**The gravitational search algorithm for incorporating TCSC devices into the system for optimum power flow**

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| **Article Info** |  | **ABSTRACT** |
| ***Article history:***  Received  Revised  Accepted |  | This article proposes to delegate a gravitational search algorithm to the thyristor-controlled compensator series (TCSC), incorporated into the issue of reactive power management (GSA). TCSC units aim to minimize active and reactive power losses, to improve the voltage profile and to keep it above thermal limits, and improve the flow of transmission lines while maintaining a marginally affected average device generation cost in comparison to its base case of a single object. The best size and place of TCSC devices were considered to solve technical-economic problems to reduce the fuel cost of generation units as well as the costs of the setup of TCSC devices by the optimal power flow (OPF) system. The GSA algorithms are tested on three 9, and 30 bus test systems to demonstrate the high capacity to overcome a suggested multi-objection problem. The standard operating conditions and emergencies of four case studies are included for each test device. The results from the proposed GSA approach suggest that the GSA offers a high-quality and effective solution and the results are produced to increase the efficiency of the system. |
| ***Keywords:***  Gravitational Search algorithm The thyristor-controlled series compensator  Optimal power flow  Multi-objective |
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1. **INTRODUCTION**

Currently, power systems face significant demand and marketing challenges. The overloading of the liner, The voltage of the buses is decreased, and when power systems malfunction, the reactive power from the system is not provided by the generation units. Therefore, three methods, such as increasing power generation, can be used to solve the problem, namely to create new lines and to introduce adaptive alternative current transmission systems (FACTS). New electrical generating units cannot be built to increase power generation and to install new transmission lines because of economic and environmental restrictions. Therefore, for the economic and secure operation,

It's really important to control the optimal reactive flow, Improving the performance of the system, mitigating power losses, reducing reactive power generation, and increasing the voltage profile and reactive power reserve [1-2]. TCSC is well-known among FACTS types for its quick response and lower cost. The decision to make the best use of TCSC equipment is therefore a direct result to boost the performance of current power systems [3-4]. Heuristic algorithms can optimize various convex and non-convex problems by generating random numbers without considering the complexity and constraints of the problem [5-6]. Thus, various intelligent techniques, including seeker optimization algorithm [7], differential evolution [4,8], Jaya algorithm [9], gravitational search algorithm [10], particle swarm optimization [11-12], bacteria foraging algorithm [13], exchange market algorithm [14], Firefly algorithm [15], shuffle frog leaping algorithm [16] and harmony search algorithm [17] have been proposed to successfully solve OPF problem.

one of the most powerful optimization algorithms is a gravitational search algorithm. In solving various optimization problems, GSA has checked high-quality performance. Therefore, recently GSA is used in many papers for solving various complex and nonconvex problems [18-19]. GSA algorithm is categorized as a physics-based algorithm depending on the law of gravity and mass interactions. The operating principle of the GSA method is based on the law of Newtonian gravity and the laws of motion [20]. In this paper, For the effective technological and economic operation of the power grid, the GSA approach is used to assign TCSC devices to transmission networks, formulated as a non-linear problem of optimization, with constraints on equality and inequality. This paper discusses the multi-objective function of reducing active/reactive losses of electric power, enhanced voltage profiles, decreased costs, and the number of TCSC units both during nominal as well as during contingency operations.

On the standard IEEE 9-bus, 30-bus, and 57-bus test systems the performances of the proposed approach are tested. The results have been compared with other approaches which indicate that the proposed approach offers very important results in solving this problem. Section 2 describes Thyristor-controlled compensator series modeling into the power grid. The other text is designed accordingly. Section 3 describes the problem of mathematical terminology and Section 4 introduces the suggested GSA algorithm. The effects of the simulation are compared to other approaches in Section 5. Section 6 also includes an illustration of the conclusion of the application of the proposed GSA process.

1. **THYRISTOR-CONTROLLED SERIES COMPENSATOR**

TCSC has numerous advantages, including low cost, fast sensitivity, and excellent performance. It is the most regular set of FACTS. The transmission line reactions in the TCSC mode which be increased or decreased by two functioning modes that are capacitive and inductive. Most articles spoke about the simulation of TCSC. The TCSC models are named in [21-22] three parallel switches. Only one element is linked to avoiding resonance in this model, while the other two elements and TCSC reactance value are disconnected () is considered as a function of transmission-line reactance ( ). To avoid overcompensation of the transmission line, the value of can be calculated by Eq. (1):

(1)

In references [23-24], the value of XTCSC varies from one application to another and is constrained by Eq. (2) and (3). Figure 1 shows the transmission-line model of the TCSC.

(2)

(3)

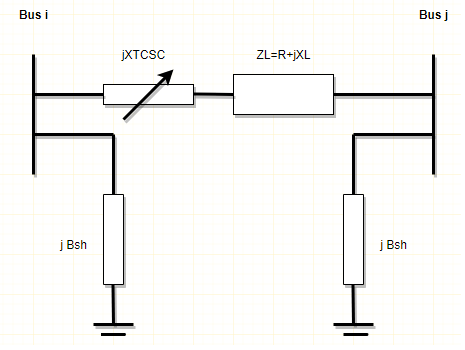


Figure 1. TCSC modeling in the electricity transmission line

The position of TCSC devices is limited. In all transmission lines, TCSC devices are available except lines that do not have to be linked to the transformers between the two generation buses and should not be mounted in the Light Loading systems [25].

1. **PROBLEM FORMULATION**

In this article, the optimum values for the problem are considered to be a multi-objective OPF issue considering the existence of TCSC devices. This study aims to achieve various economic and technical advantages. There are some control variables for OPF considering the TCSC device. Controls considered include active unit output, locations, and size of TCSC units, GSA, and weighting factors. The following are included: (). Usable generation costs for electricity, operating investment, loss of active and reactive power, voltage profile, and several TCSCs are the objective parameters of the proposed problem. In the problem that was suggested. The goal role is presented as follows:

(4)

where, displays weighting considerations for weighted total objectives, is the generated power in (MW) at bus and is the number of TCSC units. Eq. (5) is used to compute the total fuel cost of generation units:

(5)

Where is the number of generation unit, , and shows cost coefficients of generator. One of Eq's objectives. (4) to reduce the loss of active and reactive power that is a function of the magnitude of the bus's voltage ( ), mutual conductance and susceptance ( ), and the phase difference ( ) for the total number of buses between bus voltages and :

(6)

(7)

Another objective in Eq. (4), is to improve the profile of voltage by reducing voltage deviations in buses by (8):

(8)

Where is the voltage in bus and is the reference voltage. Due to the high cost of TCSC devices inside the power system, this cost in the objective role should be minimized. The cost can be calculated according to Eq. (9-10) [29]:

(9)

(10)

The here are TCSC's accumulated costs in line , is the operating cost of each TCSC unit in $/MVAr, and is the TCSC installed capacity in MVAr (mega volt-amperes reactive), which can be determined by Eq (11) :

(11)

Where is a nominal transmission line current through which TCSC is integrated. It is preferred to reduce the number of TCSC units ) in objective function due to improved system output by a few FACTS instruments for monitoring and repair purposes. The main function of the objective in Eq. 4 The power system subject to equity and inequality limits as follows:

**3.1. Active/reactive balance of total power**

To balance the supply and demand, The constraint of power equality should be satisfied. The total active/reactive power generated should be equal to the total system demand plus power losses to be investigated by Eq. (12–13):

(12)

(13)

Where and are active and reactive power generation in unit , respectively. and are active/ reactive power load at bus .

**3.2. Active/reactive power balance at each bus**

Active and reactive power balance at each bus can be modeled as Eq. (14-15):

(14)

(15)

Where and The flow of active and reactive power on bus lines ), respectively.

**3.3. Power inequality constraints and voltage generation limits**

The lower and upper limits should be reduced by the generator voltage, active and reactive output:

(16)

(17)

(18)

Here , , and are Active and reactive maximum and minimum power generation at bus , respectively. Also and are upper and lower limit of generation voltage at bus .

**3.4. Security constraints**

In this situation, the loading on the transmission line ( should maintain within the limits permitted for this issue and the load-bus voltages ( ) should also be limited by the lower and upper limits in agreement with Eqs. (19-20):

(19)

(20)

Where and are the maximum and minimum transmission line loading at line . and are maximum and minimum voltage values on loading bus .

1. **ALGORITHM FOR GRAVITATIONAL SEARCH**

The GSA is one of Rashedi et al [20]'s strong stochastic search algorithms. A break-through optimization approach, this optimization algorithm based on the Newtonian law of gravity and mass interaction is very powerful. At the GSA, when artifacts may be calculated by their masses and efficiency, agents are taken into consideration. All of these things pull together by the force of gravity and all of them will allow the objects to move globally toward them with heavier masses. Each object is a solution to (or part of a solution to the problem in this algorithm). Since heavier masses have higher fitness values, they are the optimal solution and pass slower than insufficient solutions. In the proposed algorithm, each mass has four particulars: its position, it is active gravitational mass (), its inertial mass ( ) and passive gravitational mass ( ). In solving optimization problems with GSA in the beginning the position of a system is described with (dimension of the search space) masses.

(21)

where n is the problem's space dimension, and indicates the agent's location in the dimension. Initially, the agents of the Newton gravity solution are described alone, and at the time t is stated according to Eq. (22), a gravitational force from mass j works mass

(22)

where is the mass of the object , is the mass of the object , ε a small constant, the gravitational constant at time and is the Euclidian distance between and objects defined as follows:

(23)

The total force acting on the the agent is calculated computed by Eq. (24):

(24)

where rand is a random number and is the set of first agents with the biggest mass and the best fitness value. Based on Newton gravitation theory to find the acceleration of the agent, at time in the dimension, the law of motion is used directly to calculate. Based on the above, the law of motion is proportional to the force acting on it and the inverse of the agent's mass. can be calculated according to Eq. (25):

(25)

The searching approach to this principle can also be used to locate an agent's next location and next velocity according to Eq. (26-27) :

(26)

(27)

where and are the position and velocity of an agent at time in dimension, respectively. is a random number between 0 and 1. is a gravitational constant and is used to control the search accuracy and is initialized randomly at the starting and will decrease with increasing iteration number of programs.

(28)

The α is a user-specified constant, the cumulative number of iterations, and is the individual iteration. The weight is measured using a fitness evaluation. The heavy mass travels slower with a higher force pull, depending on Newton's gravity and motion law. The masses are modified as follows in the suggested algorithm:

(29)

(30)

(31)

Where shows the fitness value of the agent at time , and in each population, the and Shows the most efficient and weakest fitness agent, based on Eq (32-33) was determined for the problem of minimum fitness:

(32)

(33)

Any agent in the search field is located at a certain point that specifies a solution to the problem, in resolving the optimization problem with the proposed algorithm at the start of the program. Afterward, after Eq. (26) and (27), upgrade the agents and compute their following locations. Other algorithm parameters such as G, M masses, and a velocity are evaluated employing eq. 28, 29, 30, 31, and (25), respectively, and are updated in each iteration of the program. The OPF problem optimization is accomplished using the GSA by taking the following steps:

Step 1. Generate initial population Selecting initial values and.

Step 2. Calculate for the problem the importance of each agent's fitness function.

Step 3. Update

Step 4. Total force measurement in various ways.

Step 5. Calculation of acceleration and velocity.

Step 6. Updating agents’ position and checking problem limitation.

Step 7. Jumping to step 2 until the stop criteria are reached (that is the number of program iteration).

Step 8. Stop.

1. **CASE STUDIES**

In this paper proposed GSA algorithm is implemented to solve the proposed problem. To test the efficiency and robustness of the proposed GSA method it is tested on standard IEEE 9, and 30 bus test systems. All test system detail, such as data on the line, bus and generator, and maximum and minimum control variables limits, is available at [26-27]. is set using in Eq. (28), where is set to 100, α is set to 10 and is the total number of iterations. The maximum iteration number is limited to 50 for all case studies to reach an optimal solution. The program was written in MATLAB 2016 and applied on a 2.63 GHz Pentium IV personal computer. Fifty test runs were done in each case using the GSA approach to resolve the problem. The weighting factors for the The objective function which reveals the relative significance of the goals is explained in [7].in solving each case study, To signify the contribution of this analysis the following four studies are used:

1. Case with normal operation through original data systems

2. case with critical line outage of the system

3. case with Increase of load demand at all buses or a single bus

4. case with percentage outage of generation at a specific generation unit.

**5.1. case 1 with the 9-bus test system**

The first network of IEEE9-bus power unit comprising 9 buses; bus 1 is called a slack bus; bus 1 is considered a voltage-controlled bus and bus 2 and 3 and other buses 10 are considered to be load buses. The following four experiments will underline the contribution of these study studies. Table 1 displays GSA-based findings for the IEEE 9-bus system relative to TCSC approaches for DE[4] and APSOA[7]. Table 1 shows a 26.51% decline in the active power loss from 0.04719 to 0.0352, a 0.5% decrease in reaction power losses from 0.04112 to 0.04090, and a 0.13% inducement in the cost of generating power when active and reactive power is produced by the results obtained.

As seen in the table Table 1. The results obtained by the GSA method for cases 2, 3, and 4 are compared to the outcomes of the APSOA procedure in Table 2. In case 2, line 9 is critical and is turned off. its results are highly active and reactive power losses and violate voltages compared to case 1.

As shown by table 2 where the Active Power losses are used by TCSC in the GSA system, The active power losses decreased from 0.0945 to 0.0753 by 20.31  %, while a reactive power loss was reduced from 0.765 to 0.4032 by 47.29 %. The obtained active/reactive power losses in the presence of TCSC for the APSOA method are 0.0748 and 0.5551 respectively.

The comparison results of GSA and APSOA show that the GSA method could find minimum reactive power (by 26.8%) where the APSOA method could find minimum active power losses (by 0.6%). The obtained results of solving case 3 by the GSA method in comparison APSOA method are present in Table 2.

In case 3 the load is equal to 60 % for all busses and as a result, The system improves active/reactive power loss and voltage deviation and decreases active/reactive power losses to a reasonable amount relative to case 1 with the TCSC install in line 1 (normal operation case). The active power losses decreased from 0.0892 to 0.0852 by 4 % after installation of TCSC and reactive power losses decreased by 34.14 % between 1.3553 and 0.8925 and the voltage deviation decreased to 0. As seen from Table 2, the obtained active/reactive power losses by the APSOA method after insertion of TCSC are 0.0882 and 1.1014 which shows the high ability of the proposed GSA method over the APSOA. Furthermore, the obtained TCSC cost by the GSA method is lower than the APSOA method.

In case 4 line 9, the generator outage at bus 2 is off in amount to 66,667 %. The results obtained from the GSA method suggest in line 8 that the TCSC is the best position. In this state, the active/reactive power losses have decreased respectively by 26.39% and 33.16%. In comparison, in the case of TCSC and without its inclusion in case 4, 11 GSA effects are compared to the APSOA method [7]. The results suggest that the GSA strategy offers better results on TCSC active/reactive power losses and costs.

Table 1. Comparison of GSA results with DE and APSOA methods for IEEE 9-bus system (case 1)

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Method  Optimal value | Without TCSC | | | With TCSC | | |
| DE [4] | APSOA [7] | GSA | DE [4] | APSOA [7] | GSA |
| V2(PU) | 1 | 1 | 1 | 1.0211 | 1 | 1 |
| V3(PU) | 1 | 1 | 1 | 1.0227 | 1 | 1 |
| QG1(PU) | 0.2407 | -0.0616 | 0.2490 | 0.2219 | 0.2134 | 0.2504 |
| QG2(PU) | 0.1446 | 0.3229 | 0.1668 | 0.0984 | 0.0765 | 0.1630 |
| QG3(PU) | -0.0365 | -0.0594 | -0.1143 | -0.0432 | -0.0508 | -0.1180 |
| TCSC Location | … | … | … | L7 | L2 | L2 |
| Gen. Cost($/h) | … | 5316.1 | 5318.33 | … | 5375.1 | 5311.39 |
| TCSC Cost($/h) | … | … | … | 1.184⨯106 | 5.316⨯104 | 4.688⨯103 |
| X Line (PU) | 0.0625 | 0.092 | 0.902 | 0.03125 | 0.0852 | 0.0736 |
| Compensation level (%) | … | … | … | 50 | 8 | 25 |
| P losses (PU) | 0.0494 | 0.0479 | 0.04719 | 0.04093 | 0.036598 | 0.0352 |
| Q losses (PU) | 0.5122 | 0.4104 | 0.4112 | 0.4455 | 0.4108 | 0.4090 |
| V.D (PU) | 0.0168 | 0.0162 | 0.006 | 0 | 0 | 0 |

Table 2. An optimal solution to GSA for 1-4 as compared to the APSOA.

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Method  Optimal value | Case1 | | | | Case2 | | | | Case3 | | | | Case4 | | | |
| Without TCSC | | With TCSC | | Without TCSC | | With TCSC | | Without TCSC | | With TCSC | | Without TCSC | | With TCSC | |
| APSOA | GSA | APSOA | GSA | APSOA | GSA | APSOA | GSA | APSOA | GSA | APSOA | GSA | APSOA | GSA | APSOA | GSA |
| QG1(PU) | -0.0616 | 0.2490 | 0.2134 | 0.2504 | 0.0361 | 0.0399 | 0.0234 | 0.2532 | 1.089 | 0.8920 | 0.781 | 0.8788 | 0.1482 | 0.1990 | 0.1023 | 0.1132 |
| QG2(PU) | 0.3229 | 0.1668 | 0.0765 | 0.1630 | 0.618 | 0.6938 | 0.4781 | 0.3781 | 0.542 | 0.4862 | 0.585 | 0.357 | 0.902 | 0.8192 | 0.59576 | 0.6426 |
| QG3(PU) | -0.594 | -0.1143 | -0.0508 | -0.1180 | 0.1464 | 0.2458 | 0.0881 | 0.0553 | 0.354 | 0.2622 | 0.349 | 0.1370 | 0.359 | 0.4335 | 0.2217 | 0.4333 |
| TCSC Location | … | … | L2 | L2 | … | … | L8 | L8 | … | … | L2 | L1 | … | … | L8 | L8 |
| Line Reactance (PU) | 0.092 | 0.092 | 0.0852 | 0.0736 | 0.161 | 0.161 | 0.081 | 0.0322 | 0.0625 | 0.0576 | 0.09375 | 0.0115 | 0.161 | 0.161 | 0.0805 | 0.0722 |
| Compensation level (%) | … | … | 8 | 25 | … | … | 49.69 | 80 | … | … | 50 | 80 | … | … | 50 | 55 |
| P Losses (PU) | 0.0479 | 0.04719 | 0.0366 | 0.0352 | 0.08764 | 0.0945 | 0.0748 | 0.0753 | 0.09248 | 0.0892 | 0.0882 | 0.0858 | 0.1767 | 0.1883 | 0.1378 | 0.1386 |
| Q Losses (PU) | 0.4104 | 0.4112 | 0.4108 | 0.4090 | 0.74 | 0.765 | 0.5551 | 0.4032 | 1.3553 | 1.1109 | 1.1014 | 0.8925 | 1.3066 | 1.2268 | 0.8636 | 0.82 |
| Total V. D | 0.0162 | 0.006 | 0.00 | 0.00 | 0.0669 | 0.031 | 0.0038 | 0.008 | 0.005 | 0.006 | 0.00 | 0.00 | 0.1224 | 0.03 | 0.0245 | 0.008 |
| TCSC Cost | … | … | 5.316⨯105 | 4.688⨯103 | … | … | 1.031⨯105 | 1.139⨯104 | … | … | 1.083⨯105 | 1.483⨯104 | … | … | 1.162⨯105 | 1.139⨯105 |

**5.2. case 2 with a 30-bus test system**

The second research system consists of a 30-bus, six-generation bus system, the IEEE 30-bus system. Bus 1 is slack, while the voltage controlling buses are buses 2, 13, 22, 23, and 27. There are 41 lines without transformers. The results of the IEEE 30 bus system resolution with and without TSC are presented in Table 3 compared to the GSA methods of DE[4], and APSOA[7].

The results achieved by the GSA procedure are better than the APSOA and DE methods shown in Table 3, Where the GSA system for the TCSC systems could minimize active power losses by 13.65% from 0.0249 to 0.0215, reactive power loss losses by 12.94% could be minimized from 0.0811 to 13 0.0706.The obtained active and reactive power losses in the presence of TCSC for APSOA and DE methods more than GSA. The operation cost of TCSC by the GSA method is less than the DE method while this value is more than the APSOA algorithm.

Compared with base case 1 for GAS and AP SOA processes, Table 4 summarizes cases 2, 3, and 4. In case 2, a critical line and a service outage is line 36. Its consequences are high losses of active/reactive power and the elimination of line 29 overflow under the full limit shown in Figure 2.However, after inserting the TCSC unit's power flow in line 29 is decreased from 30.09 MW to 19.2 MW under the thermal limit of 20 MW. As seen from Table 4 when TCSC is used by the GSA method, The losses of active or reactive power decreased respectively from 0.02567, 0.08558 to 0.02553, 0.08483. here lines 40, 26 are selected for installing TCSC units. The comparison results of GSA and APSOA for case 2 shows that the GSA method could find better active/ reactive power losses and TCSC operation cost over the APSOA [7] method.

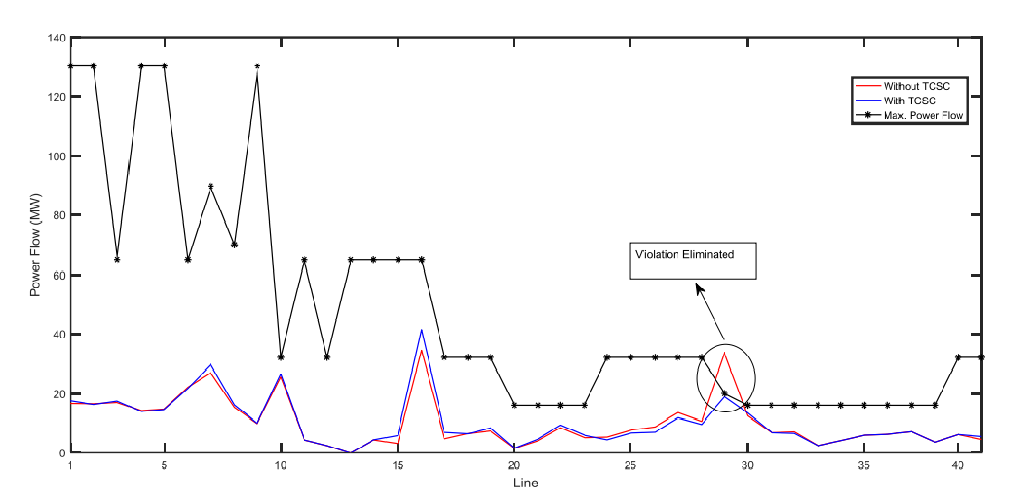


Figure 2. Enhancement of power flow with GSA Case 2.

In the case of 3.a, Busload 8 increases by 50%, resulting in higher active/reactive power losses and voltage deviation, and a power flow risk on line 29. However, the power flow from the TCSC unit is limited by the thermal limit of 20 MW, after integrating it into line 29 from 24.03 MW to 19.89. The active/reactive power losses are reduced from 0.03473, 0.12358 to 0.03017, 0.1004, respectively, in Table 4 following the implementation of the TCSC unit in case 3.a. here lines 40, 26 are selected for installing TCSC units. The compared results between GSA and APSOA method in Table 4 shows the proposed algorithm could find better active/reactive and TCSC cost over the APSOA method.

In case 3.b a new load (11MW+J11MVAr) is applied at bus 11 This does not provide good system performance as compared to Case 1, as shown in Table 4 and also overflowed in line 29. The active/reactive power losses and voltage deviation decreased by 0.0272, 0.1115, and 0.019, respectively, to 0.0268, 0.10745, and 0.001 with the addition of TCSC in lines 24,28 and 40.As seen from Table 4 after inserting TCSC units obtained active/reactive, voltage deviation and TCSC cost by proposed GSA algorithm are better than APSOA [7] algorithm.

In case 4, generator Partial Outage 2 (at bus 2) by 40% is applied. As seen from Table 4 it causes an increase in the active/reactive power system and makes overflow inline 29. However, by inserting TCSC units in the lines of 16,17, and 36 the active/reactive power losses and voltage deviation reduced successfully from 0.02531, 0.08710, and 0.01 to 0.0228, 0.07214, and 0 respectively.

Table 3. GSA results compared with the IEEE 30-bus system DE and APSOA methods (case 1).

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Method  Optimal value | Without TCSC | | | With TCSC | | |
| DE [4] | APSOA [7] | GSA | DE [4] | APSOA [7] | GSA |
| QG1(PU) | -0.01 | -0.001 | 0.0374 | 0.1129 | 0.0189 | 0.0232 |
| QG2(PU) | 0.32 | 0.335 | 0.2859 | 0.1096 | 0.3098 | 0.2211 |
| QG22(PU) | 0.3957 | 0.344 | 0.3662 | 0.2889 | 0.3417 | 0.3269 |
| QG27(PU) | 0.1054 | 0.091 | 0.0882 | 0.1644 | 0.0994 | 0.2081 |
| QG23(PU) | 0.0795 | 0.092 | 0.0887 | 0.0873 | 0.0908 | 0.08659 |
| QG13(PU) | 0.1135 | 0.129 | 0.1289 | 0.2355 | 0.1262 | 0.1179 |
| TCSC Location | … | … | … | 16,29 | 1,17 | 31,36 |
| X Line (PU) | 0.14,0.02 | 0.07,0.26 | 0.4,0.18 | 0.7,0.01 | 0.0803,0.3027 | 0.021,0.08 |
| Compensation level (%) | … | … | … | 50,50 | 17.16,16.42 | 50,55 |
| TCSC Cost($/h) | … | … | … | 2.055⨯105 | 2.87⨯103 | 4.124⨯103 |
| P losses (PU) | 0.0899 | 0.076 | 0.0811 | 0.0802 | 0.0727 | 0.0706 |
| Q losses (PU) | 0.0245 | 0.023 | 0.02490 | 0.0225 | 0.02162 | 0.0215 |
| V.D (PU) | 0.0226 | 0 | 0 | 0.0186 | 0 | 0 |

Table 4. Obtained results of GSA for cases 1-4 compared to APSOA (30-bus system).

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Cases** | **Case1** | | | | **Case2** | | | | **Case3.a** | | | | **Case3.b** | | | | **Case4** | | | |
| **Method** | **Without TCSC** | | **With TCSC** | | **Without TCSC** | | **With TCSC** | | **Without TCSC** | | **With TCSC** | | **Without TCSC** | | **With TCSC** | | **Without TCSC** | | **With TCSC** | |
| **APSOA** | **GSA** | **APSOA** | **GSA** | **APSOA** | **GSA** | **APSOA** | **GSA** | **APSOA** | **GSA** | **APSOA** | **GSA** | **APSOA** | **GSA** | **APSOA** | **GSA** | **APSOA** | **GSA** | **APSOA** | **GSA** |
| **QG1(PU)** | **-0.014** | **0.0374** | **0.0189** | **0.0232** | **-0.0644** | **0.0174** | **-0.0628** | **0.0172** | **-0.06618** | **-0.02665** | **-0.0301** | **-0.04685** | **-0.05741** | **-0.04633** | **-0.05798** | **-0.0497** | **-0.01374** | **-0.09681** | **-0.09776** | **-0.1183** |
| **QG2(PU)** | **0.3347** | **0.2859** | **0.3098** | **0.2211** | **0.439** | **0.3374** | **0.3763** | **0.3371** | **0.49175** | **0.4467** | **0.41608** | **0.35401** | **0.42255** | **0.4308** | **0.38383** | **0.4190** | **0.42432** | **0.4308** | **0.3974** | **0.34122** |
| **QG22(PU)** | **0.3437** | **0.3662** | **0.3417** | **0.3269** | **0.3624** | **0.3346** | **0.3531** | **0.3351** | **0.39533** | **0.4411** | **0.34401** | **0.39797** | **0.42843** | **0.4600** | **0.38285** | **0.4817** | **0.33054** | **0.3716** | **0.30095** | **0.32328** |
| **QG27(PU)** | **0.0911** | **0.0882** | **0.0994** | **0.2081** | **0.0204** | **0.0701** | **0.01609** | **0.0701** | **0.11886** | **0.0966** | **0.10561** | **0.25974** | **0.09979** | **0.0940** | **0.0972** | **0.0936** | **0.09326** | **0.1002** | **0.08745** | **0.2498** |
| **QG23(PU)** | **0.0924** | **0.0887** | **0.0908** | **0.0865** | **0.1083** | **0.1215** | **0.081924** | **0.1213** | **0.11208** | **0.1138** | **0.06081** | **0.104763** | **0.10309** | **0.0638** | **0.03843** | **0.0597** | **0.05765** | **0.07301** | **0.02505** | **0.05372** |
| **QG13(PU)** | **0.01296** | **0.1289** | **0.1262** | **0.1179** | **0.1356** | **0.1193** | **0.11899** | **0.1189** | **0.13533** | **0.01277** | **0.2697** | **0.1091** | **0.13226** | **0.1333** | **0.2698** | **0.1273** | **0.23677** | **0.1222** | **0.26055** | **0.14211** |
| **TCSC Location** | **…** | **…** | **1,17** | **31,36** | **…** | **…** | **1,17** | **40,26** | **…** | **…** | **1,16,17** | **26,34,36** | **…** | **…** | **1,16,17** | **24,28,40** | **…** | **…** | **1,16,17** | **36,16,17** |
| **Line Reactance (PU)** | **0.07,0.26** | **0.4,0.18** | **0.0803,0.3027** | **0.021,0.08** | **0.07,0.26** | **0.2,0.08** | **0.0803,0.3027** | **0.08,0.07** | **0.07,0.26,0.14** | **0.08,0.38,0.4** | **0.0844,0.3444,0.07** | **0.0187,0.2890,0.2390** | **0.07,0.26,0.14** | **0.07,0.15,0.2** | **0.0844,0.3444,0.07** | **0.0823,0.0474,0.0474** | **0.07,0.26,0.14** | **0.4,0.14,0.4** | **0.0844,0.3444,0.07** | **0.05326,0.07191** |
| **Compensation level (%)** | **…** | **…** | **17.16,14.42** | **50,55** | **…** | **…** | **17.16,16.42** | **60,12.5** | **…** | **…** | **20.57,32.46,50** | **76.62,23.94,40.25** | **…** | **…** | **2.57,32.46,50** | **17.5,68.5,76.3** | **…** | **…** | **20.57,32.46,50** | **86.68,48.63,82.02** |
| **TCSC Cost** | **…** | **…** | **2.869⨯103** | **4.124⨯103** | **…** | **…** | **4.404⨯104** | **2.78⨯103** | **…** | **…** | **6.385⨯104** | **6.329⨯103** | **…** | **…** | **7.9812⨯104** | **5.6⨯103** | **…** | **…** | **4.584⨯104** | **1.0627⨯104** |
| **P Losses (PU)** | **0.02293** | **0.02490** | **0.02162** | **0.0215** | **0.02978** | **0.02567** | **0.0255** | **0.02553** | **0.0355** | **0.03473** | **0.0303** | **0.03017** | **0.0292** | **0275** | **0.0269** | **0.0268** | **0.02895** | **0.02531** | **0.025** | **0.0228** |
| **Q Losses (PU)** | **0.076** | **0.08111** | **0.0727** | **0.0706** | **0.0874** | **0.08558** | **0.0762** | **0.08483** | **0.1212** | **0.12358** | **0.1008** | **0.1004** | **0.1039** | **0.1115** | **0.0896** | **0.10745** | **0.091** | **0.08710** | **0.0774** | **0.07214** |
| **Total V. D** | **0** | **0** | **0** | **0** | **0** | **0.01** | **0** | **0** | **0.006** | **0.019** | **0.002** | **0.001** | **0.0079** | **0.019** | **0.0057** | **0.001** | **0** | **0.01** | **0** | **0** |

1. **CONCLUSION**

In this article, GSA algorithms are used to resolve optimum power flow issues with TCSC devices in 9, and 30 bus testing systems. The goal of resolving the multi-objective problem was to reduce the active and reactive loss of power and voltage deviations, including the TCSC costs and numbers of TCSC devices, in normal and emergent conditions. The results achieved with the proposed GSA algorithm are compared with numerous methods such as DE and APSOA... The GSA system proposed achieved optimum active/reactive power loss reduction with low generation costs and the expense of TCSC. The results also show that the voltage profile has improved for all case studies by further decreasing the voltage deviation. A remarkable level of active/ reactive power loss reduction, generation, and cost of TCSC was achieved through the proposed GSA process, especially in comparison to others.

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