Voltage stability assessment prediction using a guide strategy-based adaptive particle swarm optimisation-neural network algorithm

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ABSTRACT

In this work, the indicators of electrical power network stability and voltage stability (VS) are discussed and developed with the aim of using a power transfer stability index (PTSI) indicator as a predictor for voltage stability (VS) in electrical power networks. The power transfer stability index (PTSI) was thus used to detect abnormally weak voltages in buses within such power system networks (weak). The target data are obtained using the Newton Raphson method (NR) and include magnitude, phase angle, and active and reactive power. A new adaptive particle swarm optimization-neural network algorithm based on a guiding strategy (GSAPSO-NN) was also used to achieve the goal of the paper by improving the mixed particle updates and the weightings of the neural network to decrease the search time. All results were then compared with actual values as calculated using the PTSI NR method. The final results show only simple differences or approximately the same values using both the proposed and the classical methods. The MATLAB-power system analysis toolbox (PSAT) package was employed to obtain most of these results and the testing of the new method was done on the IEEE14 bus system as well as the Iraqi 24-bus power system. The effectiveness validation of the new hybrid method for assessing voltage stability was thus achieved.

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1. INTRODUCTION

Problem of voltage stability in electrical power systems within appropriate operational limits is one of the most important problems currently faced by major companies working in the power system field, mainly due to the inability of operators to manage imbalances. Due to ongoing development in electrical power systems and major increases in noticeable imbalances now commonly occur in the power supplies, which offer the possibility of losing stability during any emergency situations in the system that lead to a collapse in voltage. This, in turn, can have very dangerous results. A stable electric power network is the main driver of modern industry, and any system breakdown as a result of a serious failure that leads to a complete loss of the network, or a collapse in reliability has extensive knock-on effects [1].

Studies of such situations have confirmed that ensuring the stability of the voltage increases reliability, supporting the growth and development in electric power systems driven by the increasing use of modern technology that has increased the need for high-pressure systems, however, offering new techniques to stabilise the transient states of power systems [2], [3]. Several layers' performance can be compared using AI probability techniques or methods; such probability is developed within an artificial neural network

(ANN) toolbox, and the resulting systems can be digitally analysed to assess the control stability of the linear single-loop voltage, R, in each case [4] in order to determine critical frequency that defines the stability region of R. Artificial intelligence can thus also be applied to find effective solutions to stabilising the voltage in electrical power systems using limited data [5]. The principal goal for such work is to build monitoring system which can assess all changes that occur to the network by monitoring states of both stability and instability, as such a system takes into account all the malfunctions that do occur and all those that will occur to offer detailed and satisfactory analytical results [6].

To study the power flow in electrical networks in a detailed and analytical manner in order to calculate the data transferred between elements randomly more accurately, a separate Markov method has been developed; this method enables workers to identify recurring [7] network faults and their causes and to propose appropriate solutions in a dynamic architectural manner, as well supporting online services.

In the study areas of both electrical power networks and voltage stability systems, artificial intelligence is thus now well developed, based on its utility over several layers, multiple functions and both simple and limited data, which allows finding solutions that are both rapid and appropriate [8], [9].

Alaraifi *et al.* [10], present solutions to situations that could not previously be controlled in power networks were investigated by studying the stability of the static state of the network; the most important of the resulting solutions was the proposal of the theory of improvement of the particle swarm. Zhou *et al.* [11] present a high temperature superconducting fault current limiter (HTS-FCL) was thus presented as a method of improving stability as well as reducing fault currents during network failure and the frequency of short circuits and the resulting current issues. The New England 29 bus system was also used in [12] to apply ANN, with data from the power flow such as magnitude and angle; this was compared to the classical monitoring system for which the online phase measurement units (PMU) system was used.

MATLAB with the power system analysis toolbox (PSAT) was used to access the results for this paper. Adaptive PSO-NN guiding strategy-based algorithm (GSAPSO-NN) was adopted to achieve voltage stability assessment (VSA), and to make the study more comprehensive, a comparison was made with the classical method using Newton Raphson (NR) calculations for PTSI. Two standard networks are used to test approaches, the IEEE14-bus and the 24-bus Iraqi power system.

2. MATERIALS AND METHODS

Two power system networks were used to test the proposed method, the IEEE14 bus Standard Network and the Iraqi electrical network. The main diagram of the IEEE14 bus (1 slack bus, 9 PQ bus, 4 PV bus and 20 lines) was extracted from [13]. This is comprised of five synchronous machines with IEEE exciters, with three of the five compensators utilised only for reactive power provision. This system has nine loads, for a total of 81.3 MVAR and 259 MW. Dynamic data for generator exciters was drawn from [14]. Iraqi electrical network also consists of both 132 kV network and a 400 kV network (super grid network) [15].

2.1. Power transfer index (PTSI)

The PTSI offers two main advantages: firstly, the easiness in applying and the offering of rapid results; it can thus be readily utilized to show the conditions for the stability of voltage in electrical power networks. Any change that can be sensed by PTSI suggests a voltage stability problem, implying that the system is near to the voltage avalanche or breakdown. The PTSI was drawn from interpretation of the simple equivalent two bus Thevenin system in [16], as shown through Figure 1.

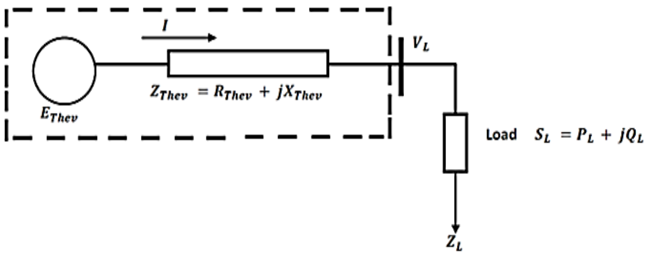

Figure 1. General schema of two busses

The proposed PTSI indicator equation is:

$$\mathrm{PTSI} = \frac{2S_L Z_{Thev}(1+\cos(\beta-\alpha))}{E_{Thev}^2} \quad (1)$$

Where Z_{Thev} is Thevenin impedance, β is Thevenin impedance's angle, and (S_L and α) are apparent power and the impedance for the load respectively. E_{Thev} is thus the voltage explained by the evaluated. PTSI from (1) for every bus employing the relevant (Z_{Thev}, Z_L,α, V_L, and V_{Thev}), The PTSI takes values with range (0 to 1) and index value of PTSI < = 1 represents a secure level [17].

The VS of the power networks is assessed by regularly raising the loads on them until breakdown levels are reached; in most cases, the increasing load is a factor of concern, as the loading factor (λ) tends to affect the power network's tendency to voltage collapse.

$$P_L = \lambda P_{Lo} \quad , \; Q_L = \lambda Q_{Lo} \tag{2}$$

Where P_{Lo} is any load bus's initial true or real power, Q_{Lo} is any load us's initial reactive or useless power, and (λ) indicator for the factor loading.

2.2. Guide strategy-based adaptive particle swarm optimisation (GSAPSO) algorithm for PTSI

GSAPSO is considered an effective way to assess and determine the fastest solutions for an upcoming period as well as the easiest way to find the optimal location for intervention. One of the most important strengths of this method is its ability to verify knowledge from a local level using subsequent enumeration improvement work to obtain the best values from the second, third, and fourth sections completed using mixed particles with poor values.

To allow a better understanding of the updating of the mixed particles with the standard algorithm of PSO, the process can be outlined as follows, with calculations as shown in (3) to (7): (i) the main particles are randomly generated; (ii) the second section involves two categories of central particles [18], with the first part produced and formed based on the optimal individual value of all particles; (iii) cooperative particles allow numerous starts for independent particles from an ideal global position; and (iv) chaotic particles are produced through logistic mapping as a means of identifying suboptimal particle solutions in the surrounding region.

$$x_{SCP} = \frac{1}{n}\sum_{i=1}^{n} x_{id} \tag{3}$$

$$x_{GCP} = \frac{1}{n}\sum_{i=1}^{n} P_{id} \tag{4}$$

$$x_{id} = P_{id} + rand * vec \tag{5}$$

$$Vec = V_{imax} * \left(1 - \alpha * \frac{exetime}{gen}\right) \tag{6}$$

$$\begin{cases} k = 4 * k * (1 - k) \\ x_{id} = x_{imin} + k * (x_{imax} - x_{imin}) \end{cases} \tag{7}$$

Where x_{imin} and x_{imax} are coordinates for minimum in addition to maximum values, respectively, while chaotic factor for inertia weight strategy is represented here by k. By changing periods, system weights change in a direct relationship: the less inertia, the greater the number of global outcomes, while the smaller inertia, the stronger local results. Average and maximum focus distances are shown in (8) to (11).

$$Dist_{mean} = \frac{\sum_{i=1}^{m}\sqrt{\sum_{d=1}^{D}(X_{id} - P_{gd})^2}}{m} \tag{8}$$

$$Dist_{max} = \max_{i=1,2,\ldots,n}\left(\sqrt{\sum_{d=1}^{D}(X_{id} - P_{gd})^2}\right) \tag{9}$$

$$K = \frac{Dist_{max} - Dist_{mean}}{Dist_{max}} \tag{10}$$

$$\omega = \begin{cases} \ln(a - k) + b & k \geq 0.05 \\ 0.75 + rand/4 & k < 0.05 \end{cases} \tag{11}$$

Algorithm involved inertia weights were ω_{max} = 0.9, ω_{min} = 0.3. And the proposed algorithm objective function can be most easily defined in (12):

$$J = \sum \frac{(net\_f(inputs) - targets)^2}{length(net\_f(inputs))} \tag{12}$$

3. GSAPSO-NN ALGORITHM

The proposed adaptive GSAPSO-NN algorithm for calculating the threshold values for voltage collapse points was implemented. PSO is used to verify the weights for high-quality solutions. The proposed algorithm is more efficient from the comparison with the classical method as shown in Figure 2 [19]–[21], Figure 2 is a flowchart for the adaptive GSAPSO-NN.

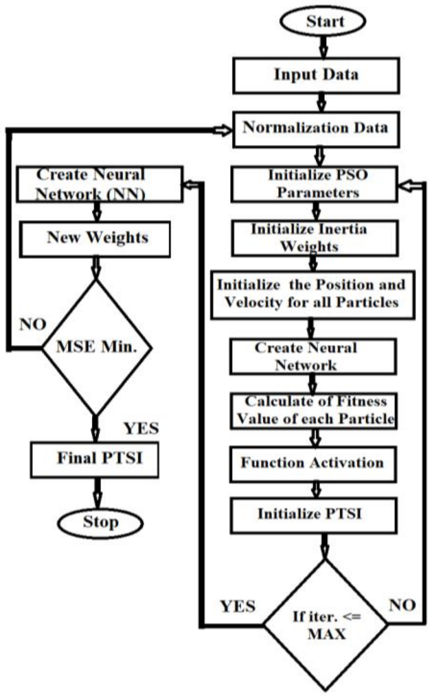

Figure 2. Flowchart for GSAPSO-NN

4. SIMULATION RESULTS AND DISCUSSION

This work tested a new method on the Iraqi electrical network (24-bus) and the IEEE14 bus Standard Network. The efficiency of the adaptive PSO-NN algorithm based on a guiding strategy (GSAPSO-NN) was confirmed by simulation results. As illustrated in Tables 1 and 2, the PTSI indicator was used to study the effects of VSA in these electric power networks [22]–[24]

Table 1. PTSI comparison between GSAPSO-NN and NR for 24-bus network

Parameter	Value											
PQ Bus	12	13	15	16	17	18	19	20	21	22	23	24
V p.u.	0.976	0.978	1.027	1.033	0.899	0.899	1.015	1.01	0.942	1.022	0.899	0.895
PTSI NR	0.9991	0.9821	0.9983	0.9934	0.0185	0.6308	1.0041	0.9974	0.9612	0.9936	0.8211	0.8992
Proposed method	1.0073	1.002	0.9896	1.0041	0.0223	0.6425	1.0055	1.0081	0.9608	0.9513	0.7832	0.9032
MSE PTSI NR			7.2547×0^{-4}				MSE Proposed method			4.0323×10^{-4}		

Table 2. PTSI comparison between GSAPSO-NN and NR for IEEE14-bus network

Parameter	Value							
PQ Bus	4	5	9	10	11	12	13	14
V p.u.	0.899	0.899	0.895	0.898	0.899	0.899	0.898	0.897
PTSI NR	0.8187	0.6887	0.3632	0.2747	0.4753	0.5939	0.1231	0.4977
Proposed method	0.8111	0.6642	0.3711	0.2821	0.4853	0.6047	0.134	0.4963
MSE PTSI NR		2.8297×10^{-4}			MSE Proposed method		1.3942×0^{-4}	

MATLAB was employed to obtain the appropriate test results, when comparing GSAPSO-NN and NR, it was particularly conspicuous that the mean square error (MSE) variance between them was small. The MSE value in the case of the 24-bus network for the GSAPSO-NN was 4.0323×10^{-4}, as compared with that for the NR MSE, which was (7.2547×10^{-4}), while in the case of the IEEE14-bus network, the GSAPSO-NN MSE was (1.3942×10^{-4}), which was less than that for the NR MSE at 2.8297×10^{-4}. The target data and input data were derived from targets and power flow, where the values of the stability indicators are actual. Where the value of PTSI for a bus approaches unity (equal to one), this can thus be identified as the weakest bus in the power network with regard to finding areas of weakness that should be monitored [25], [26].

GSAPSO-NN is a useful method for addressing such problems. The 24-bus Iraqi network reached its collapse limitation at around 0.9, and the GSAPSO-NN method, in this case, had an MSE value of about 4.4×10^{-4} after 60 epochs, highlighting that this was the best solution; the GSAPSO-NN method also offered the best solution at about 1.04×10^{-3} in the IEEE14-bus standard network after the same number of iterations, as shown in Figure 3. Regression rates for the GSAPSO-NN method were R=0.99634 for the 24-bus network and R=0.99905 for the 14-bus network, as illustrated in Figures 4 and 5, respectively. The MSE values of 4.0323×10^{-4} (24-bus) and 1.3942×10^{-4} (14-bus) shown in Table 1, suggest that these are very similar to the PTSI results.

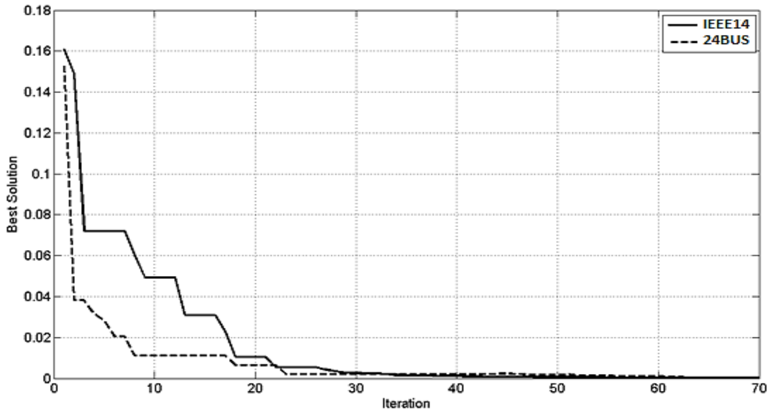

Figure 3. Convergence of GSAPSO-NN (24-bus & 14-bus networks)

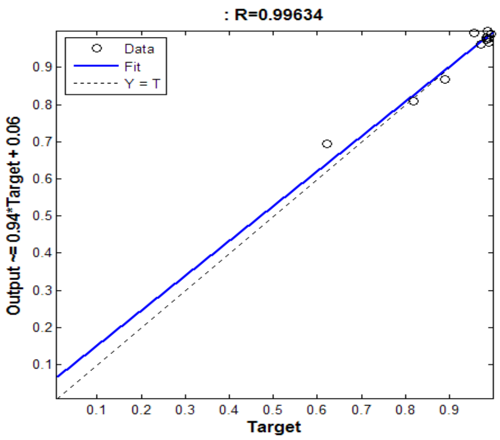

Figure 4. Regression GSAPSO-NN (24-bus)

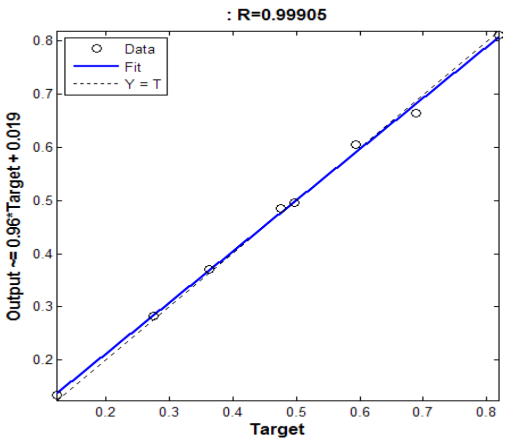

Figure 5. Regression GSAPSO-NN (14-bus)

For the Iraqi power network (24-bus) Figure 6, based on the PTSI indicator, the buses can be arranged from weaker to stronger. Thus, for the NR algorithm, the busses' optimal arrangement is 17, 18, 23, 24, 21, 13, 16, 22, 20, 15, 12, and 19, while the corresponding order for proposed algorithm (GSAPSO-NN) is 17, 18, 23, 24, 22, 21, 15, 13, 16, 19, 12, and 20. For the IEEE14 bus Figure 7, where the PTSI reaches 1, the possibility of a voltage collapse increases, a result that becomes evident as the load is gradually increased from 0 to 1. Employing the Newton Raphson method to calculate the values of such collapse, bus 13 is shown to be stable when it has a value of 0.1231, while bus 4 is critical but within the stability limit at a value of 0.8187. Utilising the NR method, the PTSI rankings from stable to less stable values are 13, 10, 9, 11, 14, 12, 5, and 4, as shown in Table 2. The GSAPSO algorithm thus achieved a good correlation with the Newton-Raphson method [26].

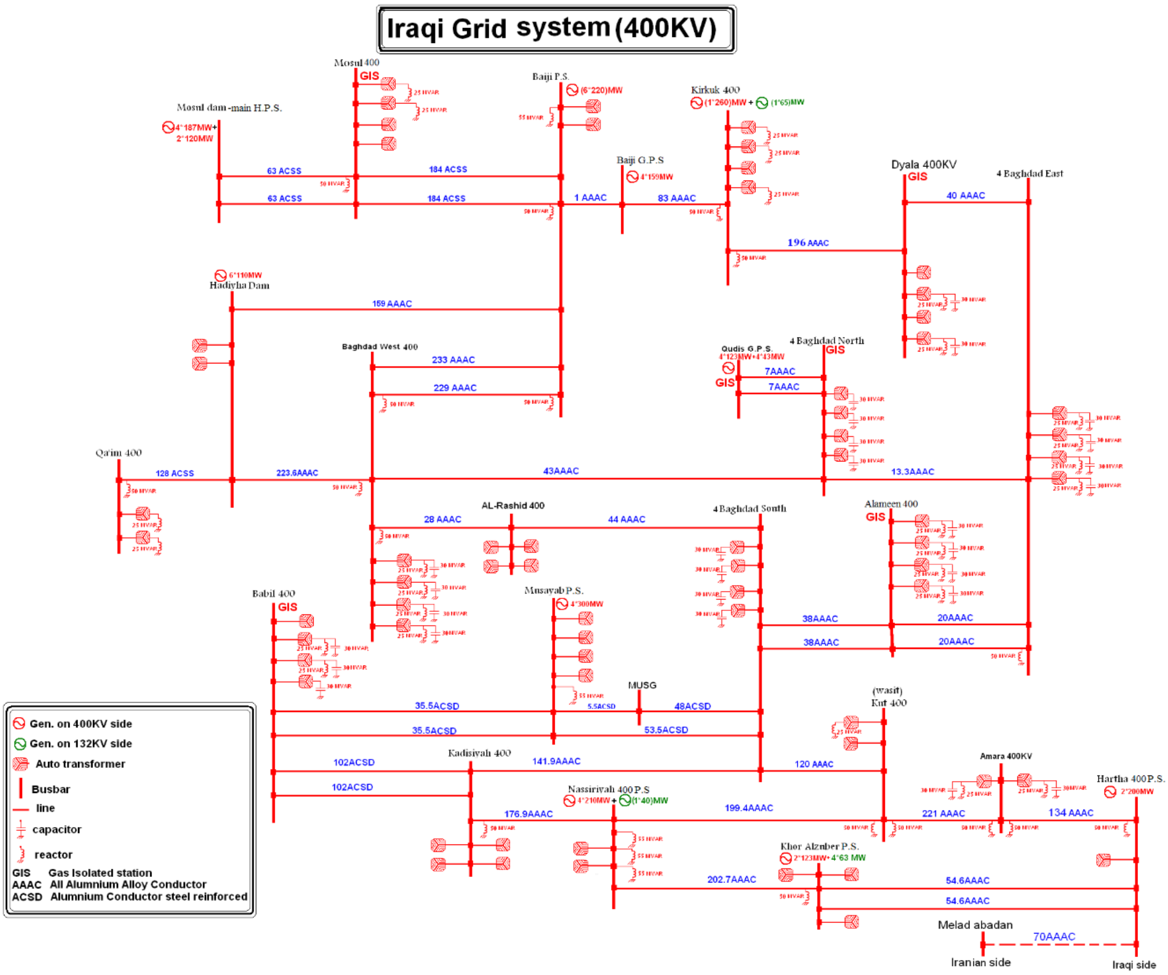

Figure 6. General diagram for Iraqi power system [3]

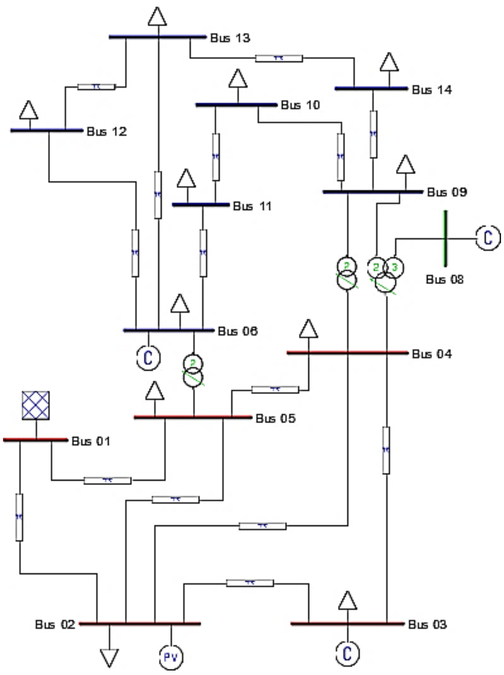

Figure 7. Standard diagram for IEEE14 bus [22]

5. CONCLUSION

In such a paper, the GSAPSO-NN algorithm was presented and tested. Problems with voltage instability relate to increases in loading, bus weakness, and transmission line length. Here, MATLAB was used to calculate results for each of the GSAPSO-NN and classical NR methods as a way to measure the PTSI as a function of time (VSA). The target of this paper was thus to develop PTSI as calculated by the Newton Raphson method using a more rapid method. The inputs for the GSAPSO-NN were derived from the power flow of the networks, and for the two power systems networks mentioned in this paper, sound PTSI indicators and bus rankings were achieved. Enhancements in two of the more important performance aspects, precision (accuracy) and speed, of the proposed method, which are considered excellent indicators for voltage assessment in power systems, were achieved. Global convergence was also effectively improved, and the importance of the voltage stability indicator proved, confirming this as an effective and efficient indicator for power systems. The results show good agreement between the inputs and targets, as well as suggesting that GSAPSO-NN offers an exceptional level of performance.

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