Reactive Power Optimization of Nigerian Grid System Using Firefly Algorithm for Power Loss Reduction and Voltage Profile Enhancement

Bakare G. A.
Department of Electrical and Electronics Engineering
Abubakar Tafawa Balewa University
Bauchi, Nigeria
gabakare@atbu.edu.ng

Ibrahim K. A.
Department of Electrical and Electronics Engineering
Abubakar Tafawa Balewa University
Bauchi, Nigeria
ibrahimkafayatsubomi@gmail.com

Haruna, Y. S.
Department of Electrical and Electronics Engineering
Abubakar Tafawa Balewa University
Bauchi, Nigeria
ysharuna@atbu.edu.ng

Abba Gana M.
Department of Electrical and Electronics Engineering
University of Maiduguri
Maiduguri, Nigeria
mag1898@unimaid.edu.ng

***Abstract*—Reactive power optimization (RPO) is required in power system for simultaneous real power losses minimization and also improvement in the voltage profile. It involves identification of the optimal values of transformer tap-settings, generator voltage excitation magnitudes and discrete switching of doses of capacitor and inductor. This is a non-linear combinatorial problem that includes the various equality and inequality constraints. Thus, there is need to develop evolutionary techniques to achieve the global optimum solution to the problem. This paper presents the application of firefly algorithm (FFA) to solve the RPO problem. Firefly Algorithm solves the major drawbacks in conventional methods which includes the time consumption and the local minima criterion. The effectiveness of the approach has been tested on standard IEEE network and subsequently on updated 54-bus Nigerian 330kV grid system modelled in MATPOWER under three different loading conditions. Simulation results revealed improved voltage profile and significant real power loss reduction for real time online application.**

Keywords—Reactive power optimization, power loss minimization, firefly algorithm, reactive power control device, convergence characteristics.

I. Introduction

Due to continuous growth of the population and consequent increase in the demand of electricity and the demand far in excess of generations. This can lead to system instability such as system collapse. So, insufficient power generations, lack of transmission capacity expansion, voltage instability, insufficient reactive power sources are the main problem that can lead to voltage collapse [1]. Reactive power is the dissipated power resulting from inductive and capacitive loads measured in volt-ampere reactive (VAR). The reactive power dispatch has two-fold objectives thus: to improve system voltage profiles and minimize system losses at all times. Reactive power flow can be controlled by suitably adjusting the following facilities: tap changing under load transformers (TCUL), generating unit reactive power capability, switched capacitors and inductors, discrete static Var compensators (SVC), switching of transmission line. The above mentioned control variables have their lower and upper permissible limits and are distributed system-wide. By changing a combination of these control variables discretely and/or continuously, manifest not only in adjusting the system voltage profiles to the desired limits but also the transmission losses are reduced [2]. The existence of multiple optimum solutions is inevitable most especially when there are many reactive power control devices to be manipulated in a typically large power system like Nigeria grid to secure desired target system voltages. Thus, there is need to develop intelligent technology to achieve the global optimum solution of a reactive power dispatch problem [3].

Extensive efforts have been made in the past to develop and utilize several conventional optimization techniques. However, these techniques generally suffer from algorithmic complexity, premature convergence and sensitivity to initial search point [4]. Evolutionary computing based algorithms have been found to be suitable to overcome the drawbacks in conventional technique. Evolutionary algorithms have high modeling capabilities and enhanced search power. Such algorithms like genetic algorithm, particle swarm optimization, gravitational search algorithm, simulated annealing, differential evolution, artificial bee colony, harmony search algorithm, honey bee mating optimization algorithm etc., have been applied in solving various power system problems [5].

This paper presents the application of firefly algorithm approach to reactive power and voltage control problem. The algorithm has been developed using MATLAB software and demonstrated on two sample networks: standard IEEE 30-bus and updated 54-bus Nigeria 330kV grid system modeled in full operation detail. Simulation results on the two networks revealed that the algorithm procured power loss reduction of 0.9677%, 0.6341% and 27.130% and 10.2873%, 8.0712% and 11.7945% respectively for 90%, 100% and 110% loading conditions.

II. LITERATURE REVIEW

In [2] differential evolution (DE) was proposed as optimization algorithm for reactive power dispatch for voltage profiles improvement and reduction of real power losses. The algorithm was demonstrated on Nigerian power system grid. The results revealed that the algorithm was able to keep the abnormal bus voltages within the prescribed limits at the same time returning lower system power losses.

In [3] DE and PSO based reactive power and voltage control were comparatively investigated on Nigerian grid system and the New England power system. The simulation results revealed that both approaches were able to remove voltage limit violation, but PSO procured in some instances slightly higher power loss reduction when compared with DE and DE required a considerably lower number of function evaluations as compared with PSO.

In [4] hybrid modified imperialist competitive algorithm (MICA) and invasive weed optimization (IWO) were used to solve the optimal reactive power dispatch problem. The proposed technique was applied to ORPD problem on IEEE 30-bus, 57-bus and 118-bus respectively for testing and validation purpose. The proposed method provided better results compared to the original ICA, IWO and other methods.

In [5] hybridized FFA was applied to determine optimal setting of generator voltages, tap positions of tap changing transformers and VAR output of shunt capacitors to optimized two different objective functions such as minimization of real power loss and voltage deviation. Results obtained revealed that the proposed method provides better solution.

Micro–genetic algorithm was proposed in [6] to solve the reactive power/voltage control problem of the Nigerian grid system. In the paper, a relatively small population size was utilized when compared with conventional GA and premature convergence was avoided by different call of a “start and restart” procedure. The objective function was to minimize the real power losses in the system via the NR power flow with the application of proposed penalty function.

In [7], swarm intelligence and evolutionary approaches for reactive power and voltage control was presented using four algorithms: DE, PSO, a hybrid combination of DE and PSO, and a mutated PSO (MPSO). The MPSO was compared against a hybrid results with DE and PSO on Nigerian power system. The strength of the approaches was implemented on the Nigerian 31-bus 330 kV transmission grid. These studies were implemented in MATLAB, computation was not in real time and a real time simulator will be better.

In [8] ABC was proposed to solve the reactive power optimization problem. Multi-objective RPO was used considering voltage deviations of buses, active power losses and reactive power generator costs. The proposed technique was applied on IEEE 10-bus system and the results obtained were compared with the Pareto evolutionary algorithm. The system runs more effective and economically with ABC.

In [9] GA approach to improve voltage stability level of the system under base case and against the critical single line outage in the system to obtain the optimal settings of the reactive power control variables was presented. The effectiveness of this algorithm was demonstrated through voltage stability improvement in IEEE 30-bus system and IEEE 57-bus test system.

In [10], ABC algorithm was applied to reactive power control and reduction of transmission loss. The proposed approach was analyzed and demonstrated on the standard IEEE 30-bus test system. The simulation results obtained by the proposed approach revealed its robustness and effectiveness to solve the multi-objective RPO problem.

In [11], ABC algorithm for solving optimal reactive power dispatch problem (ORPD). It was tested on the IEEE 30-bus and IEEE 118-bus systems and the results obtained were compared with those obtained using PSO, self–organizing hierarchical PSO–time varying acceleration coefficient (HPSO-TVAC), and other methods. It was concluded that the proposed method obtained better results.

Enriched firefly algorithm (EFA) to solve multi-objective optimal power dispatch problem simultaneously with load and wind generation uncertainties was proposed in [12]. The method was tested on IEEE30-bus test system. Simulation results showed that the proposed approach outperformed other reported algorithms in minimization of real power loss.

In [13], FA for reactive power control and power loss reduction was tested on IEEE 30–bus system was proposed. The results were compared to the biogeography based optimization (BBO) and particle swarm optimization (PSO). Test results showed that FA was more efficient and procured high quality solution.

In [14] hybrid particle swarm optimization technique-multi verse optimizer (HPSO-MVO) to solve optimal reactive power dispatch problem was introduced. Improved convergence rate was achieved using Roulette wheel selection method. The HPSO-MVO was applied to unconstraint bench mark function and IEEE-30 bus test System. From the results obtained, HPSO-MVO was more effective.

In [15] ant colony optimization (ACO) and BAT algorithm were comparatively applied to find the optimal setting of on-load tap changing transformer

(OLTC), generator excitation and static VAR compensator (SVC) to minimize the sum of square of the stability L-indices of all load buses. Simulation studies revealed that both voltage profile and voltage stability was enhanced.

III METHODOLOGY

A. Problem Formulation

The optimal reactive power optimization problem is formulated as follows [3]:

$$Min\ P_{T,loss}(X,U) = \sum_{j=1}^{nl} P_j \tag{1}$$

Subject to the following constraints:

$$G(X,U) = 0$$

$$H(X,U) \geq 0$$

$$X^{\min} \leq X \leq X^{\max}$$

$$U^{\min} \leq U \leq U^{\max}$$

Where: Pj is the real power losses in line j; nl is the number of transmission lines.

$$X^T = [V_{L1}, V_{L2} \ldots, V_{L_{nd}}, Q_{g_1}, Q_{g_2} \ldots Q_{g_{ng}}]$$

$$U^T = [V_{g_1}, V_{g_2} \ldots V_{g_{ng}}, T_1, T_2 \ldots T_{nt}, Q_{C_1}, Q_{C_2} \ldots Q_{C_{nc}}]$$

X is the vector of dependent variables comprises of load bus voltages VL, generator reactive power outputs Qg. and U is the vector of control variables comprises of generator voltages Vg, transformer tap settings T, and shunt VAR compensation QC. G(X, U) = 0 and H(X, U) ≥0 are typical load flow equations. This is solved using the Newton Raphson power flow technique.

B. C`Concept of Firefly Algorithm

Firefly algorithm (FFA) developed by Xin-She Yang in 2007 was inspired by mechanisms of firefly communication via luminescent flashes [16]. The FFA is a nature-inspired, meta-heuristic, optimization algorithm, based on the flashing behavior of fireflies. Some characteristics of fireflies, based on the three idealized rules are [17]:

All the fireflies are of the same sex and are attracted to any other brighter fireflies. The brightest firefly is not attracted to any other firefly.

The degree of attraction of one firefly to another is proportional to their brightness.

The value of energy function determines the brightness of each firefly. In minimization problems, the firefly with a lower energy function value exhibits higher light intensity [17].

C. Attractiveness and Light Intensity

In FA, there are two important issues: the variation of the light intensity and the formulation of the attractiveness. Light intensity varies according to the inverse square:

$$I(r) = \frac{I_S}{r^2} \tag{2}$$

Where, I(r) is the light intensity at a distance r and Is is the intensity at the source. When the medium is given the light intensity can be determined as follows:

$$I(r) = I_0 e^{-\gamma r} \tag{3}$$

To avoid the singularity at r = 0 in the equations can be approximated in the following Gaussian form as:

$$I(r) = I_0 e^{-\gamma r/2} \tag{4}$$

Thus, the attractiveness β of a firefly is determined β0 and the β0 attractiveness at r = 0

$$\beta = \beta_0 e^{-\gamma \hat{r}/m} \quad (m \geq 1) \tag{5}$$

D. Distance

The distance between any two fireflies i and j at Xi and Xj respectively, the Cartesian distance is determined by the equation where xik is the kth component of the spatial coordinate xi of the ith firefly and d is dimension of the problem.

$$R_{ij} = \sqrt{\sum_{k=1}^{d} (x_{ik} - x_{jk})^2} \tag{6}$$

E. Movement

The movement of a firefly i is attracted to another more attractive (brighter) firefly j is determined using:

Xi=xi + β0e-γrij^2(xj – xi) + αε. (7)

The flow chart is as shown in Figure 1.

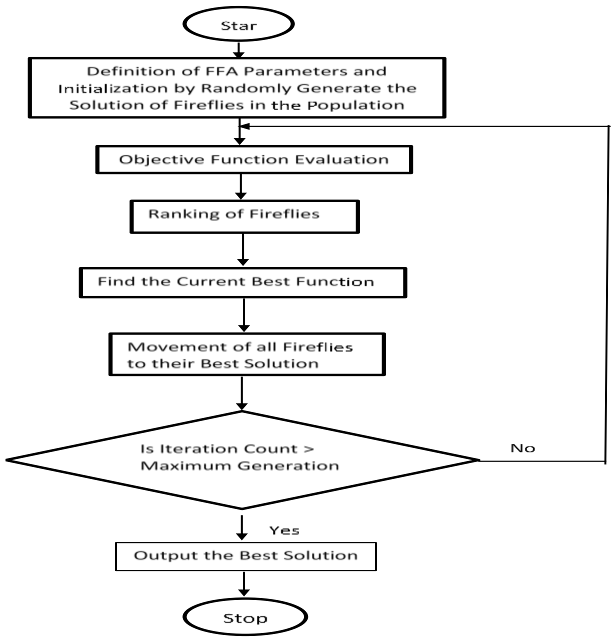

Figure 1: Flow Chart of Firefly Algorithm

F. Single Line Diagram

The two power system networks used for the purpose of verification of the developed algorithm are describe as follows: the 30-bus IEEE test system and the 54-Bus updated 330 kV Nigerian networks [18].

G. IEEE 30-bus test system

The single line diagram of IEEE 30-bus test system consisting of six generating units is shown in [18]. The system has 19- reactive power control variables are follows:6- generator voltage magnitudes, 4 transformer tap settings and 9- switchable Var sources.

H. 54-bus Nigerian 330kV grid system

The updated 54-bus Nigerian 330 kV grid network is characterized with major problems like voltage instability (voltage profile violation), long transmission lines, nature of transmission lines and high power losses which affect power generation and distribution systems. The updated Nigerian 330 kV grid consists of 54-buses, 12 generating stations and 36 transmission lines. The single line diagram of 330 KV Nigerian network is shown in Figure 2.

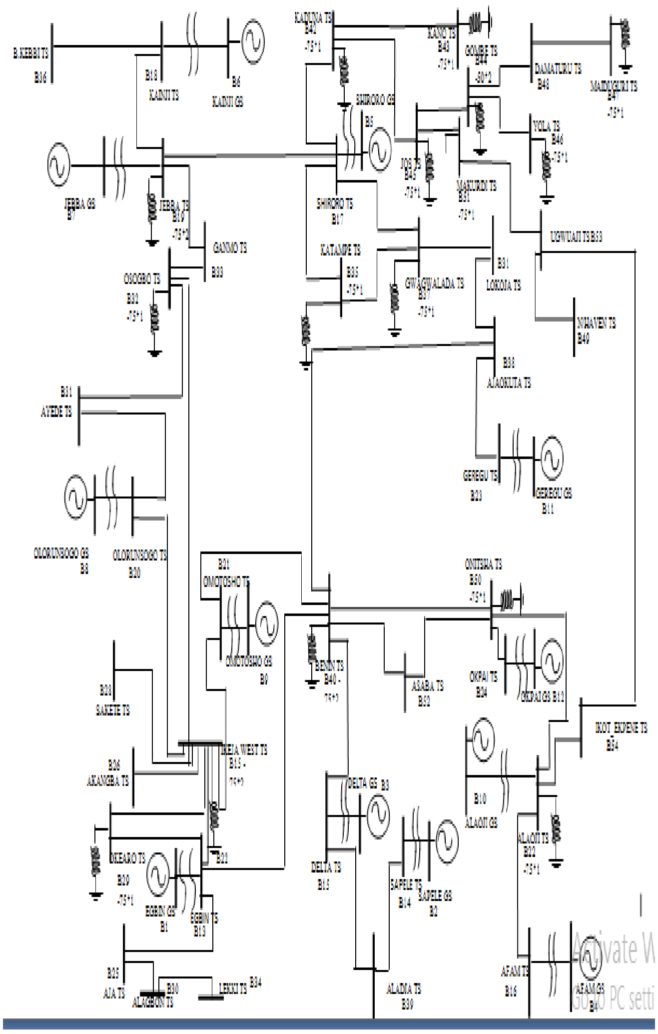

Figure 2:Updated 54-Bus Nigerian 330 kV Grid System

I. Realization of Firefly Algorithm Based Reactive Power Dispatch

The steps used in the implementation of the firefly algorithm for the optimal reactive power dispatch are describe below and shown in Figure 3:

Step 1: At the initialization stage, the relevant FFA parameters such as number of fireflies (swarm size) in the population NP, maximum number of generation NGmax, search parameter space D, light absorption coefficient γ , attraction coefficient base value β, mutation coefficient α etc. were defined. Also relevant power system data such as bus data, generator data and branch data required for power flow computation were actualized from the MATPOWER data files.

Step 2: Perform base case Newton Raphson (NR) power flow analysis in order to determine the initial bus voltage profiles and active power losses respectively.

Step 3: With each reactive power control devices of generating units' set-points, transformer tap setting and switchable reactors treated as control variables, randomly generate initial NP population of fireflies within the search space and compute the fitness function. Light intensity is directly proportional to objective function. In this case light intensity is taken as the objective function value itself. Calculate the fitness function value of all candidate solution by running the NR power flow. Each firefly is a vector of control variables i.e. [Vg1, Vg2, Vg3…Vgn; Tp1, Tp2, Tp3,.., Qsvc1, Qsvc2, Qsvc3…Qsvcn]

Step 4: Compare the intensity of a randomly selected firefly against the intensity of other firefly in the population. If the intensity is smaller, then move the firefly towards the other with high brightness. The attractiveness also varies.

Step 5: Repeat step 3 until the convergence criterion of generation count greater than the preset maximum number of generations is met. The parameters of the fittest individual will be returned as the desired optimum settings.

Step 6: With the optimal setting of the control devices, perform final NR power flow analysis to obtain the final voltage profiles and the corresponding system power losses.

IV. SIMULATION RESULTS AND DISCUSSION

To demonstrate the effectiveness of the FFA based reactive power optimization, the algorithm has been tested on two standard power systems: 30-bus IEEE network and updated 54-bus Nigeria 330kV grid system modelled in MATPOWER. Samples of simulation results for 90%, 100% and 110% loading condition are presented.

A. Simulation Results on Standard 30-Bus IEEE System

The developed algorithm of FFA based RPO was applied on the 30-bus IEEE network considering 90%, 100% and 110% loading conditions. The results obtained and the optimal parameter settings used are summarized in Tables 1 and 2 respectively. Sample of results of 90% loading condition where three buses violated the voltage limit before the reactive power control are presented. Figure 4 shows the voltage profile improvement while Figure 5 shows the convergence characteristics of the FFA based RPO.

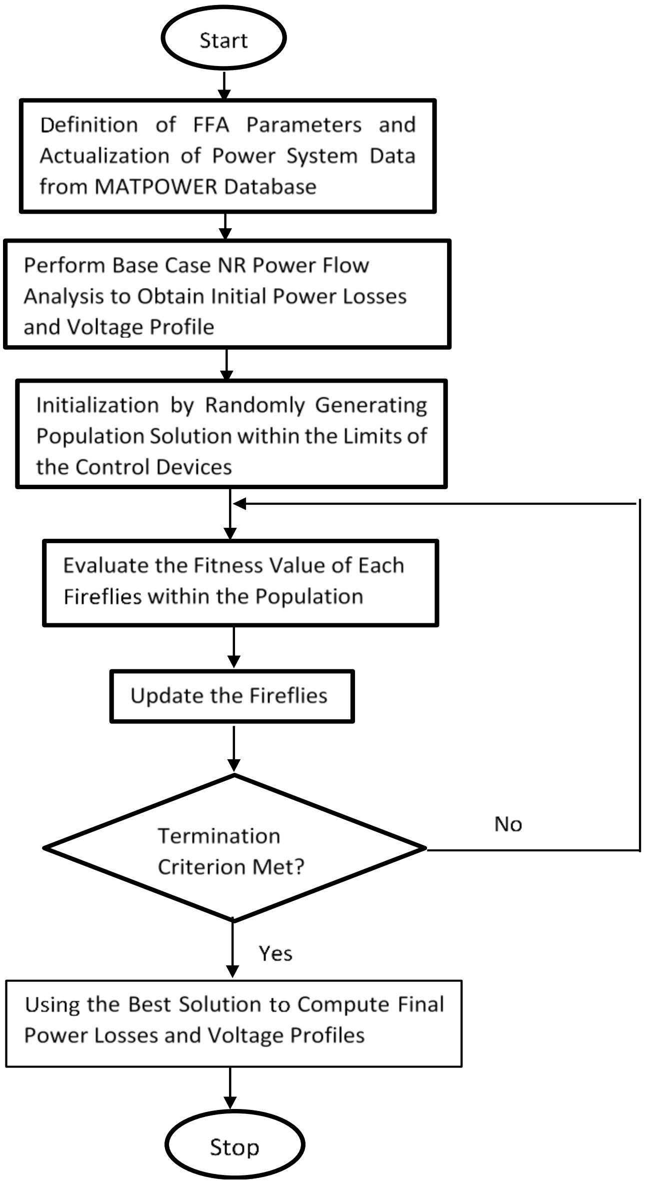

Figure 3: Flowchart of Firefly Algorithm for Reactive Power Optimization

Table 1: Optimal Parameter Setting for FFA based RPO Using 30-bus IEEE Study System

S/N	Parameter	90% Loading	Full Load	110% Loading
1.	Maximum number of iteration, NG^{max}	90	120	110
2.	Number of Fireflies (swarm size) NP	50	50	50
3.	Light Absorption Coefficient, γ	1	1	1
4.	Attraction Coefficient Base value, β	2	2	2
5.	Mutation Coefficient, α	0.2	0.2	0.2
6.	Mutation Coefficient Damping Ratio	0.98	0.98	0.98

Table 2: Performance Indices for FFA based RPO Using 30-bus IEEE Study System

S/N	Parameter	90% Loading	Full Load	110% Loading
1.	Initial Power Losses (MW)	10.6149	17.556 9	36.4226
2.	Final Power Losses (MW)	10.469	17.446	26.541
3.	Percentage Loss Reduction (%)	0.9677	0.6341	27.130
4.	Number of buses violating the limits before FFA based RPO	3	2	3
5.	Number of buses violating the limits after FFA based RPO	0	0	0

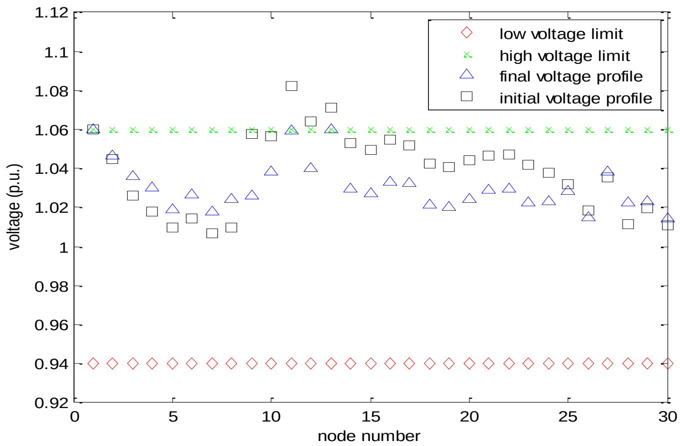

Figure 4: Voltage Profile Enhancement and Loss Reduction Using FFA based RPO for 90% loading Condition

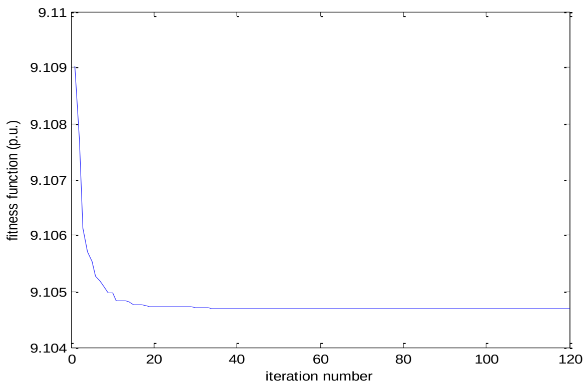

Figure 5: Convergence Characteristic of FFA Based RPO for 90% Loading Condition

B. Simulation results on Updated 54 - bus Nigerian 330 kV Grid system

The developed algorithm was later applied to 54-bus Nigeria 330kV grid system considering two loading conditions; 100% and 110%. The developed algorithm of FFA based RPO was applied comprising 12 generating units, 13 tap changing transformers and 16 switchable reactors. The results obtained and the optimal parameter settings used are summarized in Tables 3 and 4 respectively for the two cases. Figures 6 and 8 depict the voltage profile improvement while Figures 7 and 9 depict the convergence characteristics of the FFA based RPO using 54-bus Nigeria 330kV grid system for full load and 110% loading conditions.

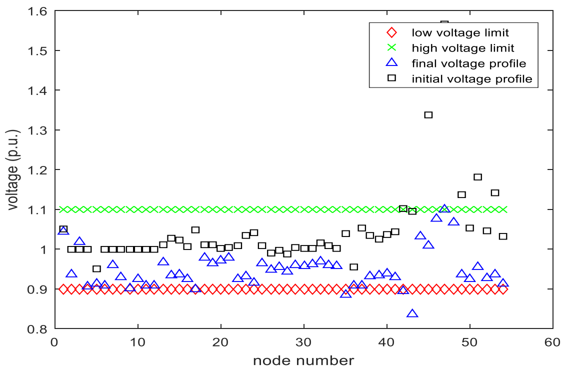

Figure 6: Voltage Profile Enhancement and Loss Reduction Using FFA based RPO for 100% loading Condition

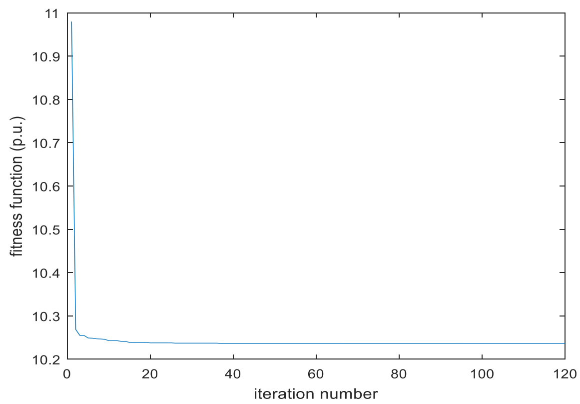

Figure 7: Convergence Characteristic of FFA based RPO for 100% loading Condition

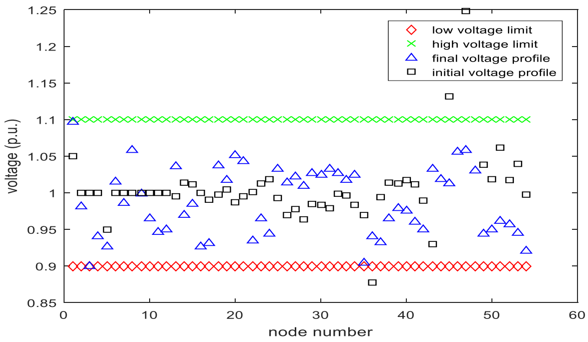

Figure 8: Voltage Profile Enhancement and Loss Reduction Using FFA based RPO for 110% loading Condition

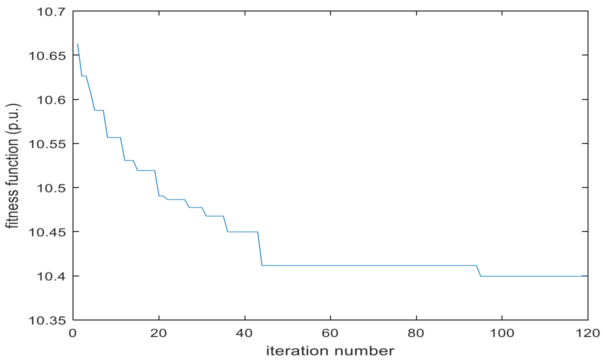

Figure 9: Convergence Characteristic of FFA based RPO for 110% loading Condition

Table 3: Optimal Parameter Setting for FFA based RPO Using 54-bus Nigeria 330kV Grid System

S/N	Parameter	Full Load	110% Loading
1.	Maximum number of iteration, NG^{max}	120	120
2.	Number of Fireflies (swarm size) NP	50	50
3.	Light Absorption Coefficient, γ	1	1
4.	Attraction Coefficient Base value, β	2	2
5.	Mutation Coefficient, α	0.2	0.2
6.	Mutation Coefficient Damping Ratio	0.98	0.98

Table 4: Performance Indices for FFA based RPO Using 54-bus Nigeria 330kV Grid System

S/N	Parameter	Full Load	110% Loading
1.	Initial Power Losses (MW)	134.4376	158.9256
2.	Final Power Losses (MW)	123.587	139.947
3.	Percentage Loss Reduction (%)	8.0712	11.7945
4.	Number of buses violating the limits before FFA based RPO	4	2
5.	Number of buses violating the limits after FFA based RPO	0	0

The percentage power loss reduction using Nigerian 54-Bus 330kV grid system under three loading conditions are 10.2873%, 8.0712% and 11.7945% while for IEEE 30-bus test system are 0.9677%,0.6384% and 0.9677%. For both system studies, the algorithm was able to eliminate the voltage limits violations. Therefore, this paper revealed that proper adjustment of reactive power control devices has significant influence on the transmission system real power loss reduction and voltage profile enhancement. This thus leads to reduction in the cost of energy to the consumers and voltage profiles enhancement; hence improvement in the network power quality and voltage stability.

V. CONCLUSION

This paper presents developed a tool for optimizing reactive power for voltage profile improvement and real power loss reduction on power system. The following conclusions can be drawn:

i. The model for IEEE 30-Bus and 54-Bus updated Nigerian 330kV Grid System was developed.

ii. The firefly algorithm for reactive power optimization of power system has been developed in the MATLAB environment.

iii. Effectiveness of the algorithm has been demonstrated and validated on standard 30-bus IEEE test system and on the updated 54-bus Nigerian 330 kV grid system.

Therefore, proper adjustment of reactive power control devices can result to reduction in the cost of energy to the consumers and voltage profiles enhancement; hence improvement in the network power quality and voltage stability.

ACKNOWLEDGEMENTS

This research is funded by the Tertiary Education Trust Fund (TETFund) Institution Based Research TETFUND/DESS/UNI/BAUCHI/2017/Vol.1 and this is graciously acknowledged. The author also appreciate the Transmission Company of Nigeria (TCN) for providing the necessary network data.

REFERENCES

[1] Govindaraj, T. and Tamildurai, V. (2014).”Firefly Algorithm for Optimal Power Flow Considering Control Variables”, International Journal of Innovative Research in Electrical, Electronics, Instrumentation and Control Engineering, Vol. 2, Issue 2, pp.1116-1121

[2] Bakare, G. A., Venayagamoorthy, G. K. and Aliyu, U. O. (2007). “Differential Evolution Approach for Reactive Power Optimization of Nigerian Grid System”, IEEE PES General Meeting, June 2007, Tampa, Florida, USA, pp. 1-6.

[3] Bakare, G. A., Krost, G., Venayagamoorthy, G. K. and Aliyu U. O., (2007), “Comparative Application of Differential Evolution and Particle Swarm Techniques to Reactive Power and Voltage Control”, 14th International Conference on Intelligent System Application to Power Systems, Nov. 4-8, 2007, Kaohsiung, Taiwan. pp. 406-41.

[4] Mojtaba, G., Sahand, G., Mohammad, M. G. and Amir, H. (2014).”A New Hybrid Algorithm for Optimal Reactive Power Dispatch Problem with Discrete and Continuous Control Variables,” Applied Soft Computing, Vol.22, pp.126-140

[5] Abhishek, R. and Malakar, T. (2014). ”Optimal Reactive Power Dispatch Using Hybrid Nelder-Mead Simplex Based Firefly,” Electrical Power and Energy System, Vol.66, pp.9-24.

[6] Bakare, G. A., Venayagamoorthy, G. K. and Aliyu, U. O.(2005), “Reactive Power and Voltage Control of Nigerian Grid System using Micro Genetic

Algorithm", IEEE PES 2005 General Meeting, 12-16 June 2005, San Francisco, California, USA, pp. 1-7.

[7] Grant, L,Venayagamoorthy G. K., Krost, G. and Bakare, G. A. (2008), "Swarm Intelligence and Evolutionary Approaches for Reactive Power and Voltage Control", IEEE Swarm Intelligence Symposium St. Louis MO USA, September 21-23, 2008.

[8] Ali O., Serkan, C., Pakize, E. and Salih, T. (2010). "Reactive Power Optimization with Artificial Bee Colony Algorithm", Scientific Research and Essays, Vol.5, pp.2848-2857.

[9] Devaraj, D. and Preetha, J. R. (2010). "Genetic Algorithm Based Reactive Power Dispatch for Voltage Stability Improvement," Electrical Power and Energy System, Vol.32, pp.1151- 1156.

[10] Prajapati, B. S. and Srivastava, L. (2012), "Multi-Objective Reactive Power Optimization Using Artificial Bee Colony Algorithm". International Journal of Engineering and Innovative Technology. Vol. 2(1), pp.126-131.

[11] Vo Ngoc, D. and Huu, T. N. (2013),"Optimal Reactive Power Dispatch Using Artificial Bee Colony Method", Greater Mekang Sub-Region Academic and Research Network International Journal, Vol.9, pp. 29-36.

[12] Liang, R., Wang, J., Chen, Y. and Tseng, W. (2015) "An Enhanced Firefly Algorithm to Multi-Objective Optimal Active/Reactive Power Dispatch with Uncertainties Consideration", International Journal of Electrical Power and Energy System, Vol. 64, pp. 1088-1097.

[13] Deenadhayalan, H. (2015). "Real Power Loss Minimization using Firefly Algorithm", IJAICT, Vol. 1(8), pp. 677-682. https://doi.org/01.0401/ijaict.2014.08.03.

[14] Pradeep, J., Siddharth, A., Parma, I., Trivedi, N. and Bhesdadiya, R. H. (2016). "A Novel Hybrid Particle Swarm Optimization and Optimal Reactive Power Dispatch Problem", Engineering Science and Technology, an International Journal, Vol. 20, pp. 570-586.

[15] Katuri, R., Guduri, Y. and Askani, J. (2017). "BAT Algorithm and Ant Colony Optimization Based Optimal Reactive Power Dispatch to Improve Voltage Stability", European Journal of Engineering Research and Science, 2. 27, 10.24018/ejers.2017.2.6.378.

[16] Szymon, L. and Piotr, A. K. (2014). "Fully Informed Swarm Optimization Algorithms: Basic Concepts, Variants and Experimental Evaluation", Proceedings of Federated Conferences on Computer Sciences and Information Systems, Vol. 2, pp.155-161.

[17] Ruey-Hsun, L., Jia-Ching, W., Yie-Tone, C. & Wan-Tsun, T. (2015). "An Enhanced Firefly Algorithm to Multi-Objective Optimal Active/Reactive Power Dispatch with Uncertainties Consideration", Electrical Power and Energy System, Vol.64, pp. 1088-1097.

[18] Lawal, L. A. (2020), "Reactive Power and Voltage Control of Nigeria 330kV Grid Based on Artificial Bee Colony Algorithm". Unpublished MEng. Thesis, Abubakar Tafawa Balewa University, Bauchi-Nigeria.

[19] Ulas, K. and Ayan, K. (2016). "Artificial Bee Colony Algorithm Based Optimal Reactive Power Flow of Two-Terminal HVDC Systems", Turkish Journal of Electrical Engineering and Computer Sciences, Vol. 3, pp. 1075-1090.

[20] Suresh, R. and Baskaran, J. (2016). "Firefly Algorithm Applied for Optimal Reactive Power Dispatch", International Journal of Advanced Engineering Technology, Vol. VII (III), ISSN: 0976-3945.

[21] Basu, M. (2016). "Multi-Objective Optimal Reactive Power Dispatch Using Multi-Objective Differential Evolution", Electrical Power and Energy System, Vol. 82, pp. 213-224.