The estimation of transmission line loadability Based on Artificial Intelligence Algorithm & Voltage Stability Index

Dunya Sh Wais1*, Assist Prof. Dr. Wafaa S Majed1
1Department of Electrical Engineering, Al-Mustansiriayah University, Baghdad, Iraq
*E-mail: dunyawais2016@gmail.com

Abstract. The continuous changes in electricity demand and supply are contributing to the disparity in quantities of power transferred between transmission networks, i.e. some lines are lightly loaded and others are overloaded. This presents a significant challenge to the secure and reliable operation of the power system. The current research is concerned with enhancing the loadability of electric transmission lines, that secure the increase in load demand through Flexible AC Transmission System (FACTS) injection. This paper is focused on the Thyristor Controlled Series Compensator (TCSC), the optimum location of the TCSC was determined by applying two different techniques. The first technique was based on an artificial intelligence algorithm while the second technique was based on the level of voltage stability indices for all system lines. The optimal location is based on the fulfillment of multi-objective functions represented by an increase in the load capacity, reduce levels of the voltage stability index, the cost of installing the TCSC, and the voltage deviation. The IEEE-9 bus standard test system as a study case and MATLAB-programmes has been used for the analysis of the optimal power flow, and estimating the loadability of transmission lines without and with TCSC.

1. Introduction
There is a need to expand the power transmission system's size, durability, efficiency, and protection due to the increase in populations and economies. Power utilities are looking for new options to successfully use old transmission lines up to their operational limits because of the changing market conditions. To accomplish these aims, power flow management systems such as Flexible AC Transmission System (FACTS) devices are used to spread power flow equally across the system [1]. In the last two decades, much focus has been provided to (FACTS). It uses high-current electronic electrical equipment for a transmission system's stability, voltage control, power flow, etc. [2]. A recent IEEE paper [3] explains the terminology and meanings of different FACTS devices. The FACTS devices are very useful and can improve the power transfer capacity of a line if the thermal limit permits the same level of stability while maintaining [4]. The main purpose of FACTS technology is to retain control of a system and to transfer more power from one location to another, system stability is also improving by FACTS.

In several cases, such as a series, shunt, or series and shunt combinations, FACTS systems may be connected to a transmission line. Static var compensator (SVC) and static synchronous compensator (STATCOM) are connected, for example, in shunt; static synchronous series compensator (SSSC) and thyristor-controlled series compensator (TCSC) are linked in a series; the thyristor-controlled phase-shifting transformer (TCPST) and combined power flow control (UPFC) are linked in series and shunt combinations.

TCSC has many advantages strong performance, fast response, and the lowest cost among other devices, for example. TCSC is one of the best FACTS devices. As an inductor or capacitor, TCSC can be used. There is, therefore, a limited percentage to control the reactance of the transmission line [11]. Over many years, FACTS series devices, especially TCSC, have been used successfully to improve the loadability...
of high-voltage (HV) transmission networks. The key interest in a steady-state condition is the use of series compensation to control the impedance of transmission lines [5]. FACTS devices provide enhanced transmission capacity, reactive power support, and voltage and flow control when installed in the optimal location. The FACTS devices are often expensive because of the market situations and the active use of these devices. So, TCSC's device needs to be placed in optimum places [6]. Various approaches [7-8] include the optimal placement of FACTS equipment such as linear programming techniques, technological artificial intelligence methods, stability indicators, and sensitivity index techniques.

The best place and size for TCSC devices that resolve techno-economic problems to reduce the costs of installed TCSC devices and to reduce development costs are considered to be the best Optimal Power Flow (OPF) system. OPF is considered a nonlinear and constrained optimization problem, it aims to optimize specific objective functions such as fuel cost minimization, total power loss minimization, voltage profile improvement, and voltage stability enhancement, via finding the optimal control variables of power system with preserving equality and inequality operational constraints [10]. The MATLAB software is used to achieve optimum power-flow analysis on the IEEE 9 bus [9] test systems using the power system analysis tool. The current research discusses assessing the loadability of a transmission line and calculating the line voltage stability index (LVSI) for the best location for a TCSC in an IEEE 9 power system network bus. The best position for TCSC was determined by two techniques: the first technique was to identify the best location based on an artificial intelligence algorithm, and the second technique was based on the high value of the line voltage stability index, which was calculated for each transmission line in the normal operating state. The proposed technique is used to solve the multi-objective OPF problem, besides, reduce the voltage stability index.

The paragraph of our article includes the subsections; section 2: a mathematical model for the transmission line is described; section 3: the optimum position of the TCSC device is explained based on an artificial intelligence algorithm; section 4: The study of line voltage stability index; section 5: test the system and the results obtained; section 6: conclusions.

2. The mathematical model of a transmission line

2.1. Without TCSC

A transmission line with the admittance of $Y_{ij}$ is considered between a bus node-$i$ and bus node-$j$ in π model as given in Figure 1.

![Figure 1. The description of a line between two buses.](image-url)
The voltages at node–i and node–j are considered to be $V_i$ at the angle of $\delta_i$ and $V_j$ at the angle of $\delta_j$. From bus node–i to bus node–j, the real and reactive power flows are $P_{ij}$ and $Q_{ij}$ respectively. If $\delta_{ij} = \delta_i - \delta_j$, then equations for power flows are given by,

$$P_{ij} = V_i^2 G_{ij} - V_i V_j (G_{ij} \cos \delta_{ij} + B_{ij} \sin \delta_{ij}) \quad (1)$$

$$Q_{ij} = -V_i^2 (B_{ij} + B_{sh}) - V_i V_j (G_{ij} \sin \delta_{ij} - B_{ij} \cos \delta_{ij}) \quad (2)$$

Real and reactive power flow equations from bus node–j to bus node–i, in a similar way, are,

$$P_{ji} = V_j^2 G_{ij} - V_i V_j (G_{ij} \cos \delta_{ij} + B_{ij} \sin \delta_{ij}) \quad (3)$$

$$Q_{ji} = -V_j^2 (B_{ij} + B_{sh}) - V_i V_j (G_{ij} \sin \delta_{ij} - B_{ij} \cos \delta_{ij}) \quad (4)$$

Where,

$$G_{ij} = \frac{r_{ij}}{r_{ij}^2 + x_{ij}^2}, \quad B_{ij} = \frac{-x_{ij}}{r_{ij}^2 + x_{ij}^2}$$

2.2. With TCSC

Several attempts are discussed in the literature to model the TCSC. There are three parallel switches in [11] of the TCSC model. Only one part of the model is linked to the avoidance of resonance, while two are separated. TCSC ($X_{TCSC}$) reaction modeled as a transmission line reaction ($X_{TL}$). Function. For the transmission line to prevent overcompensation, the necessary value of $X_{TCSC}$ can be determined by using (5) in [11]:

$$-0.8X_{TL} \leq X_{TCSC} \leq 0.2X_{TL} \quad (5)$$

The specified TCSC devices can be placed on any transmission line, except on lines linked to any two-generation bus. There are several limitations to TCSC. The TCSCs shall not be put in a series of transformers as well. Besides that, TCSC is not preferred to be located as seen in [8] in light loaded lines. Consider a TCSC linked between node–i and node–j with steady-state static reactance $\pm jX_{TCSC}$ as Figure 2 given in.

Figure 2. The description of a line between two buses with TCSC.
The real and reactive power flows from bus node-\(i\) to bus node-\(j\) and the real and reactive power flows from bus node-\(j\) to bus node-\(i\) in line can be written as (1) to (4) with modified \(G_{ij}\) and \(B_{ij}\) as given below after placing TCSC in the line linked between bus nodes-\(i\) and \(j\).

\[
G_{ij} = \frac{r_{ij}}{r_{ij}^2 + (x_{ij} + x_{TSC})^2}, \quad B_{ij} = \frac{-x_{ij} + x_{TSC}}{r_{ij}^2 + (x_{ij} + x_{TSC})^2}
\]

3. Optimum location of TCSC based on an artificial intelligence algorithm

In recent years, methods of optimization are continuously being developed. Researchers, especially at the level of design and economics, are still being taken into account their high impacts and achievements [12]. Advanced optimization strategies are usually challenged with the increased difficulty of real-world issues. Meta-heuristic optimization algorithms, particularly for solving advanced mathematical models [13], have become a common choice. Genetic algorithm (GA), particle swarm optimization (PSO) algorithm, biogeography-based optimization, optimization of ant colonies, gravitational search algorithm (GSA), an algorithm for seeker optimization (SOA), an algorithm for differential evolution (DE), an algorithm for elephant herd optimization (EHOA), etc. Several methodologies to achieve optimum solutions [14-16] include meta-heuristic techniques. These approaches aim for the best solution by proposing search space for different elements of fitness, displacement, and crossover. The optimum value, the number of iterations, and the time to get as much from all optimization techniques are rather different.

APSOA is a heuristic search algorithm that simulates the intellect of humans when looking at them using their memorization, perceptions, and even uncertainties. The proposed algorithm changes its multi-objective operation parameters, and calculation variables optimally for various cases and test systems, paper [10] relied on artificial intelligence algorithms (APSOA) in determining the optimal location of TCSC and thus achieved an increase in the loadability of the IEEE 9 bus test system up to 60% of its original capacity. While the current research aims to adopt the same algorithm in determining the optimum location for TCSC, then to achieve an increase in the loadability of the transmission system to about 90% of its initial capacity, taking into account the thermal limit of transmission lines. Also observing the effect of overloading on the line voltage stability indicator.

4. Implementation of voltage stability indices

Scalar magnitudes ranging from 0-1 are monitored by voltage stability indices. It is a measure of the position of the operating point of the device for the critical stability limits under such load conditions [17]. To describe the critical lines and weakest buses, the line voltage stability index is used.

A vital line is the transmission line that records the highest value of VSI, while the bus that records the lowest limit value allowed in the demand load is the weakest busload [18]. It refers to the maximum possible related load defined as an ultimate liability at the nose point in (PV&QV) curves when Line VSI comes close to unity [19]. Previous studies have analyzed several indices of line voltage stability, all of which are interested in three points:

- The study of load flow equations is used to compute these indices.
- All indices are valued between (1) which refers to the collapse voltages, and (0) the no-load situation.
- All indices of voltage stability can be obtained from the basic two line-connected bus networks, which can then be applied to the interconnected n-bus system [20].

The derivation of its mathematical formula in reference [21], and line voltage stability index

\[
L_{ij} = \frac{4 \times q_{ij}}{|V_i\sin(\theta - (\delta_j - \delta_i))|^2}
\]

The current research relied on the algorithm mentioned in the source [10], it solved the OPF problem by integrating TCSC and simulating normal operating states and emergencies in the power system. Here
the researcher's role was to focus on the transmission line load state as it was mentioned in the source to the extent of 60%, and the researcher worked to increase the loadability to the thermal limit, through the addition of one device from TCSC, therefore, the researcher's addition was a new objective function is to reduce the line voltage stability index and compare the results in the event of changing the location of the device, depending on the weakest line in the network. Figure 3 shows the detailed steps taken by researchers to improve the ability of the system load and to take enhance system performance into account.
Focused on the maximum $L_{ij}$ to find the optimal location for TCSC

Based on artificial intelligence algorithm APSOA to find the optimal location for TCSC

Load flow simulation method for Newton Raphson

Line voltage stability index $L_{ij}$ calculations, according to normal operating state

The optimum position of the TCSC device

Boosted in load demand for all buses over maximum, even equally

If $L_{ij}=1$ [Less $<$]

Assessment of the transmission line load ability with increasing load demand to the thermal limit

Assessment of the transmission line load ability with increasing load demand to the thermal limit

Load ability improvement, reduce $L_{ij}$, VD-deviation minimization, and lowering TCSC’S device installation cost

End

Figure 3. This is the flow chart for estimating the loadability margin.
5. Result and discussion

The present article depends on the load is increased from 60% to 90% at all the buses equally to specify the loadability margin, as well as the optimum location and compensation level for TCSC which reduces LVSI and improves power system performance and stability.

The IEEE standard test systems 9 bus is chosen for the calculation of the line voltage stability index, the data is available in reference [9]. Figure 4 illustrates the single-line diagrams for IEEE 9-bus. The system contains nine buses, with bus 1 considered as slack buses, buses 2 and 3 are considered as voltage-controlled buses and other buses are considered as the load buses. A total of 9 transmission lines with 100MVA as the power base and 60Hz as the frequency base are usable for the system. The voltage range (0.9-1.15) pu.

![Figure 4. The single-line diagram for IEEE 9-bus system.](image)

Table 1, discusses the results of the LVSI calculation with and without TCSC’s device in cases of normal operation. Line 3, connecting to buses 5 and 6 in table 1, has the highest rank by considering the LVSI values for any line within the network’s value for a stable line, \( L_{ij} \) must be less than 1. So, line 3 is considered to be the network's weakest line.

TCSC is installed in Line 2, which is linked between buses 4 and 5, with a compensation level of 8%. LVSI decreased to 0.4366. But when the TCSC is repositioned to Line 3 based on the weaker line previously calculated with an 18% compensation level, LVSI is 10.55% lower than the previous value in line 2. The cost of installing and operating TCSCs in line 3 decreased from ($\ 35,318 \) to ($\ 25,780 \) $ / hour less than the cost to install them in Line 2. The results show when the TCSC is placed on line 3, the LVSI decrease is more than the decrease when the TCSC is placed in optimal positions in line 3 compared with line 2.

As seen in Table 2, the optimal location technique (APSOA) provides better grid performance by reducing cost and enhancement in voltage profile in cases of normal operation. Consequently, in a previous study, FACTS devices demonstrated major advantages but it is very costly. Therefore, the cost of the objective function is included in the assessment reduces it to the lowest possible value. Another goal is to optimize the voltage profile and also improve the power system stability by minimizing voltage deviations between buses. The cost of installation of the FACT device and the compensation level for the transmission line impedance, as well as the voltage deviation, calculated, was according to the laws mentioned, in [10].
Table 1. The results of the line voltage stability index $L_{ij}$.

| RANK | WITHOUT TCSC | WITH TCSC at LINE 2 [10] | WITH TCSC at LINE 3 |
|------|--------------|--------------------------|---------------------|
|      | LINES $L_{ij}$ | LINES $L_{ij}$ | LINES $L_{ij}$ | LINES $L_{ij}$ |
| 1    | 5--6 0.438766 | 5--6 0.436616 | 5--6 0.390529 |
| 2    | 3--6 0.308125 | 3--6 0.30695  | 3--6 0.315459 |
| 3    | 8--2 0.293346 | 1--4 0.286102 | 1--4 0.276137 |
| 4    | 1--4 0.283125 | 8--2 0.259982 | 8--2 0.26016 |
| 5    | 9--4 0.183992 | 9--4 0.184727 | 9--4 0.187982 |
| 6    | 7--8 0.141276 | 7--8 0.141185 | 7--8 0.143749 |
| 7    | 4--5 0.121954 | 4--5 0.114472 | 4--5 0.107621 |
| 8    | 6--7 0.030281 | 6--7 0.030799 | 6--7 0.026477 |
| 9    | 8--9 0.005807 | 8--9 0.005937 | 8--9 0.000493 |

Table 2. This is a result of the optimal location in terms of security and cost.

| The objective function | With TCSC at line 2 [10] | With TCSC at line 3 |
|------------------------|--------------------------|---------------------|
| $V_1$ (PU)             | 1.04                     | 1.04                |
| $V_2$ (PU)             | 1                        | 1.025               |
| $V_3$ (PU)             | 1                        | 1.025               |
| TCSC Cost($/h)         | $5.316 \times 10^5$      | $7.06359 \times 10^3$ |
| X Line (PU)            | 0.0852                   | 0.13899             |
| Compensation level (%) | 8                        | 18.24               |
| V.D (PU)               | 0                        | 0                   |

Table 3. This is a result of the optimal location when the load increasing 60%.

| The objective function | With TCSC at line 2 [10] | With TCSC at line 7 |
|------------------------|--------------------------|---------------------|
| $V_1$ (PU)             | 1.04                     | 1.04                |
| $V_2$ (PU)             | 1                        | 1.025               |
| $V_3$ (PU)             | 1                        | 1.025               |
| TCSC Cost($/h)         | $1.0831 \times 10^6$     | $12.649 \times 10^3$ |
| X Line (PU)            | 0.09375                  | 0.0125              |
| Compensation level (%) | 50                       | 80                  |
| V.D (PU)               | 0                        | 0                   |

Table 4. An estimation of transmission line loadability within thermal limits considering the LVSI. The TCSC optimum position had an important efficacy for LVSI-reducing, VD-deviation minimization, and lowering TCSC’S device installation cost. Where the researchers investigated the possibility of loading the transmission lines to the thermal limit by injecting the TCSC devices in the optimal location, which benefits in reducing the line voltage stability index as well as in reducing the cost of installing the device and taking into account the security of the system. Table IV shows, when the load increasing 60% and equally for all buses, the optimal location which is depending on Meta-heuristic optimization algorithms give the best results to reduce LVSI in many lines compartment with the sensitive line 3, but the cost of installation on line 3 is lower than line 7 by 12.9%. After increasing the load to 70%, 80% in the respective, voltage deviation also raising but the result shows that line 2 is
the optimal location for reducing LVSI, compensation level, and the cost of installation device, in many lines. Line 2 is the optimal place to reduce the LVSI value, but slightly raises the VD deviation as the overload increases to 90%. But Figure 5 shows a comparison between the best location for TCSC based on the two techniques used, which has achieved the loadability of the transmission line to the thermal limit, it was observed that the transmitted power when placing the TCSC in line 2 was increased, compared to the second method.

**Table 4.** An estimate of the transmission line load ability within thermal limits considering LVSI compared to a different TCSC location.

| INCREASING LOAD of 60% | INCREASING LOAD of 70% | INCREASING LOAD of 80% | INCREASING LOAD of 90% |
|------------------------|------------------------|------------------------|------------------------|
| optimal location by meta-heuristic algorithms (APSOA) | optimal location by weakest line | optimal location by meta-heuristic algorithms | optimal location by weakest line |
| LINE 7 | LINE 3 | LINE 2 | LINE 3 | LINE 2 | LINE 3 | LINE 2 | LINE 3 |
| $L_{ij}$ | $L_{ij}$ | $L_{ij}$ | $L_{ij}$ | $L_{ij}$ | $L_{ij}$ | $L_{ij}$ | $L_{ij}$ |
| 5–6 | 0.421568 | 0.356 | 5–6 | 0.410 | 0.346 | 5–6 | 0.401 | 0.360 |
| 3–6 | 0.241766 | 0.271 | 3–6 | 0.308 | 0.269 | 3–6 | 0.304 | 0.275 |
| 7–8 | 0.239712 | 0.563 | 7–8 | 0.297 | 0.262 | 7–8 | 0.266 | 0.260 |
| 4–5 | 0.224876 | 0.205 | 4–5 | 0.206 | 0.208 | 4–5 | 0.248 | 0.248 |
| 1–4 | 0.183902 | 0.196 | 1–4 | 0.170 | 0.188 | 1–4 | 0.180 | 0.180 |
| 8–9 | 0.125599 | 0.191 | 8–9 | 0.166 | 0.175 | 8–9 | 0.165 | 0.165 |
| 9–4 | 0.11225 | 0.111 | 9–4 | 0.142 | 0.145 | 9–4 | 0.101 | 0.136 |
| 8–2 | 0.077924 | 0.039 | 8–2 | 0.071 | 0.050 | 8–2 | 0.077 | 0.052 |
| 6–7 | 0.027766 | 0.039 | 6–7 | 0.001 | 0.036 | 6–7 | 0.004 | 0.028 |

X Line (PU) 0.0125 0.034 0.072771 0.056027 0.070999 0.084344 0.058466 0.054169
Compensation level (%) 80 80 20.9 67.04 22.82 71.56 36.45 68.13
TCSC Cost($/h) 12.649 $10^3 11.0127 $10^3 7.445x1 8.8502 $10^3 9.29241 $10^3 9.94891 $10^3 10.1603 $10^3 10.1126 $10^3
VD (PU) 0 0 0.0063 0.0098 0.0115 0.0126 0.0198 0.0168
Figure 5. The effect of TCSC on power flows in transmission lines when increasing the load to the thermal limit.

The reduction in power flow across the lines and thus the power flow supply to the lines for an emergency response is one of the most significant benefits of integrating TCSCs into the power grid. Figure 6, Figure 7, and Figure 8 explaining the power flow through the transmission lines when line 2 is the optimal location, with the load increasing from 70%, 80%, and 90% respectively. Moreover, Figure 9. Shown the voltage improvement with and without TCSC which is located on line 2, when loading increases by 90%.
Figure 6. The Power flow in transmission lines improved with and without TCSC on line 2 and an increasing load of 70%.

Figure 7: The Power flow in transmission lines improved with and without TCSC on line 2 and an increasing load of 80%.
Figure 8. The Power flow in transmission lines improved with and without TCSC on line 2 and an increasing load of 90%.
Figure 9. The voltage enhancement with and without TCSC in the optimal location line 2 and an increasing load of 90%.

6. Conclusion

TCSC is considered a power system control system with many advantages, such as increased overall transmittable power, lower reaction lines, improved power system reliability, and enhanced voltage transmission line deviation. Also, the introduction of TCSCs in the power grid leads to reduce power flow in lines whose load is close to their thermal limits and thus rearranges the power transfer to other lines to respond to any emergency. The current research is concerned with determining the optimal location of (TCSC) through two techniques, which are the artificial intelligence algorithm (APSOA) and one of the indications for the voltage stability of the lines, and the results showed that only one TCSC device was used to improve the power system performance.

To testing both techniques, the MATLAB program was applied to the IEEE 9 bus test system. The results were compared in terms of the best economic gain, security, and stability of the system. From the results, the optimum location of (TCSC) is line2, since the transmitted power was increased, reduce LVSI's value in many lines, but raising slightly the cost of installation when the load increasing to the thermal limit compared to the second method. So, the best results were obtained by using artificial intelligence methods (APSOA) to find the optimal position of the TCSC device. As seen the voltage profile is enhanced after the placement of TCSC in these locations. It can conclude that TCSC's device enhances system performance and maintains system security at the time increasing the loadability of transmission lines.
References

[1] Zhang, X. P., Rehtanz, C., & Pal, B. (2012). Congestion management and loss optimization with FACTS. Flexible AC Transmission Systems: Modelling and Control (pp. 269-290). Springer, Berlin, Heidelberg.

[2] Kumar, A., & Priya, G. (2012, December). Power system stability enhancement using FACTS controllers. In 2012 International Conference on Emerging Trends in Electrical Engineering and Energy Management (ICEETEEEM) (pp. 84-87). IEEE.

[3] Boonpirom, N., & Paitoonwattanakij, K. (2005, November). Static voltage stability enhancement using FACTS. In 2005 International Power Engineering Conference (pp. 711-715).

[4] Snadat, H. (1999). Power system analysis (Vol. 2). McGraw-Hill.

[5] Raihan-Al-Masud, M., Islam, M., Hasan, M., & Podder, P. (2019). Capacity Enhancement and Voltage Stability Improvement of Power Transmission Line by Series Compensation. EAI Endorsed Transactions on Energy Web, 6(23).

[6] Jadhao, C. W., & Vadirajacharya, K. (2015). The optimal placing of FACTS devices to improve power system security. International Journal of Engineering Research & Technology, 4(5), 1060-1063.

[7] Manganuri, Y., Choudekar, P., & Asija, D. (2016, July). Optimal location of TCSC using sensitivity and stability indices for a reduction in losses and improving the voltage profile. In 2016 IEEE 1st International Conference on Power Electronics, Intelligent Control and Energy Systems (ICPEICES) (pp. 1-4). IEEE.

[8] Sakr, W. S., El-Sehiemy, R. A., & Azmy, A. M. (2016). Optimal allocation of TCSCs by adaptive DE algorithm. IET Generation, Transmission & Distribution, 10(15), 3844-3854.

[9] Washington University. Available at http://www.ee.washington.edu/research/pstca/

[10] Shafik, M. B., Chen, H., Rashed, G. I., & El-Sehiemy, R. A. (2019). Adaptive multi-objective parallel seeker optimization algorithm for incorporating TCSC devices into optimal power flow framework. IEEE Access, 7, 36934-36947.

[11] Slochanal, S. M. R., Saravanan, M., & Devi, A. C. (2005, December). Application of PSO technique to find optimal settings of TCSC for static security enhancement considering installation cost. In 2005 International Power Engineering Conference (pp. 1-394). IEEE.

[12] Malladi, K. T., & Sowlati, T. (2018). Biomass logistics: A review of important features, optimization modeling, and new trends. Renewable and Sustainable Energy Reviews, 94, 587-599.

[13] Hachem, H., Gheith, R., Aloui, F., & Nasrallah, S. B. (2018). Technological challenges and optimization efforts of the Stirling machine: A review. Energy conversion and management, 171, 1365-1387.

[14] Dai, C., Chen, W., Zhu, Y., & Zhang, X. (2009). Seeker optimization algorithm for optimal reactive power dispatch. IEEE Transactions on power systems, 24(3), 1218-1231.

[15] Baghaee, H. R., Vahidi, B., Jazebi, S., Gharehpetian, G. B., & Kashefi, A. (2008, October). Power system security improvement by using differential evolution algorithm-based FACTS allocation. In 2008 Joint International Conference on Power System Technology and IEEE Power India Conference (pp. 1-6). IEEE.

[16] Elhosseini, M. A., El Sehiemy, R. A., Rashwan, Y. I., & Gao, X. Z. (2019). On the performance improvement of elephant herding optimization algorithm. Knowledge-Based Systems, 166, 58-70.

[17] Mohamed, A., Jasmon, G. B., & Yusoff, S. (1989). A static voltage collapse indicator using line stability factors. Journal of industrial technology, 7(1), 73-85.

[18] Musirin, I., & Rahman, T. A. (2002, July). Novel fast voltage stability index (FVSI) for voltage stability analysis in the power transmission system. In Student conference on research and development (pp. 265-268). IEEE.
[19] Rahman, T. A., & Jasmon, G. B. (1995, November). A new technique for voltage stability analysis in a power system and improved load-flow algorithm for the distribution network. In Proceedings 1995 International Conference on Energy Management and Power Delivery EMPD'95 (Vol. 2, pp. 714-719). IEEE.

[20] Suganyadevia, M. V., & Babulalb, C. K. (2009, June). Estimating of loadability margin of a power system by comparing Voltage Stability Indices. In 2009 International Conference on Control, Automation, Communication, and Energy Conservation (pp. 1-4). IEEE.

[21] Saeed, W., & Tawfeeq, L. Ultimate Loadability Improvement Based on Contingency Ranking and Line Voltage Stability Index Using Genetic Algorithm.