POWER SYSTEMS OPERATION IMPROVEMENT CONSIDERING LOSS MINIMIZATION AND VOLTAGE STABILITY ENHANCEMENT

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ABSTRACT

The challenge of energy and power losses during electrical energy transmission from generation plants to users is a major problem that cannot be over-emphasized. These Losses are inevitable because they are inherent in the conduction of electrical energy through physical means but can be minimized. This paper presents a VSC-PSO method for optimizing the power system operation by simultaneously minimizing the loss and enhancing the voltage stability which are the objective functions. The optimal power flow (OPF) was performed on IEEE 30-bus system with Newton Raphson algorithm implemented in MATLAB simulation software. The simulation results showed that the VSC-PSO approach performed more excellently with concurrent consideration of line loss reduction and voltage stability improvement when compared with other methods in literature

Keywords: Optimal Power Flow, Power Loss Minimization, Voltage Stability, Newton Raphson, Particle Swarm Optimization

DOI: https://doi.org/10.54043/laujet.2021.15.02.04

1. INTRODUCTION

Electric power's importance in today's world cannot be overstated, as it is the primary source of energy for industrial, commercial, and residential activities and this has resulted in continuously increasing demand. According to statistics, almost one-third of the world's populations do not have access to electricity (Adeagbo and Ariyo, 2018) and this implies that the demand will be on an increase as new customers are getting connected to the grid. The demand has imposed many challenges such as overloading of transmission and distribution lines, voltage stability deviation and high power losses on the power industry due to the market conditions as power demand is more than the power available (Simeon *et al*., 2018, Dutta *et al.,* 2018 and Kamel *et al*.,). Power networks have been operating near their stability limitations in recent years in order to reduce the cost of constructing new transmission lines. As a result, the idea of voltage stability is regarded as the most important consideration in power system research (Hadavi *et al.,* 2017). Voltage stability issues and the extreme problems of indiscriminate voltage collapse remain a crucial challenge to the reliable and economic operation of power systems in Nigeria (Adewuyi *et. al.,* 2019).

Smart grids, which were recently introduced as a result of creative advancements in generation, transmission, and distribution systems, have brought tremendous value to today's electrical power networks. The integration of new regulations, as well as the constant growth in load demand, has increased the grids' danger of voltage instability (Adebayo *et al*., 2017). Rotor angle, frequency, and voltage stability are the most common classifications for power system stability, but these cases are usually intertwined. A voltage collapse occurring at a bus can result in significant deviation in frequency, rotor angle and subsequently results in total or partial blackout. Similarly, large frequency digressions can result in great changes in the magnitude of the voltage. Hence, dealing with voltage stability issues in power system operation affects the overall state of the power system (Adewuyi *et al.,* 2018).

In the same vein, power losses in transmission line systems are affected by a variety of variables, including the amount of losses in transmission and distribution lines, transformers, capacitors, and insulators, among others. Power losses can be either real or reactive, however real power attracts greater attention from utilities since it lowers the efficiency of transmitting energy to users. When these losses are severe, especially when heavy loads are present, reactive power generation may exceed its limit, and the voltage support provided by a generator is lost. This might cause the system's voltage to become unstable. Consequently, improving the functioning of power systems has become critical in minimizing power losses to a minimum and improving voltage stability (Bagriyanik *et al.,* 2003).

Bouktir *et al.*, (2004) presented a fuzzy multi-objective optimization and genetic algorithm (GA) based method to determine the optimal operating conditions of a power system. The proffered method used GA to address fuzzy optimization problem for reactive power loss minimization in the IEEE 30- and 14-buses transmission systems with thyristor controlled series capacitor (TCSC) used as a control device. Ettappan *et al*., 2020 used GA to address the OPF problem of IEEE 30-bus transmission system by minimizing the cost of fuel while keeping the various constraints in their secure limits. Reis *et al.*, (2006) used an Artificial Bee Colony for minimizing the real power loss and the voltage deviation and voltage stability enhancement on IEEE 30- and 57-buses systems and the results showed faster convergence to better solutions.

2. PROBLEM FORMULATION

The OPF was performed on IEEE 30- bus system with Newton Raphson algorithm implemented in MATLAB simulation software and the particle swam optimization. Newton Raphson algorithm is preferred because of its easy modification and consistency for analyzing transmission network.

The steps considered in achieving the objectives of this study is highlighted below;

1. The IEEE 30 bus system shown in Figure 1 which is a standard test system was modeled on MATLAB using the bus, line and generator parameters.
2. The OPF problem was formulated as a multi-objective problem with line loss minimization and voltage stability enhancement as the objective functions.
3. The base case was evaluated using Newton Raphson algorithm as illustrated in Figure 2 and it is combined with PSO algorithm for achieving the OPF analysis, as shown in Figure 3.
4. The results of the base analysis was compared to that of the optimal solution (OPF) analysis and previous work on voltage stability enhancement and line loss minimization.

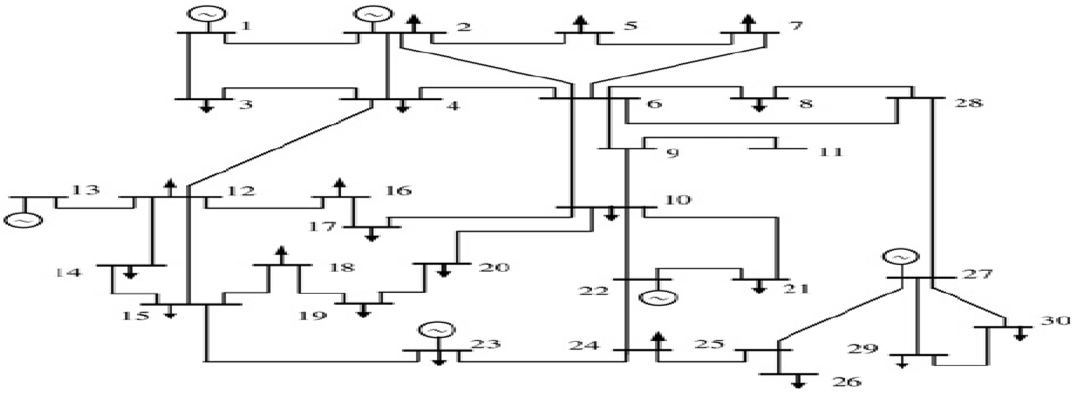

Figure 1: IEEE 30-BUS System Schematic Diagram

2.1 Objective function

The objective function representing the problem to be solved is the minimization of the total transmission line losses and enhancement of voltage stability as described by Eqs. 1 and 2.

i. Line loss minimization

Minimize $$P_{Tloss} = \sum_{n=1}^{nl} P_{loss} \qquad (1)$$

ii. Voltage stability improvement

Minimize $$FVSI_{\max} \qquad (2)$$

Where nl represents the total number of transmission, P_{loss} is the power loss in each line, P_{Tloss} is the overall power losses in all the lines.

FVSI is the Fast Voltage Stability Index given as Eq. 3

$$FVSI = \frac{4z^2 Q_k}{(V_i)^2 x_{ik}} \qquad (3)$$

For a stable power system, FVSI is expected to have a small value i.e. a value that is approaching 0 on a scale of 0 to 1.0 [12].

2.2 Constraints

i. Equality constraints (power balance equations)

$$P_{gk} - P_k = \sum_{k \neq l}^{n} P_{kl} \tag{4}$$

$$Q_{gk} - Q_k = \sum_{k \neq l}^{n} Q_{kl} \tag{5}$$

ii. Inequality constraints

$$P_g^{\min} \leq P_{gk} \leq P_g^{\max} \tag{6}$$

$$Q_g^{\min} \leq Q_{gk} \leq Q_g^{\max} \tag{7}$$

$$V^{\min} \leq V_k \leq V^{\max} \tag{8}$$

$$\left| S_{Lik} \right| \leq S_{Lik}^{\max} \tag{9}$$

The flow charts for the implementation of the power flow with Newton Raphson algorithm using the Particle swarm optimization approach are given as Figures 2 and 3.

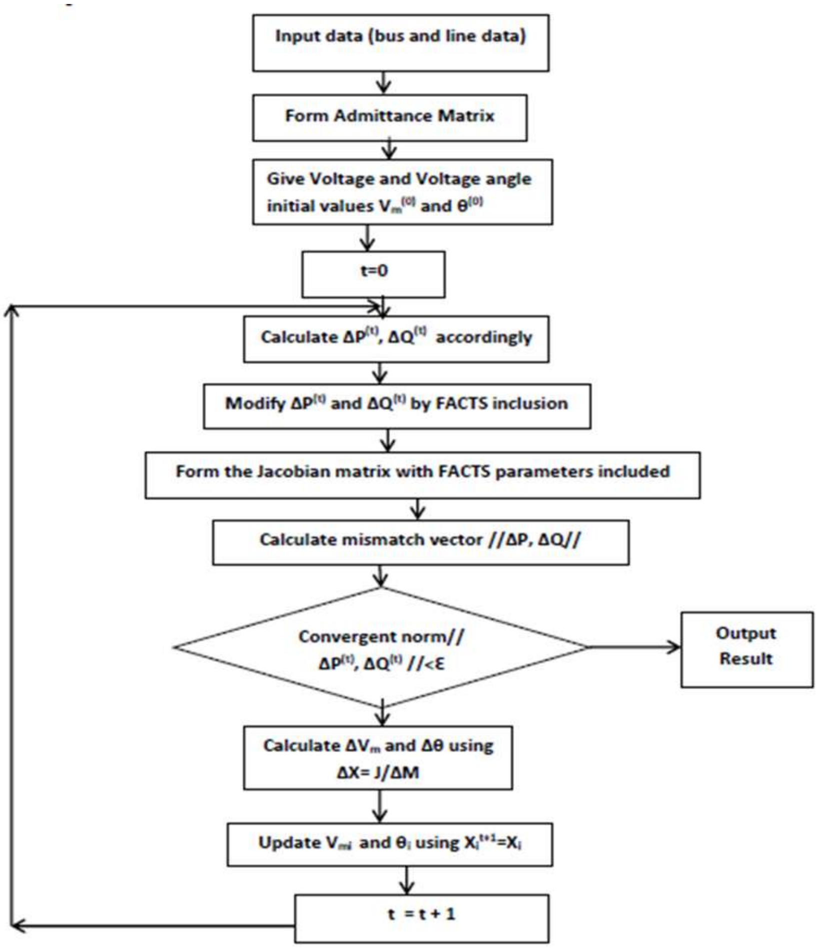

Figure 2**:** Flow chart diagram for implementing Newton Raphson method

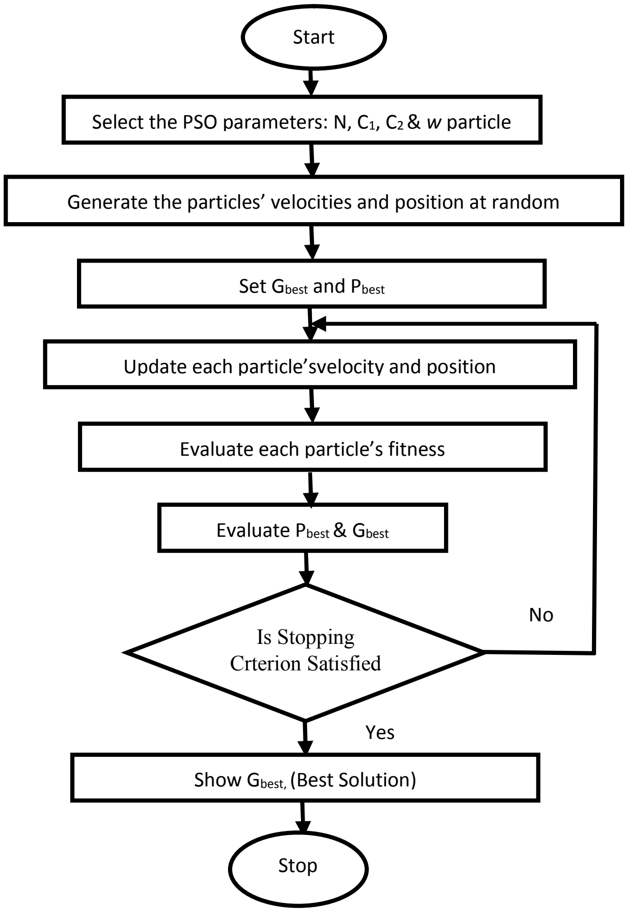

Figure 3: Flowchart of implementing Particle Swarm Optimization

3. SIMULATION RESULTS

The OPF which was performed on the IEEE 30 bus system using the Newton Raphson method and the particle swarm optimization approach and implemented using MATLAB Simulation gave the results which was compared with the results of other works obtained from literatures. Tables 1 and 2 represent the generator cost of parameters for IEEE 30 bus system and a table of comparison of the obtained results from the optimization procedure involving loss minimization and with constraint for voltage stability improvement with the results obtained from some single objective optimization problems involving only loss minimization.

Table 1: Generator Cost of Parameters for IEEE 30 Bus System

Gen. Bus	**a**	**b**	**C**	**min P_{gen}**	**Max. P_{gen}**
	$/MW2h	**$/MWh**	**$/h**	**MW**	**MW**
1	0.00375	2	0	50	200
2	0.0175	1.75	0	20	80
5	0.0625	1	0	15	50

8	0.0083	3.25	0	10	35
11	0.025	3	0	10	30
13	0.025	3	0	12	40

Table 2: Comparison with of VSC-PSO with optimal results [13]

Parameter	Unit	Base	NSGA II	PSO	CoPSO	VSC-PSO*
P_{gen1}	MW	99.00	134.55	107.05	108.80	52.08
P_{gen2}	MW	80.00	46.29	59.88	56.93	80.00
P_{gen3}	MW	50.00	32.94	43.62	20.00	50.00
P_{gen4}	MW	20.00	30.12	33.40	34.76	35.00
P_{gen5}	MW	20.00	18.74	30.00	30.00	30.00
P_{gen6}	MW	20.00	26.54	23.56	37.26	40.00
P_{loss}	MW	5.90	5.77	5.67	4.85	3.68
% $P_{loss\ (red.)}$	MW	-	2.2%	3.9%	17.8%	37.6%
Q_{loss}	MVAR	24.86	-	-	-	19.10
$FVSI_{max}$		0.1746	-	-	-	0.1699
$FC(P_{gen})$	$/h	902.14	823.89	847.01	845.32	897.08

The results obtained from the optimization was focused on different parameters which includes the voltage magnitude, the line power flow, the real and reactive power loss and the fast voltage stability index which is in terms of the voltage stability condition. Figures 3 – 8 show the detailed significant changes in power loss (active and reactive) and enhancement in bus voltage magnitude observed in the various parameters during the MATLAB simulation.

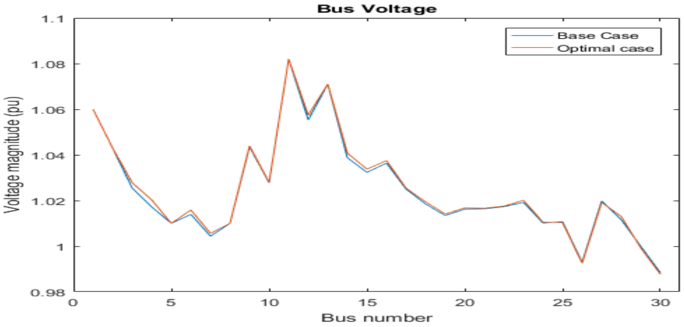

Figure 4: Voltage magnitude profile graph

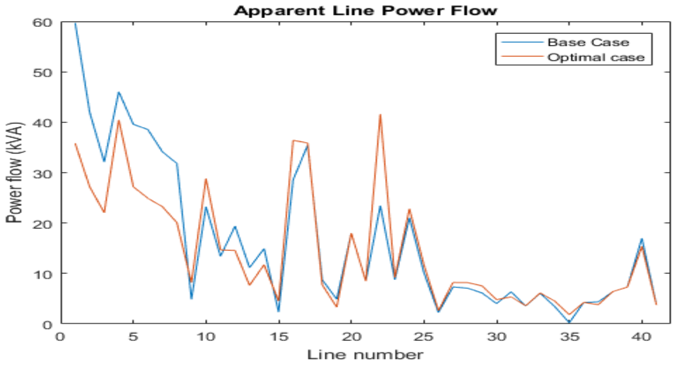

Figure 5: Line power flow graph

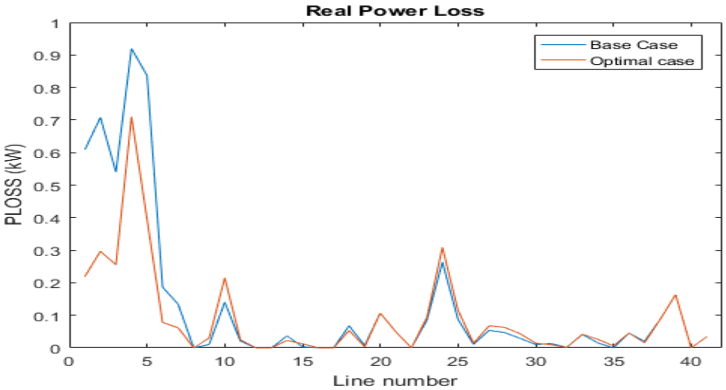

Figure 6: Real power loss graph

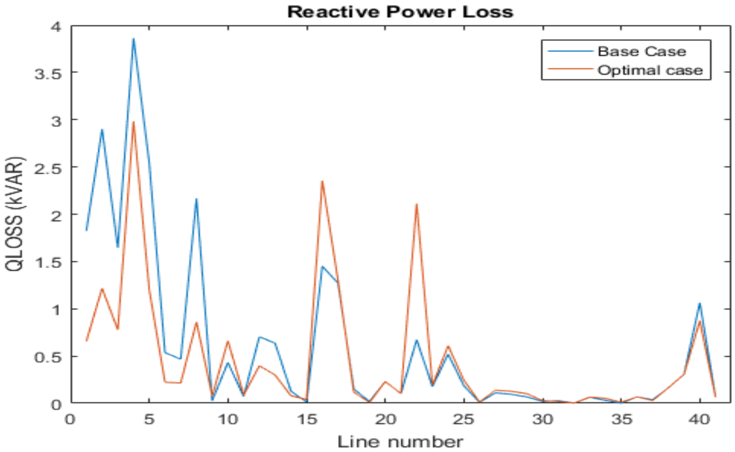

Figure 7: Reactive power loss graph

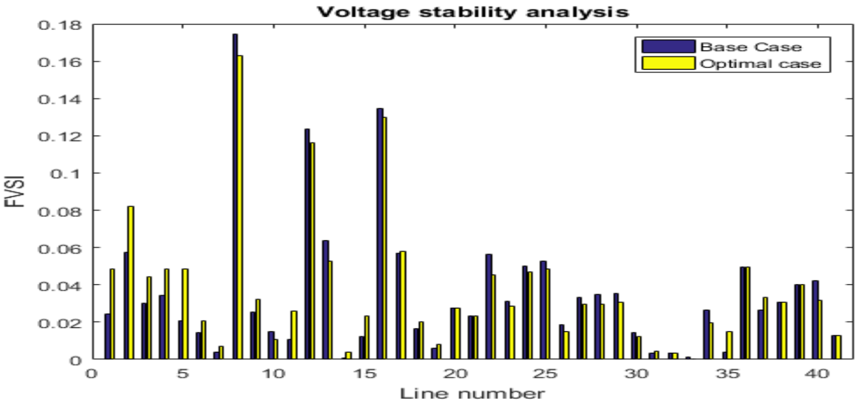

Figure 8: Voltage stability condition using FVSI

Figure 4 shows the effect of the on the voltage magnitude; as it can be observed, there is a noticeable increase in the voltage magnitude profile in the optimal case when compared with the non-optimized case.

Figure 5 shows a significant measure of performance of a power system in the steady state which ensures that the line flow limit of power system is not violated, the VSC-PSO guarantees non-violation of the line flow limit with significant reduction in the line flow along each branch at optimal case compare to the base case. Figures 6 - 7 show the effect of the optimization procedure on the real and reactive power loss. As indicated in Table 2, there is a significant reduction of about 37.6% in the overall real power loss of the IEEE 30 bus system using the proposed voltage stability constrained PSO for active power loss minimization and this is conspicuously seen in the active power loss profile shown in Figure 6. As observed in Figure 7, there is a corresponding significant reduction in the reactive power loss as well. In the reactive power loss shown in Figure 7, there are some spikes (rises) in the reactive power loss at lines 16 and 22, but in total the reactive power loss reduces from 24.8571 MWAR in base case to 19.1036 MVAR after optimization as shown in Table 2.

Figure 8 shows the effect of the optimization process on the voltage stability state of the power system. The voltage stability index, FVSI, was deployed in this study to monitor the power system's stability condition under the base case and optimal case conditions. Generally, a reduction in maximum FVSI (line 8) value from 0.1746 in the base case to 0.1699 after optimization shows significant improvement in the voltage stability state of the system under study; and except for few lines, a significant reduction is noticed in the FVSI values of almost all the lines. It is also worth mentioning that the relatively critical lines with the higher FVSI values, such as lines 8, 12 and 16, have significant level of improvement after optimization.

4. CONCLUSION

This study explained how Power system operations can be improved while considering loss minimization and voltage stability condition. It focused on the optimization of the transmission system on IEEE 30-bus system and the analysis was done using MATLAB simulation where the result was compared to the base values from other available works done on this same topic. After the optimization, the optimal values showed significant improvement when compared with the base values. The results obtained from the optimization are in terms of active power loss, reactive power loss, voltage magnitude and the voltage stability index, FVSI which monitors the stability condition of the power system showed a significant change compared to the other results of the available works done.

REFERENCES

Ayooluwa Peter Adeagbo and Funso Kehinde Ariyo (2018) Optimal Control of Pv-Wind Hybrid for Rural Electrification. International Journal of Innovative Science and Research Technology 3(11), 680 – 685.

Matthew Simeon, Wara Samuel Tita, Adejumobi I. A. and Amuta Elizabeth. (2018). Minimization of Active Transmission Loss in Power Systems using Static Var Compensator. International Journal of

Applied Engineering Research, 13(7), 4951 - 4959.

Susanta Dutta, Sourav Paul and Provas Kumar Roy. (2018). Optimal Allocation of SVC and TCSC using Quasi-oppositional Chemical Reaction Optimization for Solving Multi-objective ORPD Problem. Journal of Electrical Systems and Information Technology, 5, 83 - 98. doi:https://doi.org/10.1016/j.jesit.2016.12.007

Mariana Kamel, Abdelrahman Karrar and Ahmed Eltom. (2017). Development and Application of a New Voltage Stability Index for On-line Monitoring and Shedding. IEEE Transactions on Power Systems, 1 - 12. doi:10.1109/TPWRS.2017.2722984

S. Hadavi, B. Zaker, H. Karami, A. A. K. Arani and G. B. Gharehpetian, "Optimal placement and sizing of DGs considering static voltage stability," 2017 Conference on Electrical Power Distribution Networks Conference (EPDC), 2017, pp. 12-16, doi: 10.1109/EPDC.2017.8012733.

Oludamilare B. Adewuyi, Mark. K. Kiptoo, Ayodeji F.Afolayan, Ayooluwa .P. Adeagbo and Tomonobu Senjyu. (2019). Gas-to-electricity investment planning for power system stability improvement and environmental sustainability in Nigeria. E3S Web of Conferences. EDP Sciences. doi:https://doi.org/10.1051/e3sconf/201912002005

Isaiah Adebayo, Adisa A. Jimoh, Adedayo Yusuff. (2017). Voltage Stability Assessment and Identification of Important Nodes in Power Transmission Network through Network Response Structural Characteristics. IET Generation, Transmission & Distribution, 11(6), 1398 - 1408. doi:10.1049/iet-gtd.2016.0745

Adewuyi, O. B., Danish, M. S. S., Howlader, A.M., Senjyu, T. and Lotfy, M.E. (2018) Network Structure-Based Critical Bus Identification for Power System Considering Line Voltage Stability Margin. Journal of Power and Energy Engineering, 6, 97-111. https://doi.org/10.4236/jpee.2018.69010

F. G. Bagriyanik, Z. E. Aygen and M. Bagriyanik, "Power loss minimization using fuzzy multi-objective formulation and genetic algorithm," 2003 IEEE Bologna Power Tech Conference Proceedings, 2003, pp. 5 pp. Vol.4-, doi: 10.1109/PTC.2003.1304713.

T. Bouktir, L. Slimani, and M. Belkacemi. "A genetic algorithm for solving the optimal power flow problem." Leonardo Journal of Sciences 4 (2004): 44-58.

M. Ettappan, V. Vimala, S. Ramesh, V. Thiruppathy Kesavan, (2020) "Optimal reactive power dispatch for real power loss minimization and voltage stability enhancement using Artificial Bee Colony Algorithm", Microprocessors and Microsystems, Volume 76, 2020,103085,ISSN 0141 - 9331, https://doi.org/10.1016/j.micpro.2020.103085.

Claudia Reis and F. P. Maciel Barbosa. (2006). A Comparison of Voltage Stability Indices. IEEE MELECON, (pp. 1007 - 1010). Benalmádena (Málaga), Spain.

Adewuyi, O. B., Howlader, H. O. R., Olaniyi, I. O., Konneh, D. A., Senjyu, T.. (2020), Comparative analysis of a new VSC-optimal power flow formulation for power system security planning, International Transaction of Electrical Energy System, e12250.

Furukakoi, M., Adewuyi, O. B., Danish, M. S. S., Howlader, A. M., Senjyu, T., Funabashi, T, (2018), Critical Boundary Index (CBI) Based on Active and Reactive Power Deviations, International Journal of Electrical Power and Energy Systems, vol. 100, issue 1, pp. 50–57

K. Nadhir, D. Chabane and B. Tarek, "Firefly algorithm for optimal allocation and sizing of Distributed Generation in radial distribution system for loss minimization," 2013 International Conference on Control, Decision and Information Technologies (CoDIT), 2013, pp. 231-235, doi: 10.1109/CoDIT.2013.6689549.