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Gravitational Search Algorithm Based Technique for Voltage Stability Improvement

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ABSTRACT

Voltage instability problem has been known as a significant threat to power system operation since its occurrence can lead to power interruption. This phenomenon can be due to uncontrollable load increment, line and generator outage contingencies or unplanned load curtailment. Optimal reactive power dispatch involving reactive power support can be one of the options for improving voltage stability of a power system, which also requires optimization process. Optimal sizing and location can of reactive power support can avoid the system from experiencing over-compensated or under-compensated phenomena. The presence of optimization techniques has helped solving non-optimal phenomenon, nevertheless some setbacks have also been experienced in terms of inaccuracy and stuck in local optima. This paper presents the application of Gravitational Search Algorithm (GSA) technique in attempt to solve optimal reactive power dispatch problem in terms of reactive power support for voltage stability improvement. Optimization process tested on IEEE 14-bus Reliability Test System (RTS) has revealed its superiority with significant promising results in terms of voltage stability improvement in the test system.

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1. INTRODUCTION

Aside of thermal overload and angle instability issue, voltage instability has been known to be a major issue in a power system operation. Voltage instability can be observed in terms of progressive reduction of voltage level which eventually leads to system disruption due to voltage collapse phenomenon [1]. Voltage instability can occur due to various reasons such as highly stressed power system, high loading in a power system, extensive usage of shunt compensation device, switching of loads and protective devices as well as improper reactive power support [2]-[4]. In recent years, blackouts occurrences have been reported due to undetected progressive reduction in voltage stability in power systems [5].

In order to improve the voltage stability of a power system, optimal reactive power dispatch can be employed. Several researchers have implemented various optimization technique to solve optimal reactive power dispatch problem. In [6], Genetic Algorithm (GA) has been implemented to solve optimal reactive power dispatch problem in minimizing the total power loss in IEEE 30-bus system. On the other hand, GA has been implemented in [7] for solving optimal reactive power dispatch problem to improve voltage profile of a practical Indian power system. The research compares the optimized results using GA with optimization results provided by Linear Programming (LP) technique, which revealed that GA is capable to produce higher quality results compared to LP. Authors in [8] has attempted to solve the same problems as in [7] by using Particle Swarm Optimization (PSO) technique and comparative study was conducted with respect to LP technique, resulting in PSO providing better results compared to LP. PSO was further improved by several researchers where authors in [9] has implemented modified Evolutionary PSO (EPSO) to solve optimal reactive power dispatch problem while authors in [10] has modified the acceleration coefficient of PSO technique which then produce a technique known as PSO with time varying acceleration coefficients (PSO-TVAC). Aside of the mentioned techniques, several other techniques which has been implemented to solve optimal reactive power dispatch problem are Artificial Bee Colony [11], Cuckoo Search Algorithm [12] and Ant Colony Optimization [13].

Classical optimization technique such as LP, Non-Linear Programming, Quadratic Programming and Newton Programming has been implemented to solve optimal reactive power dispatch problem. However, these classical techniques suffer from drawbacks such as insecure convergence, sensitivity to search starting point [10], difficulties on handling problem with discrete variables [6], and difficulty to solve the problem due to the nonlinearity of the problem [9].

In this study, GSA was employed in the attempt to solve optimal reactive power dispatch problem in order to improve the voltage stability of IEEE 14-Bus RTS. A pre-developed voltage stability index termed as Voltage Stability Load Index (VLSI) developed by T. K. Abdul Rahman et. al [15] was utilized as the indicator. In this paper, 3 case studies are considered which involves the manipulation of load at the weakest bus in the system. Results obtained from the study revealed the feasibility of GSA in producing promising results.

2. RESEARCH METHOD

2.1. Problem Formulation

In this study, the aim of the optimization process is to improve the voltage stability in the system by minimizing the voltage stability index of the weakest bus in the system. Hence, the objective function of the optimization process can be expressed as:

$$OF = min(VSLI) \tag{1}$$

where VSLI is the value of voltage stability of the weakest bus in the system.

During the optimization process, a crucial constraint needs to be satisfied where the total reactive power produced by the generation unit Q_g and total reactive power injected to the test system Q_inj should cater the reactive load demand Q_demand and the reactive power loss in the system Q_loss. It can be expressed as:

$$Q_{demand} + Q_{loss} = \sum Q_g + \sum Q_{inj} \tag{2}$$

2.2. Gravitational Search Algorithm (GSA)

GSA was first introduced by Esmat Rashedi, Hossein Nezamabadi-pour and Saeid Saryazdi in 2009 [14]. This optimization technique is inspired by law of gravity and mass interaction. Masses in GSA (Figure 1) will obey 2 main law which is the law of gravity and law of motion. For detailed explanation about GSA techniques regarding about its laws and algorithm, the brief description of the mechanics of GSA technique is discussed as the followings.

Step 1: Agents initialization

Considering a system which consists of N agents, the initial position of the agents in dth dimension is defined as follows:

$$X_i = \left(x_i^1, \dots, x_i^d, \dots, x_i^n\right) \quad for\ i = 1,2,\dots,N \tag{3}$$

where n is the number of dimensions of the optimization problem.

Step 2: Evaluate fitness value of the agents

At this step, the fitness value for each agent in the system is evaluated. In this study, the fitness value is VSLI and it is determined from the current position of the agent.

Step 3: Update of gravitational constant, best fitness, worst fitness and agent mass

In this step, the current gravitational constant G(t) is updated. The value of G(t) is related based on the initial iteration number t0, current iteration number t and constant β. Later on, the best fitness and the worst fitness in current iteration is defined. In this study, the best fitness bestfit(t) is defined as the lowest fitness value while the worst fitness worstfit(t) is defined as the highest fitness value. Finally, the agent mass Mi(t) for the agents is then computed based on the fitness value fiti(t), best fitness value and the worst fitness value.

$$G(t) = G(t_0) \times \left(\frac{t_0}{t}\right)^{\beta} \tag{4}$$

$$best_{fit}(t) = \min_{j \in \{1,\ldots,N\}} fit_j(t) \tag{5}$$

$$worst_{fit}(t) = \max_{j \in \{1,\ldots,N\}} fit_j(t) \tag{6}$$

$$m_i(t) = \frac{fit_i(t) - worst_{fit}(t)}{best_{fit}(t) - worst_{fit}(t)} \tag{7}$$

$$M_i(t) = \frac{m_i(t)}{\sum_{j=1}^{N} m_j(t)} \tag{8}$$

Step 4: Computation of total force in every direction

During this step, the force acting on ith agent from jth agent at dth dimension F_ij^d (t) will be calculated based on the active gravitational mass related to jth agent Maj(t), passive gravitational mass related to ith agent Mpi(t), Euclidian distance between ith agent and jth agent Rij(t) as well as small constant ε.

$$M_{ai} = M_{pi} = M_{ii} = M_i \quad for\ i = 1, \ldots, N \tag{9}$$

$$R_{ij}(t) = \sqrt{\sum_{d=1}^{n} \left(x_j^d - x_i^d\right)^2} \tag{10}$$

$$F_{ij}^d(t) = G(t) \times \frac{M_{pi}(t) \times M_{aj}(t)}{R_{ij}(t) \times \varepsilon} \times \left(x_j^d(t) - x_i^d(t)\right) \tag{11}$$

Step 5: Computation of acceleration and velocity

Next, the acceleration of the agents a_i^d (t) is computed. Acceleration of the agents are determined by the total force acting on ith agent F_i^d (t) over the inertial mass of ith agent M_ii (t). Then, the velocity of the agent v_i^d is updated based on the acceleration of the agents and the influence of randomization where 〖rand〗_i is a random number in the interval of 0 to 1.

$$F_i^d(t) = \sum_{j=1,\ j \neq i}^{N} \left(rand_j \times F_{ij}^d(t)\right) \tag{12}$$

$$a_i^d(t) = \frac{F_i^d(t)}{M_{ii}(t)} \tag{13}$$

$$v_i^d(t+1) = rand_i \times v_i^d(t) + a_i^d(t) \tag{14}$$

Step 6: Agents position update

After the velocity of the agents has been updated, then the position of the agent x_i^d will also be updated based on the agent velocity.

$$x_i^d(t+1) = x_i^d(t) + v_i^d(t+1) \tag{15}$$

Step 7: Convergence Test

Now, the algorithm will check the termination criteria of the optimization process. If the optimization process has reach its maximum iteration limit, the optimization process can be terminated. Otherwise, the algorithm will proceed back to step 2.

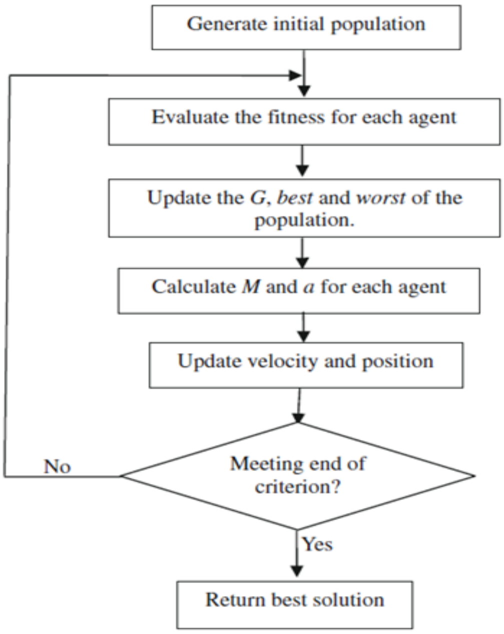

Figure 1. Flow Chart of GSA

2.3. Voltage Stability Load Index

Voltage stability index used in this paper is an index developed by T.K. Abdul Rahman [15] in 1995 known as Voltage Stability Load Index (VSLI). VSLI can be implemented to determine the voltage stability at a load bus and identify the weakest bus in a power system. In Figure 2, V_th is the open circuit voltage represent by no load voltage and angle, V_o and θ_orespectively. While V_Land θ_L is load voltage and angle view from each load bus. V_o, θ_o, V_L, and θ_L were calculated using load flow analysis. In VSLI, a bus with voltage stability index close to 1.00 is considered as the critical bus. On the other hand, voltage stability index lesser than 1.00 implies less weak bus in the system. VSLI can be expressed mathematically as:

$$VSLI = \frac{4\left[V_O V_L \cos(\theta_O - \theta_L) - V_L^2 \cos(\theta_O - \theta_L)^2\right]}{V_O^2} \qquad (16)$$

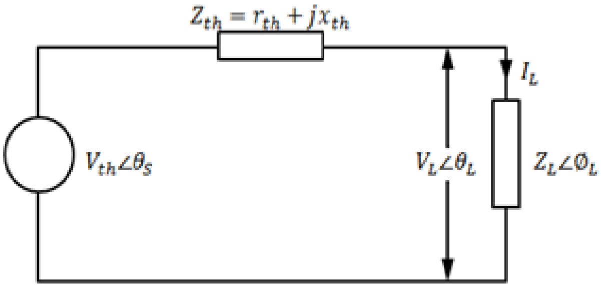

Figure 2. Equivalent Thevenin circuit view from each load

3. RESULTS AND ANALYSIS

In this study, 3 case studies have been conducted which involved manipulation of the loading at the weakest bus in the given condition. Case studies which conducted in the study are active load manipulation, reactive load manipulation and manipulation on both active and reactive load. The optimization results for each case study is discussed in the section 3.1, 3.2 and 3.3.

3.1. Manipulation of active load demand

In this case study, the active load demand is manipulated where the load is subjected to increment. During this case, bus 14 has been determined to be the weakest bus. The active load at bus 14 has been increased up to 2.5 times its nominal loading value. The loads at other buses are maintained as in nominal operating condition.

Upon the completion of the optimization process, it can be observed that GSA has successfully improve the voltage stability of the system by solving optimal reactive power dispatch problem by reducing the value of VSLI for all loading conditions. As the load multiplier increases, the value of VSLI also increased. However, solving optimal reactive power dispatch has improved the voltage stability at bus 14, hence making extra loading at bus 14 possible. Optimization results using GSA is presented in Table 1 and graphically presented as in Figure 3.

Table 1. Optimization results for active load manipulation condition

Load multiplier at bus 14	Pre-optimized VSLI	Post-optimized VSLI
1.0	0.1001	0.0003
1.1	0.1257	0.0377
1.2	0.1690	0.0632
1.3	0.2091	0.0842
1.4	0.2637	0.1188
1.5	0.3172	0.1518
1.6	0.3840	0.1982
1.7	0.4490	0.2430
1.8	0.5187	0.3008
1.9	0.5919	0.3569
2.0	0.6672	0.4182
2.1	0.7428	0.4842
2.2	0.8162	0.5543
2.3	0.8841	0.6275
2.4	0.9422	0.7025
2.5	0.9840	0.7774

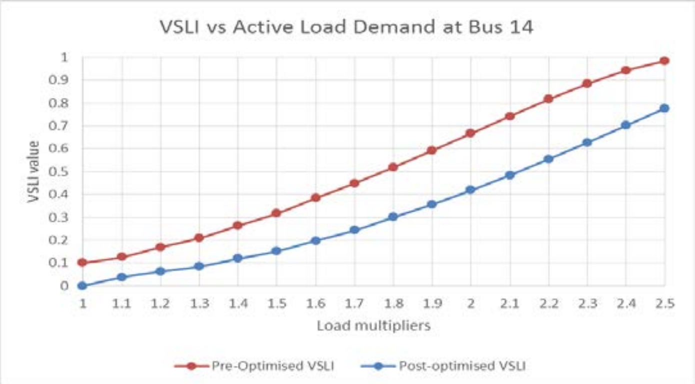

Figure 3. VSLI values at different active load multiplier

3.2. Manipulation of reactive load demand

In this case study, the reactive load demand at the weakest bus in the system is manipulated. Bus 14 was found to be the weakest bus in the system during the nominal condition. The reactive load demand was increased at the highest value possible and the voltage stability at the bus is observed.

After the optimization process has been conducted, GSA has successfully solved optimal reactive power dispatch to improve the voltage stability at bus 14 of the test system. It can be observed that as the reactive load is increased, the voltage stability index was also increased for both pre-optimized and post-optimized condition. However, the post-optimized voltage stability index value remains lower than the pre-optimized voltage stability index, which implies the success of GSA. The optimization result is tabulated in Table 2 and it is depicted in Figure 4.

Table 2. Optimization results for reactive load manipulation condition

Load multiplier at bus 14	Pre-optimized VSLI	Post-optimized VSLI
8	0.9152	0.6613
8.1	0.9251	0.6702
8.2	0.9349	0.6791
8.3	0.9447	0.6881
8.4	0.9543	0.6972
8.5	0.9637	0.7064
8.6	0.9730	0.7157
8.7	0.9819	0.7252
8.8	0.9902	0.7348
8.9	0.9975	0.7446

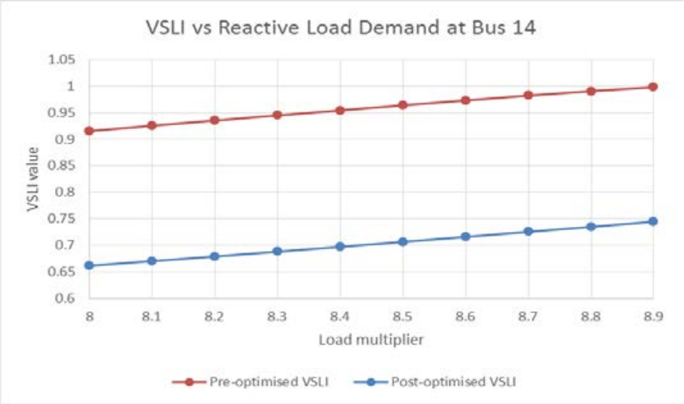

Figure 4. VSLI values at different reactive load multiplier

3.3. Manipulation of active and reactive load demand

In this condition, both real and reactive load demand of the weakest bus in the system is manipulated and GSA is implemented to solve optimal reactive power dispatch problem. Here, bus 14 has been identified to be the weakest bus in the system. During the optimization process, the active and reactive load has been increased in steps and the voltage stability index value is observed.

Upon completion of optimization process, it can be observed that GSA has successfully solve optimal reactive power dispatch for voltage stability improvement problem. The results yielded by the optimization process shows that the voltage stability index at bus 14 of the test system has been improved through reduction of the voltage stability index value. At maximum loading, the post-optimized voltage stability index value has been significant reduction, which enables further loading at the bus. The optimization results and its graphical representation is provided in Table 3 and Figure 5 respectively.

Table 3. Optimization results for active and reactive load manipulation condition

Load multiplier at bus 14	Pre-optimized VSLI	Post-optimized VSLI
1.0	0.1453	0.0096
1.1	0.1801	0.0615
1.2	0.2315	0.0941
1.3	0.2864	0.1296
1.4	0.3470	0.1631
1.5	0.4057	0.2096
1.6	0.4692	0.2612
1.7	0.5366	0.3108
1.8	0.6069	0.3654
1.9	0.6787	0.4247
2.0	0.7503	0.4881
2.1	0.8196	0.5551
2.2	0.8837	0.6248
2.3	0.9389	0.6961
2.4	0.9800	0.7673
2.5	0.9996	0.8364

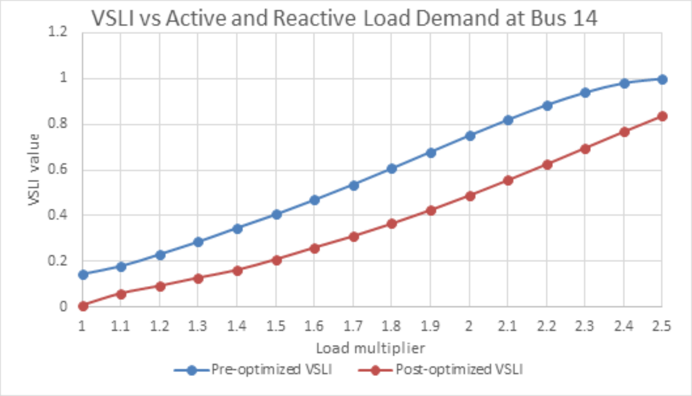

Figure 5. VSLI values at different active and reactive load multiplier

4. CONCLUSION

At the end of the study, it can be concluded that GSA has successfully solve optimal reactive power dispatch to improve voltage stability in the system. From all case studies conducted in the paper, GSA has provided excellent post-optimized results in terms of voltage stability improvement on the weakest bus in a power system. It can also be concluded that optimal reactive power dispatch can improve voltage stability index in a power system.

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