Optimal placement of shunt capacitor with VCPI to improve voltage profile using Mi power

Upendra Prasad¹, Nikhil Kumar Sinha², Bathina Venkateswara Rao³, Naraharisetti Jaya Naga Lakshmi⁴, Ramesh Devarapalli⁵

¹, ², ⁵ Birsa Institute of Technology, Sindri, Dhanbad, Jharkhand – 828123
³ V R Siddhartha Engineering College, Vijayawada, A.P, India
⁴ S R Engineering College, Warangal, Telangana 506317, India

¹ uprasad1963@gmail.com, ² kumarsinhankhil6@gmail.com, ³ bvrao.eee@gmail.com, ⁴ jayanaga_lakshmi@srecwarangal.ac.in, ⁵ ramesh.ee@bitsindri.ac.in

ABSTRACT: Day to day the importance and usage of electric power is increasing, in order to reach this power demand, generation of power is being increased. But the transmission grid fails to meet the developments in generation, as construction of new transmission lines involve more time than building new generation facilities. So, updating or upgrading the existing facilities will be more beneficial than building new ones. This is achieved by providing proper reactive compensation. This main objective of the paper is placement of shunt capacitor for voltage profile improvement and reactive power compensation. The voltage stability index, called voltage collapse prediction index (VCPI), decides the shunt capacitor placement. This paper deals with placement of shunt capacitor banks to improve voltage at weakest buses. The shunt capacitor banks connected to the system to prevent the low voltages during the high loading conditions. The reactive compensation and reduction of losses and power transfer capability can be increased by placing of shunt capacitor. The proposed technique is validated with load flow analysis on IEEE 14 bus system carry out by Mi-power software. From the results obtained it is verified that the load flow analysis can be easily done with Mi-power which is a fast and robust tool with a powerful GUI to solve. Finally, the voltage profile improvement is verified with the placement of shunt capacitor.

Key words: Mi-Power, Reactive power compensation, Shunt Capacitor, VCPI.

1. INTRODUCTION

In recent days, usage of electric power is more, the demand for electricity is ever lasting. Due to this, interconnected large power systems are inevitable. But, power transfer to the long distances with high efficiency, while maintaining its quality, security and reliability, is a major challenge in the transmission and distribution of the power. Transfer of electric power with minimum losses and minimum voltage drop is a challenging task which can be properly achieved by installing compensating devices [1], [2]. The main objective of using compensating devices is to minimize the losses and better voltage profile [3]. Among compensating devices such as shunt capacitor banks are used to voltage profile improvement and losses reduction and then by improving power transfer capacity. However, to succeed the above-mentioned benefits, the proper placement of shunt capacitor is to be done with appropriate values.
For this optimal placement, some performance of indexes should be calculated. Such as voltage collapse proximity index [4], [5] identify the week bus for optimal location of the shunt capacitor. In this paper, Mi-power software is utilized for solving the problem of optimal location and sizing of the shunt capacitor in the power system. In this paper load flow analysis without shunt capacitor can be run by using Mi-Power software. By doing voltage stability analysis using Mi Power VCPI values are computed. The best location for shunt capacitor placement is based on weakest bus i.e. highest VCPI value bus. After that shunt capacitor is placed in Mi power to run the load flow analysis. The obtained results of IEEE 14 bus system with and without placement of the shunt capacitor with different loading conditions are compared.

2. PROBLEM IDENTIFICATION
As the main objectives of this work are finding the optimal location for shunt capacitor placement in the power system in order to reduce the losses and improving the voltage profile. To verify the above objectives, the following performances index is used.

Optimal placement of shunt capacitor with VCPI
In this section, the shunt capacitor optimum location for IEEE 14 bus test system under normal and high loading condition is discussed. Balamourougan et al. [6] suggested a voltage stability index which was based on the network admittance matrix and the voltage phasor information of the participating buses and Voltage stability index based VCPI (Voltage Collapse Prediction Index) is obtained for all the buses. The value of the index gives the closeness to voltage collapse at a bus can be determined by load flow (LF) analysis. Basic power flow equation is used for deriving this technique, which can be applied for any power system irrespective of bus number. Newton Rapson method can be used for solving power flow equations. The optimal location of shunt capacitor is decided by the voltage collapse prediction index which varies between 0 and 1. Kth bus is considered as stable bus if index is in proximity to zero and there is a chance voltage collapse occurrence at that bus if the index is near to unity [7], [8]. VCPI values are obtained by using voltage stability analysis in Mi-power software. The optimal location for placing the shunt capacitor is the weakest bus which has highest VCPI.

\[ V_{k} = 1 - \frac{\sum_{m=1, m \neq k}^{n} V_{m}^{'}}{V_{k}} \]  
(1)

\[ V_{m}^{'}, = \frac{Y_{km}}{\sum_{j=1, j \neq k}^{n} Y_{kj} V_{k}} \]  
(2)

where, \( V_{k} \): phase voltage at kth bus
\( V_{m}^{'} \): phase voltage at mth bus
\( Y_{km} \): admittance of line between bus k & m
\( Y_{kj} \): admittance of line between bus k & j: bus being monitored
m: other bus that is connected to kth bus
n: total buses that are available in the system

Shunt capacitor calculation
In the year 1914, the power factor correction can be employed by shunt capacitors. The leading current absorbed by shunt capacitors compensate the lagging current required by load connected to the power system. In case of loads having heavy fluctuations, the reactive power requirement of the overall system also deviates over a vast range. Hence, a fixed-value capacitor bank would often result in either over- or under-compensation. A variable VAR compensation is, generally, achieved by using switched/variable capacitors [9], [10], where capacitor banks are put into or out of the system based on VAR requirement. The swiftness of control is completely dependent on counts of capacitors switching units being employed. Usually, the switching is done using relays with circuit breakers. The shunt capacitor size is computed using below equation:
The enhanced version of shunt capacitor is static synchronous compensator (STATCOM). This is also a shunt connected device and widely used in various application like power system stability improvement [11]-[16], in HVDC [17]-[19] and etc.

3. MI POWER

Mi-power is windows-based power system simulation and analysis software which is highly interactive with user-friendly interface. Power system design and analysis can be done with a set of modules. Mi-power features a top class windows GUI incorporated with a centralized database via which, steady state and transient including electromagnetic transient analysis can be done with very high accuracy [20, 21]. The Mi-power applications are load flow studies, harmonic load flow, short circuit analysis, network reduction, dc network solutions, transient stability studies, voltage instability analysis, electromagnetic transient analysis, sub synchronous resonances, state estimation, real power optimization, reactive power optimization, over current relay coordination ,distances relay coordination, battery sizing, available power transfer, line and cable parameter calculation, reliability assessment and open access feasibility. Some of the authors use the Mi power for placement of the shunt capacitor using L index for enhancing the voltage levels in load flow studies; they observe that it is very use full in solving power system problems [22, 24].

4. RESULTS AND DISCUSSION

In IEEE 14 bus test system, 1st bus is taken as the slack (reference) bus and bus bearing numbers 2,3,6 and 8 are chosen as PV (voltage-controlled) buses, whereas all the other buses are taken as PQ (load) buses. There are total 20 interconnected lines as shown in figures 3 and 4. VCPI values are calculated using the voltage instability analysis tool in software package of Mi-power. It also utilized for LF studies and the obtained results are analyzed. Table I to Table III indicate line data, bus data and load data respectively of IEEE 14 bus test system.

The power loss and active power generation for the IEEE 14 bus test system before and after placing shunt capacitor are given in Table IV and Table VI respectively and it can be observed that losses of active power have been reduced to 13.3875 MW from previous 13.5318 MW value after placing the shunt capacitor in load flow analysis at normal load condition. The value of shunt capacitor is changed to 9.55 MVAR by the help of Mi-power. The impact of shunt capacitor at 125% and 150% loading conditions, both real and reactive loads are observed in better way. At 125% of loading condition without capacitor real and reactive losses are increased to 23.6031MW and 81.0311 MVAR respectively. After placing the 10.8525 MVAR capacitor at bus 14, these losses are reduced to 21.888 MW and 63.2614 MVAR respectively. At 150% of full load, losses in real power are decreased to 37.635 MW from the previous 41.5481 MW value by placing 12.985 MVAR shunt capacitor at bus 14 and reactive losses are reduced to 133.865 MVAR from 161.025 MVAR. From this table it is also observed the by increase in load the losses have been enhanced, but after placement of shunt capacitor at bus 14 these values are getting reduced. Table V indicates the VCPI values. At bus 14 the VCPI value is 0.148321p.u, which is the highest value compared to VCPI value at other buses because it is located far away from generator buses and reactive load is also high. From this table it can be concluded that bus 14 has the highest VCPI value which implies that bus 14 is the weakest bus. Since the weakest bus is the best location for shunt capacitor bus 14 is selected as the optimal location for the placement of shut capacitor. Figure 1 represents the voltage magnitudes at different loading conditions, which indicates that by increasing the load voltage magnitude has been reduced. Figure 2 depicts the magnitudes of voltage at normal loading condition before and after using the shunt capacitor. It can be seen that after using the shunt capacitor at bus number 14, voltage profiles of overall system have been increased. Figure 3 and Figure 4 shows the IEEE14 bus diagrams in Mi power without and with shunt capacitor.
Table I: Line data of IEEE 14 bus test system

| S: NO | FROM BUS | TO BUS | R (p.u) | X (p.u) | B/2 (p.u) |
|-------|----------|--------|---------|---------|-----------|
| 1     | 1        | 2      | 0.01937 | 0.05915 | 0.00000   |
| 2     | 2        | 3      | 0.04695 | 0.19795 | 0.02196   |
| 3     | 2        | 4      | 0.05814 | 0.17633 | 0.01860   |
| 4     | 1        | 5      | 0.05433 | 0.22344 | 0.02470   |
| 5     | 2        | 5      | 0.05696 | 0.17378 | 0.01740   |
| 6     | 3        | 4      | 0.06751 | 0.17203 | 0.01830   |
| 7     | 4        | 5      | 0.01345 | 0.04221 | 0.00650   |
| 8     | 7        | 8      | 0.00000 | 0.17615 | 0.00000   |
| 9     | 7        | 9      | 0.00000 | 0.11001 | 0.00000   |
| 10    | 9        | 10     | 0.03181 | 0.08450 | 0.00000   |
| 11    | 6        | 11     | 0.09498 | 0.19890 | 0.00000   |
| 12    | 6        | 12     | 0.12291 | 0.25581 | 0.00000   |
| 13    | 6        | 13     | 0.06615 | 0.13027 | 0.00000   |
| 14    | 9        | 14     | 0.12711 | 0.27038 | 0.00000   |
| 15    | 10       | 11     | 0.08205 | 0.19207 | 0.00000   |
| 16    | 12       | 13     | 0.22092 | 0.19988 | 0.00000   |
| 17    | 13       | 14     | 0.17093 | 0.34802 | 0.00000   |
| 18    | 4        | 7      | 0.01938 | 0.05917 | 0.00000   |
| 19    | 5        | 6      | 0.01938 | 0.05917 | 0.00000   |
| 20    | 4        | 7      | 0.01938 | 0.05917 | 0.00000   |

Table II: Bus data of IEEE 14 bus test system

| SL. NO | MAGNITUDE IN PU | PHASE ANGLE DEGREE |
|--------|-----------------|--------------------|
| 1      | 1.06            | 0.0                |
| 2      | 1.045           | 0.0                |
| 3      | 1.03            | 0.0                |
| 4      | 1.0             | 0.0                |
| 5      | 1.0             | 0.0                |
| 6      | 1.0             | 0.0                |
| 7      | 1.0             | 0.0                |
| 8      | 1.0             | 0.0                |
| 9      | 1.0             | 0.0                |
| 10     | 1.0             | 0.0                |
| 11     | 1.0             | 0.0                |
| 12     | 1.0             | 0.0                |
| 13     | 1.0             | 0.0                |
| 14     | 1.0             | 0.0                |
Table III: Load data of IEEE 14 bus test system

| SL. NO. | LOAD Real load in MW | Reactive load in MVAR |
|---------|----------------------|-----------------------|
| 1       | 0.00                 | 0                     |
| 2       | 21.65                | 10.5                  |
| 3       | 94.20                | 16.23                 |
| 4       | 47.60                | 3.7                   |
| 5       | 7.50                 | 1.3                   |
| 6       | 11.25                | 6.45                  |
| 7       | 0.0                  | 0                     |
| 8       | 0.0                  | 0                     |
| 9       | 29.65                | 14.76                 |
| 10      | 9.20                 | 4.68                  |
| 11      | 3.40                 | 1.78                  |
| 12      | 6.40                 | 1.65                  |
| 13      | 13.55                | 5.85                  |
| 14      | 14.60                | 6.6                   |

Table IV: IEEE14 bus test system Power losses under loading conditions.

| S. NO | Net Real Power Generation in MW | 100%  | 125%  | 150%  |
|-------|---------------------------------|-------|-------|-------|
| 1     | 272.5318                        | 347.3531 | 430.0481 |
| 2     | 109.4254                        | 172.9061 | 271.3525 |
| 3     | 259.0000                        | 323.7500 | 388.5 |
| 4     | 73.5                            | 91.875 | 110.25 |
| 5     | 13.5318                         | 23.6031 | 41.5481 |
| 6     | 35.9254                         | 81.0311 | 161.1025 |

Table V: Weak bus identification with VCPI using Mi power

| Rank | VCPI value | Bus Number |
|------|------------|------------|
| 1    | 0.148321   | 14         |
| 2    | 0.125665   | 13         |
| 3    | 0.122707   | 10         |
| 4    | 0.122561   | 12         |
| 5    | 0.117168   | 9          |
| 6    | 0.115360   | 11         |
| 7    | 0.079382   | 7          |
| 8    | 0.027504   | 4          |
| 9    | 0.015448   | 5          |
Figure 1. Comparison of voltage magnitude at different loading conditions

Figure 2. Voltage magnitude Comparison with and without shunt capacitor at bus number 14.

Table VI: IEEE14 bus test system Power losses under loading conditions with shunt capacitor at Bus no. 14.

| S:no | 100%       | 125%       | 150%       |
|------|------------|------------|------------|
| 1    | Total Real Power in MW | 272.3875   | 345.6380   | 426.135    |
| 2    | Total Reactive Power in MVAR | 90.1555    | 144.2839   | 231.13     |
| 3    | Total Real Power Load in MW  | 259.0000   | 323.7500   | 388.5      |
|   | Total Reactive Power Load in MVAR |    |    |    |
|---|----------------------------------|----|----|----|
| 4 |                                  | 73.5 | 91.875 | 110.25 |
| 5 | Total Real Power Losses in MW    | 13.3875 | 21.888 | 37.635 |
| 6 | Total Reactive Power Losses in MVAR | 26.2055 | 63.2614 | 133.865 |
| 7 | Size of the Shunt Capacitor in MVAR | 9.55 | 10.8525 | 12.985 |

Figure 3. Simulation of IEEE 14 bus test system without shunt capacitor
5. CONCLUSION

In this paper, losses minimization and optimal shunt capacitor placement in the IEEE 14 bus test system has been demonstrated by using VCPI. Mi-Power software is utilized for the power flow studies. The load flow studies before and after placement of shunt capacitor in power system is done with the help of Mi-Power software. From the results obtained so far, it is concluded that the performance of Mi-power software is superior in terms of quality solution, iterations speed and high
computation efficiency. The shunt capacitor reduces losses and after seeing the simulation results of IEEE 14 bus system, it is evident that voltage profile is improved with proper placement of shunt capacitor.

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