BRAINSTORM OPTIMIZATION ALGORITHM FOR OPTIMAL PLACEMENT AND SIZING OF UNIFIED POWER FLOW CONTROLLER

***[1]Alhassan F., [2]Lawal, M.I. and [3]Sabitu A.**
Department of Electrical/Electronic Engineering Technology, Abdu Gusau Polytechnic, Talata-Mafara.

[2]Department of Electrical Engineering Technology, Federal Polytechnic,Kaura Namoda.
Email: fahadalhassan1990@gmail.com

Abstract

The ever-increasing demand on power system necessitates the deployment of FACTS devices to enhance controllability and also increase power system capability. Conventionally, some FACTS devices are separately used to control the voltage magnitude, whereas some are used to control the power flow on the transmission lines. However, Unified Power Flow Controller (UPFC) has the advantage of being able to simultaneously and independently control the voltage magnitude and the power flow through the transmission lines of a network on which it is connected. This paper presents a Brainstorm Optimization Algorithm (BSOA) based method for optimal placement and sizing of UPFC on standard IEEE 14-bus network. Analysis was conducted based on three scenarios (full loading, moderate loading and at critical loading) in order to demonstrate the effectiveness of the approach. The simulation results indicate that BSOA is robust based on the facts that all the voltage profile that violate $\pm 5\%$ *tolerance margin of the nominal voltage criteria were kept within the acceptable limit. Moreover, the proposed approach also records significant reduction in the overall real power loss in the whole network.*

1. Introduction

The transmission lines are frequently driven nearly or even beyond their thermal limits so as to meet the ever-increasing demand which normally resulted incongestion and voltage collapse(Bakare *et al*., 2012). Most of the domestic and industrial loads are inductive in nature; these types of loads consumed more of the reactive power, thereby leading to voltage instability of the transmission line (Kiran and Laxmi, 2011). As the demand for stable and reliable power supply keep increasing, there exist problems of high power loss and voltage instability. These problems and other factors result in voltage collapse (Adebayo, *et al.,* 2013). This has called for urgent implementation of a robust technique for analyzing and preventing voltage collapse in network prior to its occurrence.

Voltage stability is the capability of a power system to maintain steady voltages at all buses or nodes in the system, under normal operating condition and after being exposed to disturbances from a given initial operating condition. The system operating state enters voltage instability region when a perturbation or high load demand or alteration in system state results in an interminable drop in system voltage. Failure of a power system to meet reactive power demand is the major cause of instability. The flow of active and reactive power through the transmission's network inductive reactance causes voltage drop (Adebayo and Sun, 2017).The criterion for voltage stability is that, at a given operating condition for every bus in the system, the bus voltage magnitude increases as the reactive power injection at the same bus is increased, and also a system is said to be voltage unstable, if at least one bus in the system, the bus voltage magnitude decreases as the reactive power injection at the same is increased (Singh, 2011). There are several incidences causing voltage instability among them are: large distance between the sending and receiving end voltages, insufficient supply of reactive power or excessive absorption of the reactive power from the system, sudden increase in load demand in a heavily stressed network, loss of synchronism as a result of uncontrolled generator rotor swings, and action of tap-changing transformer (Richa, *et al.,* 2012; Subramanyam and Gowri, 2012)). The earlier stated causes of voltage instability when left unattended to will result in voltage collapse and subsequently, in partial or total blackout of an entire network as a result of the cascading failure it caused.

With the development of Flexible AC Transmission System (FACTS) devices, power system performance has improved. A FACT'S is a system that is utilized for AC transmission and is made up of static equipment. Its purpose is to raise power transfer capability of the given network and to up its controllability. FACTS devices are generally used to control parameters that govern a transmission line. The requirements of FACTS devices are: rapid dynamic response, ability for frequent variations in output and smoothly adjustable output (Suchak, *et al.,*2017). Out of the various FACTS devices, Unified Power Flow Controller (UPFC) has a unique advantage to control voltage magnitude at a bus and active and reactive power flow in line in which it is connected. To achieve the functionality of UPFC, it is highly important to determine the optimal location of this device in the power system with the appropriate parameter setting(Sharma and Gupta, 2012). In search for the optimal location and sizing of FACTS devices in power network, analytical and numerical techniques have been developed. Due to certain drawbacks which include computational complexity and the inability to fully incorporate the non-linearity of the power networks, search for better and more robust methods become absolutely necessary (Niu, *et al.,* 2014). The evolution of metaheuristics optimization algorithms has open up new, faster and robust approach of solving complex power system optimization problems (Binitha and sathya, 2012). Furthermore, this research employed Brainstorm Optimization Algorithm (BSOA)for the optimal deployment of UPFC.

BSOA is an optimization technique inspired by the human brainstorming process. When faced with a difficult problem which a single individual might not be able to solve, group of people will usually put heads together to come up with a solution. The rate of solving the problem collectively is usually high when compared with a solution when it involves a single individual. One way to help human beings interactively collaborate in generating good idea is to get together group of people to brainstorm (Shi, 2015).

The rest of the paper is organized as follows: Section 2 presents the UPFC overview. Section 3 gives a general problem formulation. The concept of BSOA is described in section 4. Simulation results are discussed in section 5. Finally, conclusion is summarized in section 6.

2. The Overview of Unified Power Flow Controller

The UPFC consists of shunt (exciting) and series (boosting) transformer, which are connected by two Gate Turn Off (GTO) converters and a DC circuit represented by the capacitor as shown in Figure 1. The series (Converter 2) is used to generate a voltage source at the fundamental frequency with variable amplitude ($0 \leq V_s \leq V_{smax}$) and phase angle ($0 \leq \emptyset_T \leq 2\pi$), which is added to the AC transmission line by the series connected boosting transformer. By so doing, the converter output voltage injected in series with the line can be used for used for direct voltage control, series compensation, phase shifter and their combination.

The shunt (Converter 1) is used primarily to provide the real power demand of converter 2 at the common DC line terminal from the AC power system. Converter 1 can also generate or absorb reactive power at its AC terminal, which is independent of the real power that it transfers to the DC terminal.Amongst the various FACTS devices, UPFC has an exceptional abilityto concurrently provide a flexible control of the bus voltage magnitude and active and reactive power flow through the line,in which, it is connected, this has made it more versatile than other FACTS devices.

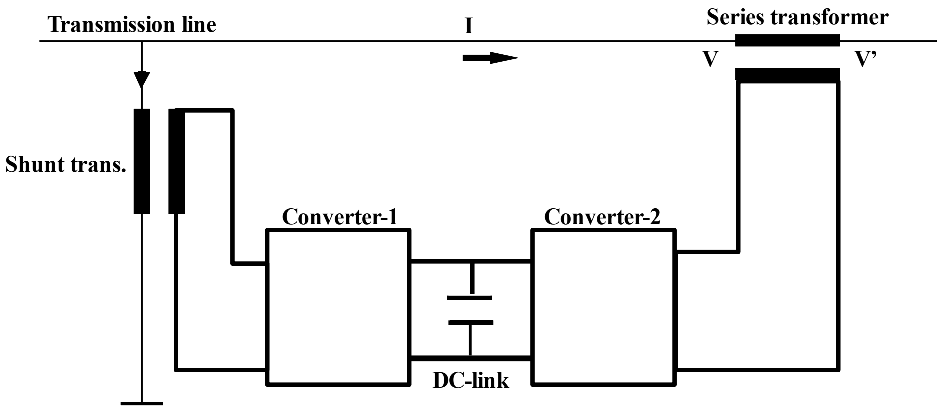

Figure 1:The Operating principle of UPFC (Zhang,*et al.*, 2012).

The equivalent circuit of UPFC is located in line –k and connected between bus-*i* and bus-*j* as shown in Figure 2.5:

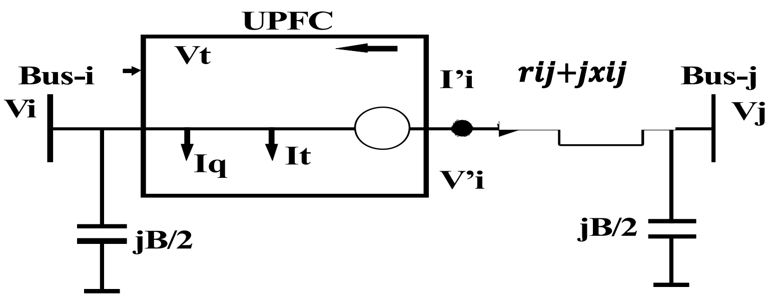

Figure 2: The equivalent circuit of UPFC (Verma *et al.*, 2001).

The active and reactive power flows of a line where UPFC is connected, is obtained mathematically using equation (2.1) and (2.2) as thus:

$$P_{ij} = (V_i^2 + V_T^2)g_{ij} + 2V_iV_Tg_{ij}\cos(\emptyset_T - \delta_i) - V_jV_T\left[g_{ij}\cos(\emptyset_T - \delta_j) + b_{ij}\sin(\emptyset_T - \delta_j)\right] - V_iV_j\left(g_{ij}cos\delta_{ij} + b_{ij}sin\delta_{ij}\right) \quad (2.1)$$

$$Q_{ij} = -V_i I_q - V_i^2\left(b_{ij} + \frac{B}{2}\right) - V_i V_T[g_{ij}\sin(\emptyset_T - \delta_i) + b_{ij}\cos(\emptyset_T - \delta_i)] - V_i V_j(g_{ij} sin\delta_{ij} - b_{ij} cos\delta_{ij}) \quad (2.2)$$

Where I_q and $g_{ij} + jb_{ij} = \frac{1}{r_{ij}+jX_{ij}}$ are the reactive current flowing via the shunt tranformer to improve the votage or the shunt connect bus of UPFC (Verma *et al.*, 2001). The power flow from bus-j to bus-i connected with UPFC is expressed in equations (2.3) and (2.4):

$$P_{ji} = -V_j^2 g_{ij} - V_j V_T[g_{ij}\cos(\emptyset_T - \delta_j) - b_{ij}\sin(\emptyset_T - \delta_j)] - V_i V_j(g_{ij} cos\delta_{ij} - b_{ij} sin\delta_{ij}) \quad (2.3)$$

$$Q_{ji} = -V_j^2\left(b_{ij} + \frac{B}{2}\right) + V_j V_T\left(g_{ij}\sin(\emptyset_T - \delta_i) + b_{ij} cos(\emptyset_T - \delta_i)\right) + V_i V_j(g_{ij} sin\delta_{ij} - b_{ij} cos\delta_{ij}) \quad (2.4)$$

The real power and reactive power injection at the bus-i with the system loading (λ) is obtained using (2.5) and (2.6):

$$P_i = P_{gi} - P_{di}^0(1+\lambda) = \sum_{j\in N_b} P_{ij} \quad (2.5)$$

$$Q_i = Q_{gi} - Q_{di}^0(1+\lambda) = \sum_{j\in N_b} Q_{ij} \quad (2.6)$$

Where P_{di}^0 and Q_{di}^0 are the initial real and reactive power demand. P_{gi} and Q_{gi} are the real and reactive power generations at bus-i respectively. It is assumed that in equations (2.5) and (2.6), that a uniform loading with the same increase in loading factor of the power demand at all the P-Q buses have been considered and is to be taken care of by the reference bus, whereas, sharing of generation amongst the generators can easily be incorporated in this model(Verma *et al.*, 2001).

3. Problem Formulation

The essence of this research is to find an optimal trade-off between conflicting objectives by including UPFC at the transmission level of the electric power network. This can be achieved with the help of the objective function below.
The objective function (J) is to minimize the active power by optimally placing the GUPFC; expressed as

Minimize (*J*) = $min(\omega_1 P_{Loss} + \omega_2 \text{VD})$ (3.1)
The network overall active power loss function is given by:
$P_{Loss} = \sum_{i=1}^{N_L} G_{i,j}[V_i^2 + V_j^2 - 2V_iV_j(\cos\delta_i - \delta_j)]$ (3.2)
The voltage deviation function is expressed as:
$\text{VD} = \sum_{i=1}^{Nb} (V_i - V_{refi})^2$ (3.3)
Where,
$\omega_1$and $\omega_2$are the weighting factors used for adjusting the network total active power loss and voltage deviation functions respectively. $V_i$is the voltage magnitude at bus i, $V_j$is the voltage magnitude at bus j, $G_{i,j}$is the conductance of line i-j, $\delta_i$is the voltage angle at bus i, $\delta_j$is the voltage angle at bus j, N_L is the total number of transmission lines, V_{refi} is the nominal or reference voltage at bus i, V_{ref} = 1.0
Constraints
The minimization problem is subjected to the following equality and inequality constraints.

1. Equality constraints:
   $P_{Gi} - P_{Di} - V_i \sum_{j=1}^{n} V_j[G_{ij}\cos(\delta_i - \delta_j) + B_{ij}\sin(\delta_i - \delta_j)] = 0$ (3.4)
   $Q_{Gi} - Q_{Di} - V_i \sum_{j=1}^{n} V_j[G_{ij}\sin(\delta_i - \delta_j) + B_{ij}\cos(\delta_i - \delta_j)] = 0$ (3.4)

Where,
P_{Gi} is the real power generation at bus i, Q_{Gi} is the reactive power generation at bus I, P_{Di} is the real power demand at bus i, Q_{Di} is the reactive power demand at bus I, n is the total number of buses, $B_{i,j}$ is susceptance of line i, j

2. Inequality constraints: The inequality constraint includes the bus voltage and GUPFC size limit.
   $P_{Gi}^{min} \le P_{Gi} \le P_{Gi}^{max}$ (3.5)
   $Q_{Gi}^{min} \le Q_{Gi} \le Q_{Gi}^{max}$ (3.6)
   $V_i^{min} \le V_i \le V_i^{max}$; i ∈ N_B (3.7)
   $T_i^{min} \le T_i \le T_i^{max}$; i ∈ N_T (3.8)

$S_{UPFC}^{min} \leq Q_n \leq S_{UPFC}^{max}$ (3.9)

Where,
T is the tap changing transformer at bus i, S is the power flow in the line, N_T is the number of tap changing transformer, NB is the total number of buses excluding slack bus.

4. Brainstorm Optimization Algorithm

Based on brainstorming process in human being, Shi proposed BSOA for solving optimization problems. Human brainstorming process involves people coming together with a diverse background as possible to solve a particular problem (Shi, 2015). In BSOA, individuals are analogous to idea in brainstorming, clusters are analogous to brainstorming group and cluster centres are analogous to best ideas of brainstorming groups. BSOA contains the following four (4) basic operations (Jordehi, 2015).

- **i.** Initialization: like all other population based heuristics, N individuals are ramdomly initialized in feasible region of search space.
- **ii.** Clustering: this operation divides the population into different cluster (brainstorming groups) according to individual features. K-means strategy is used for clustering. K-means clustering algorithm is an incremental approach to clustering that dynamically adds one cluster centre at a time through a deterministic global search procedure of N executions from the suitable initial position.
- **iii.** Cluster center perturbation: in BSOA, the best individual of a cluster is named cluster center which is analogous to the best idea in a brainstorm group. With probability P_1,a cluster center is selected and is replaced with a random individual. $P_1$is a control parameter of BSOA that affects the trade-off between its exploitative capabilities. The higher it is, the more exploration capability.
- **iv.** Individual perturbation: with probability P_2, the individuals in the clusters are perturbed as shown in the equation below.

$$X_{new}(t) = X_{selected}(t) + S(t)N(0,1) \quad (4.1)$$

Where, X N (0,1) represents Gaussians distribution with mean zero and standard deviation of one. S(t) is the perturbation step size and is updated at each iteration as in equation 4.2.

$$S(t) = \log sig\left(\frac{\frac{t_{max}}{2}-t}{K}\right).r \quad (4.2)$$

Where, K is a scalefactor, r is a random in (0,1), logsig represent logisticsig moid function. Symbols t and t_{max} represent current and maximum iteration number respectively. Furthermore, in this stage, with a specified probability P_3, two individuals participate to breed a new individual. After updating an individual, its new objective value is computed and if it is lower than its current objective value, current individual is replaced by the new one.Clustering, cluster centre perturbation and individual update are repeated till termination criterion of the algorithm is met.In this paper, the initialization parameters for the proposed PSO based method are presented in Table 4.1.

Table 4.1: Parameter Settings for BSOA

S/N	Parameters	Values
1	Population size, N_p	100
2	Number of dimension, N_c	10
3	Number of cluster, m	2
4	Maximum number of iteration, t_{max}	10

5. Results and Discussions

The developed method was tested on IEEE 14-bus network and three scenarios or cases were considered, which are: at full loading, moderate loading and at critical condition. The single line diagram, line data and bus data for this network are provided in (Sa'adat, 1999).The network voltage constraint limits have been set as 0.95p.u. and 1.05p.u. for minimum voltage V_{min} and maximum voltageV_{max}.

5.1 Scenario-1: With Full Load

Power flow analysis was performed to evaluate the initial steady-state condition of the network using Newton-Raphson method. It is observed from Figure 5.1 that at a loading of (100%) condition prior to UPFC installation, a total power loss of 26.7230MW is obtained with minimum voltage of 0.9426p.u at Bus 14.

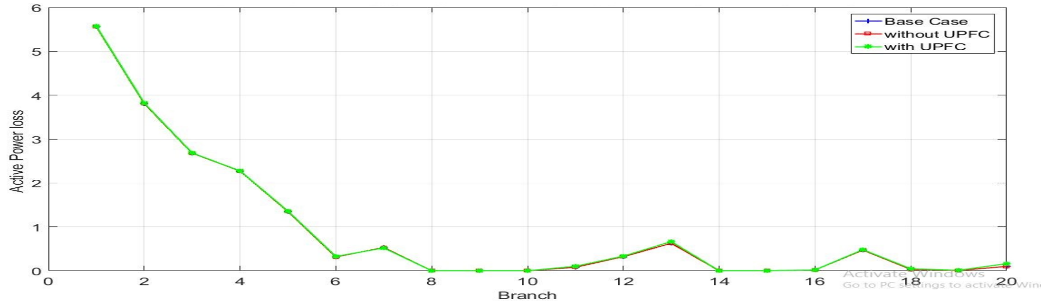

Figure 5.1: Power flow Result under Full Loading Condition

After the optimal placement of UPFC of size 61.5206MVAr, the voltage magnitude increases to 0.9624p.u as seen in Figure 5.2.From Figure 5.1, the power loss reduced from 26.7230MW to 25.1241MW representing 5.9832% power loss reduction. Voltage improvement is evident in all the load buses.

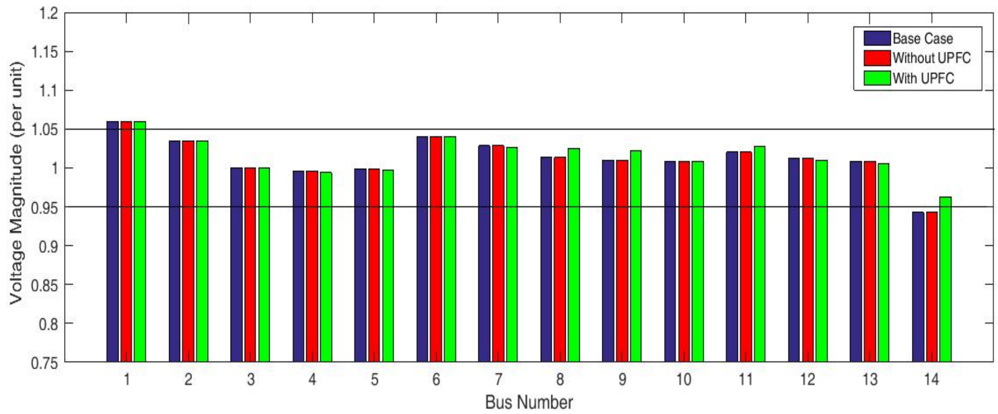

Figure 5.2: Voltage profile result under Full loading condition

5.2 Scenario-2: With Moderate Load

Power flow analysis was performed to evaluate the operating condition of the network using Newton-Raphson technique. Figure 5.3 depicts the power loss profile result under moderate loading condition. At moderate loading, that is we increase the load by 25% giving us 125%.It is observed that, the total transmission power losses increased when compared to the base case due to increase in the power demand. The highest losses occur between lines 1(13-14) because of the nearer connections to the critical lines and the distance from the generating units. Total power loss of 38.6028MW is obtained and after the installation of UPFC at Bus 14 (the bus that shows a high vulnerability to voltage collapse) the loss reduces to 25.9575MW represents 32.7575% power loss reduction with 48.7200MVAr UPFC size.

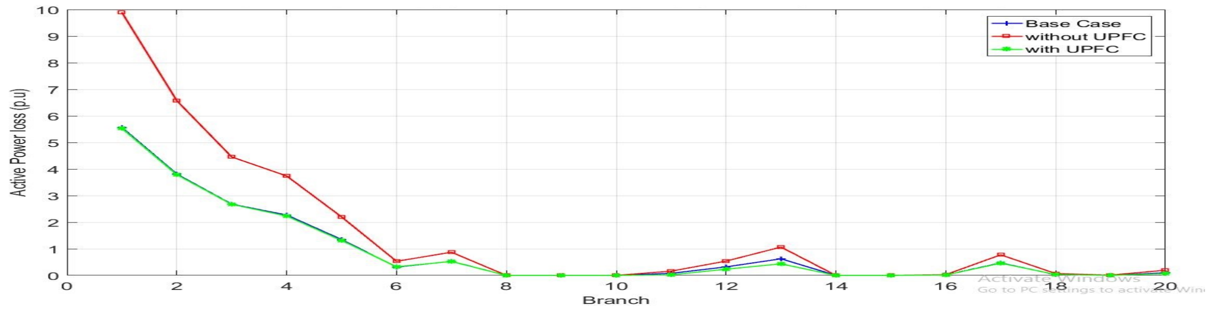

Figure 5.3: Power flow Result under moderate loading condition

Figure 5.4 shows a voltage profile results before and after installing UPFC under moderate loading condition, under the operating range voltage of 0.95-1.05p.u. It is clearly observable that bus 14 has the minimum base voltage of 0.9407p.u and after optimal placement of UPFC it increases to 1.0140p.u. It is also noticed that with the application of UPFC, an average voltage profile improvement of 22.30% was achieved on the entire load buses.

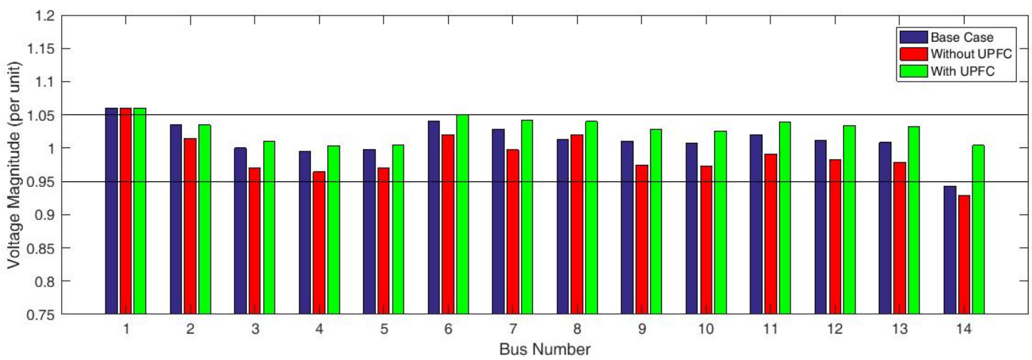

Figure 5.4: Voltage profile results under moderate loading condition

5.3 Scenario-3: With Critical Load

Power flow analysis was performed to determine the initial steady-state condition of the network using Newton-Raphson method. It is observed from Figure 5.5 that at a loading increase of 50% from the nominal loading condition prior to UPFC installation that the losses increased and the voltage magnitude in Figure 5.6 is also seen to decrease before the optimal placement of UPFC. The total power loss before the installation of UPFC is 58.4950MW is obtained with minimum

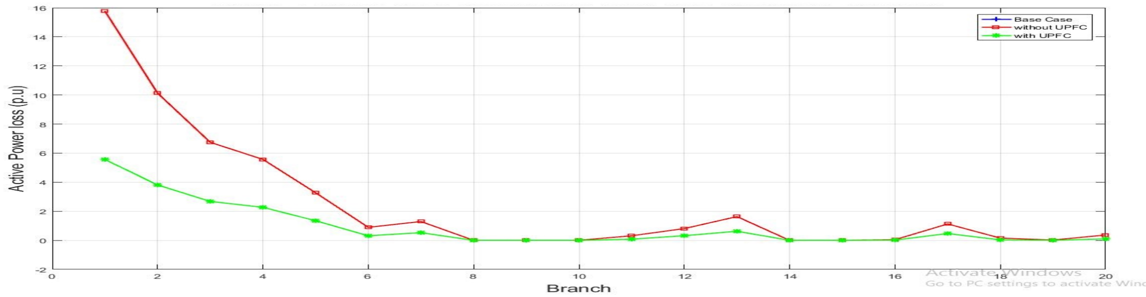

Figure 5.5: Power flow Result under Critical loading condition

voltage of 0.9426p.u at Bus 14. An overall real power loss of 58.4950MW is obtained and after optimal placement of UPFC, it reduces to 28.7330MW representing 51.3924% with installation of 78.3200MVar size of UPFC at bus 5.Furthermore, from Figure 5.6, violation of voltages nominal tolerance of ±5% was recorded in Buses 9, 10 and most especially Bus 14, due to the cascading effects. The other load buses like 4, 5, 6, 7, 12 and 13 were very close to their lower limits of voltage amplitude, which means that any slight increase in load demand will result in voltage collapse. It is therefore concluded that the critical loading (150%) is the optimum load ability of IEEE 14-bus system under the operating range of 0.95-1.05p.u.

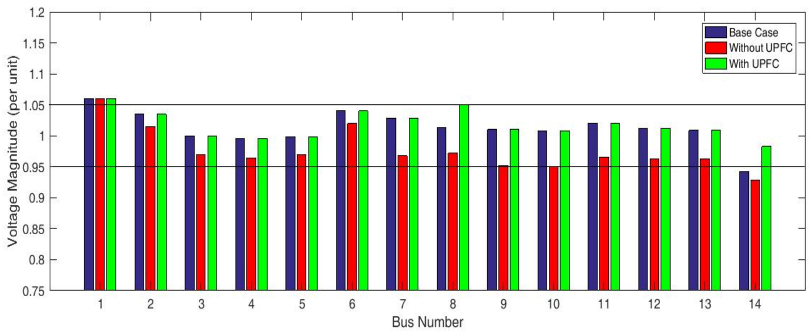

Figure 5.6: Voltage profile results under critical loading

5.1: Simulation results summary for IEEE 14-bus Network

Loading Factor	Losses Without UPFC (MW)	Rating of UPFC (MVAr)	Losses With UPFC (MW)	UPFC Location	% Power Loss Reduction
Normal (100%)	26.7230	61.5206	25.1241	5	5.9832
Moderate (125%)	38.6028	48.7200	25.9575	14	32.7575
Critical (150%)	58.4950	78.3200	28.7330	5	51.3924

6. Conclusion

This paper has proposed a Brainstorm Optimization Algorithm (BSOA) based method for optimal location and sizing of UPFC in a transmission network for power loss minimization and voltage profile enhancement. A multi-objective function comprising of total power loss and network bus voltage deviation was formulated for the developed strategy. The effectiveness and application of the approach has been demonstrated on IEEE 14-bus network. The total base case power loss on IEEE 14-bus network under different loading conditions of 100% (full), 125% (moderate) and 150% (critical) are 26.7230MW, 38.6028MW, 58.4950MW and after the placement of UPFC, the power loss reduces to 25.1241MW, 25.9575MW and 28.7330MW. Moreover, voltage profile improvement was also achieved on buses that violate $\pm 5\%$ tolerance margin of the normal voltage criteria after the optimal placement and sizable UPFC. Finally, it can be concluded that more power can be transmitted (both at full and moderate conditions) to meet ever-growing demand over an existing network without compromising the voltage stability by using the cheaper plan proposed in this methodology.

REFERENCES

Adebayo, I.G., Aborisade, D.O. and Oyesina, K.A. (2013). Steady State Voltage Stability Enhancement using Static Synchronous Series Compensator (SSSC);

A Case Study of Nigerian 330KV Grid System, *Research Journal in Engineering and Applied Sciences*, 2(1): 54-61.

Adebayo, I. and Sun, Y. (2017). New Performance Indices for Voltage Stability Analysis in a Power System, *Energies*, 10, 2042; doi: 10.3390/en10122042.

Binitha, S. and Siva, S.S. (2012). A Survey of Bio Inspired Optimization Algorithm, *International Journal of Soft Computing and Engineering (IJSCE),*2(2): 137-151.

Bakare, G. A., Aliyu, U. O., Haruna, Y. S., & Abu, U. A. (2012). Transient Enhancement of Nigerian Grid System Using Optimally Tuned UPFC Based On Small Population Particle Swarm Optimization. *Asian Journal of Natural and Applied Sciences, 1*, 79-90.

Chowdhury, A. K., Mondal, S., Alam, S. K. M., & Pal, J. (2015). Voltage Security Assessment of Power System. *World Scientific News, 21*, 83-97.

Glover, J. D., Sarma, M. S., & Overby, T. J. (2012). *Power System Analysis and Design*. Stamford, USA: Global Engineering Publishers.

Jordehi, A.R. (2015). Brainstorm Optimization Algorithm (BSOA): an efficient algorithm for finding optimal location and setting of FACTS devices in electric power systems. *International Journal of Electrical Power and Energy Systems*, 69:48-57.

Kiran, I. K., & Laxmi, J. A. (2011). Shunt versus Series compensation in the improvement of Power system performance. *INTERNATIONAL JOURNAL OF APPLIED ENGINEERING RESEARCH, DINDIGUL, 2*(1), 28-37.

Lachs, W. R., & Sutanto, D. (1994). Different types of voltage instability. *IEEE Transactions On Power Systems, 9*(2), 1126-1134. doi: 10.1109/59.317617

Ladumor, D. P., Bhesdadiya, R. H., Trivedi, I. N., & Jangir, P. (2017). Optimal Power Flow with Shunt Flexible AC Transmission System (FACTS) Device Using Grey Wolf Optimizer. *3rd International Conference on Advances in Electrical, Information Communication and Bio-Informatics (AEEICB17)*.

Mech, L. D. (1999). Alpha status, dominance, and division of labor in wolf packs. *Can. J. Zool, 77*, 1196-1203.

Muro, C., Escobedo, R., Spector, L., & Coppinger, R. P. (2011). Wolf-pack (Canis lupus) hunting strategies emerge from simple rules in computational simulations. *Behavioural Processes 88, Elsevier*, 192–197.

Mirjalili, S., Mohammad, S., & Lewis, A. (2014). Advances in Engineering Software Grey Wolf Optimizer. *Advances in Engineering Software, 69*, 46-61.

Niu, M., Wan, C., and Xu, Z. (2014). A review on application of heuristic optimization algorithms for optimal power flow in modern power systems, Journal of Modern Power system. Clean Energy, 2(4):286-297.

Park, J., Lee, K., Shin, J. and Lee, K.Y. (2005). A Particle Swarm Optimization for Economic Dispatch with Non Smooth Cost Function, *IEEE Transaction on Power Systems*, 20(1): 34-42.

Patel, N. H., Thakkar, V., & Raval, H. N. (2015). Contingency Analysis in Power System and Remedial Actions. *IJSRD - International Journal for Scientific Research & Development, 3*(03), 821-827.

Quaia, S. (2018). Critical analysis of line loadability constraints. *International Transactions on Electrical Energy Systems*, e2552.

Ratra, S., Tiwari, R., & Niazi, K. R. (2018). Voltage stability assessment in power systems using line voltage stability index. *Computers & Electrical Engineering*. doi: https://doi.org/10.1016/j.compeleceng.2017.12.046

Richa, S., Kumar, V.S. and Dhirij, K. (2012). Voltage Instability and its prevention using FACTS Controller, *International Journal of Engineering Research and Development*, 3(11): 06-08.

Sa'adat, H. (1999). "*Power System Analysis", International edition.* New York: McGraw-Hill Companies.

Selvi, V. and Umarani, R. (2010). Comparative Analysis of Ant Colony and Particle Swarm Optimization Techniques, *International Journal of Computer Applications,* 5(4): 1-6.

Sharma, P. R., & Gupta, A. (2012). Optimal Placement of FACTS Devices for Voltage Stability Using Line Indicators. *IEEE, 6*(12).

Shende, V.K. and Jagtap, P.P. (2013). Optimal Location and Sizing of Static Var Compensator (SVC) by particle Swarm Optimization (PSO) technique for Voltage Stability Enhancement and Power Loss Minimization, *International Journal of Engineering Trends and Technology (IJETT),*4(6): 2278-2282.

Shi, Y. (2015). Brainstorm optimization algorithm in objective space. *IEEE proceedings.* doi.org/10.1109/CEC.2015.7257029.

Singh, S. N., & Erlich, I. (2005, 18-18 Nov. 2005). *Locating unified power flow controller for enhancing power system loadability.* Paper presented at the 2005 International Conference on Future Power Systems.

Subramanyam, R.S.R. and Gowri, T.M. (2012). Literature Review on Voltage Stability Phenomenon and Importance of FACTS Controllers in Power System Environment, *Global Journal of Researches in Engineering,* 12(3): 25-29.

Suchak, N., Chavada, V., Shah, B., Parmar, S. and Harsoda, V. (2017). Application of Flexible AC Transmission Systems (FACTS) in Recent Power System, *International Journal of Scientific Research in Computer, Engineering and Information Technology*. 2(3): 607-612.

Verma, K. S., Singh, S. N., & Gupta, H. O. (2001). Location of unified power flow controller for congestion management. *Electric Power Systems Research, 58*(2), 89-96. doi: https://doi.org/10.1016/S0378-7796(01)00123-7

Zhang, X. P., Rehtanz, C., & Pal, B. (2012). *Flexible AC Transmission Systems: Modellingand Control*. Heidelberg New York Dordrecht London: Springer.