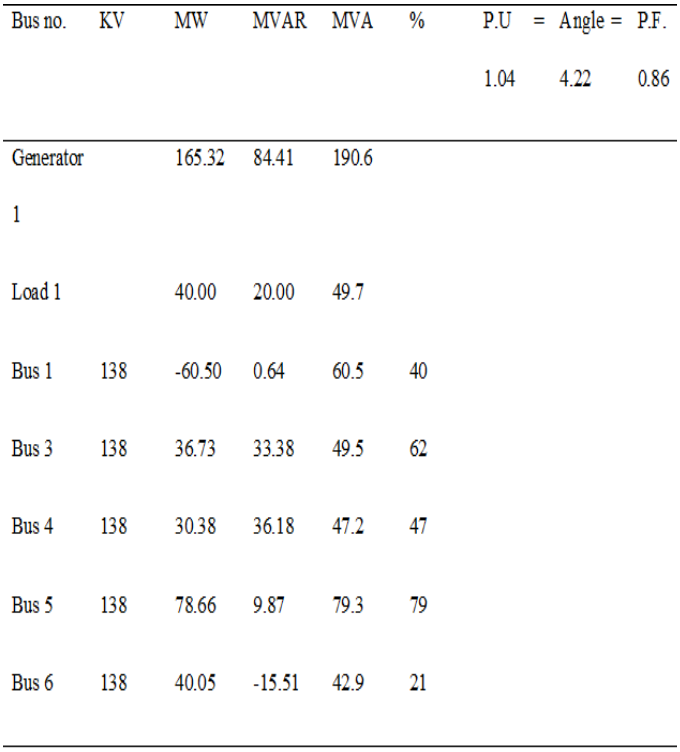


Fig. 1 Schematic diagram for the One-line 7 Buss Bars Power Grid System.

B. The Load Flow Analysis for the One-Line Diagram

After completing the one-line diagram of the power system, the simulation menu was run and the Newton-Raphson type of load flow was selected to be performed on the network. This is because there are little of no errors in the Newton-Raphson iterations, it also takes less iterative cycle to reach the solution and it can be used to solve high voltages and gives accurate values. The magnitudes and angles of the voltages are determined for each bus using the Power World Simulator. The resulting power flows are shown as arrows as triangles. Green represents real power and blue represents imaginary power. The movement of the arrows along the transmission lines represents actual direction of real and imaginary power flow. The arrows are scaled to show the magnitude of the powers flowing on each transmission line.

Table 1 Power flow values for bus-bar two



Bus no.	KV	MW	MVAR	MVA	%	P.U =	Angle =	P.F.
						1.04	4.22	0.86
Generator 1		165.32	84.41	190.6				
Load 1		40.00	20.00	49.7				
Bus 1	138	-60.50	0.64	60.5	40			
Bus 3	138	36.73	33.38	49.5	62			
Bus 4	138	30.38	36.18	47.2	47			
Bus 5	138	78.66	9.87	79.3	79			
Bus 6	138	40.05	-15.51	42.9	21			

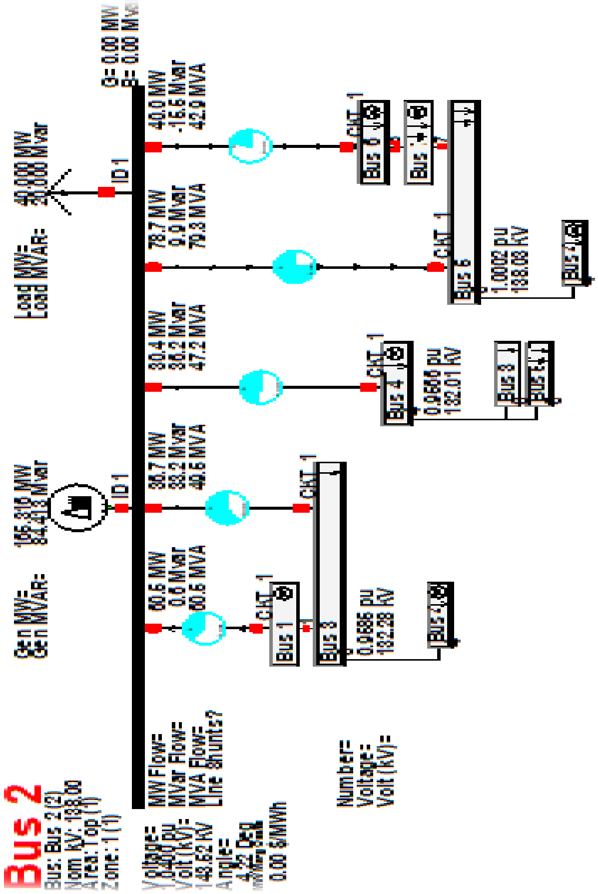


Fig. 2 Configuration of Bus-Bar Two.

C. *Load Flow Analysis Results*

The Newton-Raphson load flow analysis was performed on the power system described in Figure 1. The animated results of this load flow are shown in Figure 2. For every transmission and distribution network, one of the bus bars are chosen as the reference or the slack bus, in this project work bus 7 was set up to be the reference or the slack bus with 1 per unit output voltage at 0 ° phase angle. The connected load was 201 MW and 62 MVAr (inductive). The resulting bus voltages and phase angles are shown on the one-line diagram. The resulting power flows for each transmission line feeding the connected load are also displayed. The pie charts associated with each transmission line provides an indication of transmission line loading.

For this work, the resistance of each transmission line was not included, only the reactive component. The power flows (real and imaginary) for the purpose of this work are in the same direction.

D. *Original System Settings for the One-Line Diagram*

Table 2 shows the performance of the various buses for the original settings of the power grid system.

Bus 1 uses 93% of its MVA value which translates to a high performance of the bus. This indicates little loss on the bus. Bus 1 has a 103 MW, 19 MVAr generator connected to it. Bus 1 has no load connected to it but supplies a total of 110.2 MVA to both bus 2 and bus 3. The per unit voltage on the bus is 1.05 at an angle of 6.17. The power factor for the bus is 0.93.

Table 2 Improved data after installing the capacitor on busbar two

Bus no	Kv	MW	MVAr	MVA	%	P.U.	Angle	P.F.
1	138.0	103.19	19.40	108.0	58	1.05	6.17	0.95
2	138.0	165.00	19.57	169.2	49.8	1.04	4.32	0.97
3	138.0	110.0	40.00	120.0	56.7	0.95	1.64	0.91
4	138.0	100.0	-48.43	114.1	44	0.95	2.04	0.87
5	138.0	130.0	40.00	139.0	51	1.00	0.73	0.93
6	138.0	200.26	-6.59	203.4	14.3	1.04	2.81	0.98
7	138.0	201.75	62.00	214.1	18	1.04	0.00	0.94

Bus 2 has a high MVAr loss of about 84.41MVAr and it uses only 86% of its MVA value. Bus 2 has a total active power of 165 MW and an apparent power of 190 MVA. The per unit value of the bus is 1.04 at an angle of 4.22. Bus 2 has a load of 40 MW, 20 MVAr connected to it. Bus 2 is connected to bus 3, bus 4 and bus 6.

The slack bus chosen for the system is bus 7. It has a power factor of about 0.93 and a per unit value of 1.04 at 0 degrees. It has an active power of 201 MW, a reactive power of 62.24 MVAr and an apparent power of 215.5 MVA.

From Table 2 bus 6 performs better with a power factor of 0.97 and as low as 6.24 MVAr losses better than the rest of the buses, whiles bus 2 performs poorly with as low as 0.86 power factor and a significant 84.41MVAr loss among the rest of the buses. On the other hand, as bus 2 is performing poorly, the losses on bus 7 is also high making the entire system unhealthy. Figure 3 illustrates the variations of the MVA, MW and MVAr values of the original system. To be totally convinced that bus 2 has the greatest loss on the system, the load MVAr on bus 2 is increased.

PWS was used to design the one-line power flow system and considering one of the seven busses as the slack or reference bus. The system parameters are the standard IEEE 7-bus bar values. The system was run and the data on each bus was recorded. The system initial settings recorded a low power factor of 0.79. The system was then disturbed and showed more loss especially on bus 2.

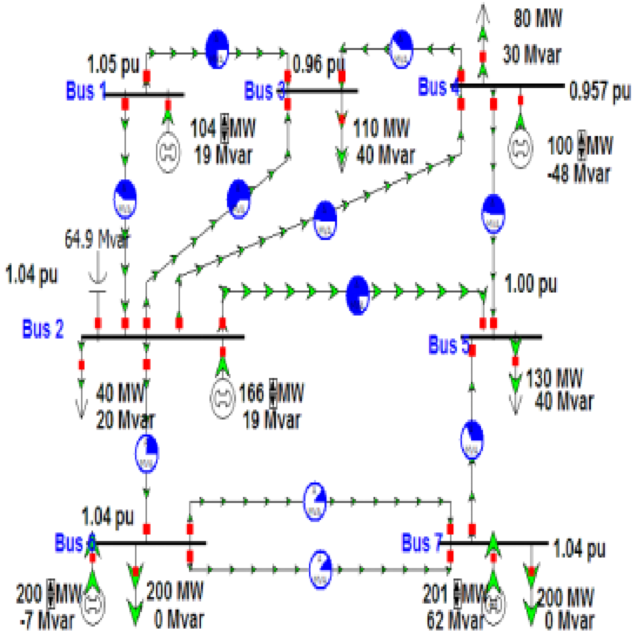


Fig 3. Schematic Diagram for the One-Line Power Grid System during Simulation

A capacitor bank rated 60 MVAr was installed on bus 2, and the system experiences an increase in power factor of 0.93. A capacitor bank rated 80 MVAr was installed on bus 4 and showed a phenomenon increase in power factor of 0.98. Finally, 5% of the total power injected to the system was lost due to the impedance of the transmission lines, when the estimated reactive power of 100 MVAr of the capacitor bank installed on bus 4.

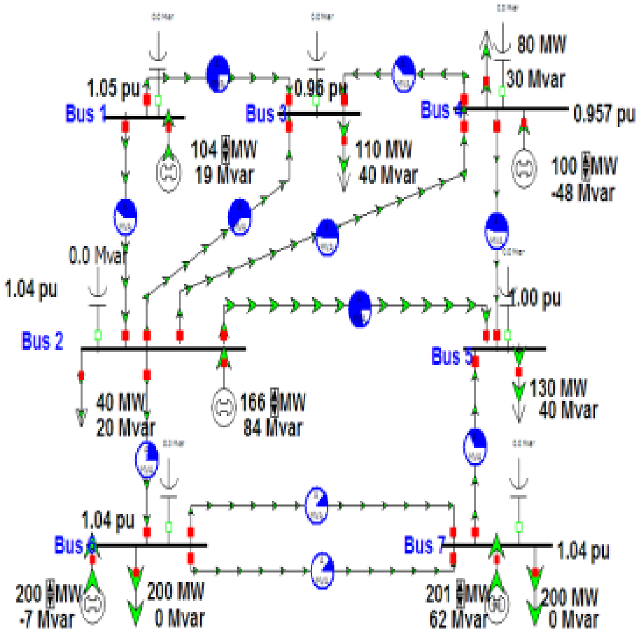


Fig 4. Schematic diagram for the 7 bus-bars power grids after installation of the capacitor bank on each bus bar.

III. RESULT AND DISCUSSION

From the simulation results, it was found out that.

The original system recorded a low power factor of 0.79 which translates to seventy-nine percent (79%) usage of the total power to the system and an MVAr loss of eighteen percent (18%).

After analyzing the system and installing the capacitor bank at the optimal location, the power factor improved to 0.98 which translates to ninety-eight percent (98%) usage of the total power to the system, and the system's MVAr reduced to 6.4%. The optimal location for the capacitor bank was identified as the bus that injects more reactive power to the system. The bus also has a low voltage per unit value and high conductance as compared to all other buses.

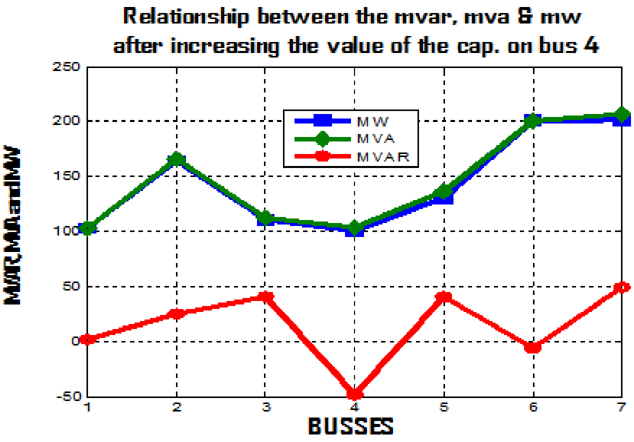


Figure 5.Relationship between the MVAR, MVA and MV after increased cap value on bus 4.

When the same capacitor was installed on bus bar 4, the MW and the MVAr lines were in phase indicating tremendous improvement than when it was installed on bus 2. As indicated in the Fig 5 the value of the capacitor has been raised from 60 MVAr to 80 MVAr resulting into optimal loss reduction in the system.

IV. CONCLUSION

The project started with the drawing of the one-line diagram of 7 buses power grid system with rated values of components needed as suggested by the simulator tool. The project was further analyzed by categorizing the analysis by cases. For case 1, the value of the load MVAr demand at the selected bus resulted from the previous findings was doubled the original size. This was to show more convincing result of MVAr losses at the bus.

For case 2, the capacitor bank was installed on each buss one at a time to indicate the optimal location of the bus that can improve the whole system the most. All the MVAr losses for each installation of the capacitor bank were recorded.

For case 3, the capacitor values were varied at the selected bus. This was to estimate the capacitor range needed for power loss minimization.

Finally, the analysis required finding the optimal capacitor location to minimize power losses, the appropriate size and rating for the capacitor, the percentage value of power losses reduction for the power system and the kVAr rating for the desired Power Factor was calculated.

It can be concluded that, for an IEEE 7-Bus bar system loss minimization, the bus that will improve the entire system the most when the shunt capacitor is installed on it should be the bus that inject more reactive power to the system. The bus should have a low voltage per unit value as compared to all other busses in the system. Again, the bus should have low resistance and high conductance.

V. RECOMMENDATIONS

Implementation of optimal placement of multiple capacitor banks on transmission and distribution network can be a good approach for loss reduction.

Transformer tap changing option with capacitor allocation and distributed generation may be done for the same reduction of real power loss. A suitable and optimal combination for both schemes can be studied for the extension of the work. The findings from this project work were based on the IEEE seven bus bar system, the findings can be extended to other IEEE buses.

By placing the shunt capacitor to the original 7-bus system and improving the systems power factor, it can be recommended for future work to be performed on the analysis to determine the cost when the system power factor is improved.

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