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PERFORMANCE OF HIGH VOLTAGE TRANSMISSION LINE BASED ON THYRISTOR-CONTROL SERIES COMPENSATOR

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Abstract: This research aims to improve the steady-state performance of high-voltage power transmission lines, which is a significant challenge for the power system grid's safe and reliable operation. The research adopted Flexible Alternating Current Transmission System for electronic devices. The flexible alternating current transmission system technology will be used in this specific work as Thyristor-Controlled Series Compensators. Thyristor-controlled series compensator devices increase transmission systems' capacity and enhance the voltage profile by regulating transmission line reactance. Gravitational Search Algorithm is a meta-heuristic approach applied to find the optimum size and optimal location of thyristor-controlled series compensators in power systems. The gravitational search algorithm is used to solve the multi-objective and integrated optimum power flow problem in reactive energy management during normal and contingency operations. The results showed reduced voltage deviation, reduced active/reactive power losses, and increased transmission line reserves above thermal limits, in addition to reducing the installed cost and number of thyristor series compensators devices. The simulation part was created with MATLAB programming language and validated with MATPOWER software. Applied to IEEE 30 bus system and 400kV super high voltage grid system.

Keywords: *Thyristor-Controlled Series Compensators, multi-target Optimal Power Flow, Gravitational Search Algorithm, Flexible AC Transmission System*

1. Introduction

The control of transmission lines in the deregulated power sector has been a significant bottleneck in electricity transmission. The transmission network is designed to pool powerplants and load centers to distribute loads at sufficient reliability and performance efficiently. Installing a new power transmission line system is expensive and time-consuming, and has a damaging effect on our environment; thus, it is important to use current transmission infrastructure. Especially in Iraq, from the last few decades until now[1].

The flexible Alternate Current Transmission System (FACTS) is a modern technological solution. FACTS technologies will enhance the flexibility of power systems to improve the control, reliability, and power transmission capacity of the AC system[2]. Based on technical features, the two generations of FACTS controllers; The first group of FACTS, uses thyristor switches to control the reactor and capacitor banks' ON and OFF times. The second group uses self-commutated AC-converters to generate reactive power internally without reactor or capacitor banks for the transmission line compensation[٣] .

Thyristor-Controlled Series Compensators (TCSC) is classified from first-generation, which

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is proposed in this research. The TCSC devices can be as a controlling device in load flows in the HVAC transmission lines for the following benefits: TCSC regulation of real and reactive power flows, increasing the transmission capacity of the transmitting system through the reduction of the transfer reactants between buses, reducing total system losses of active and reactive power. TCSC has many benefits, including high efficiency, quick responses, and lowest prices, including FACTS devices, among the best FACTS types [4].

In recent years, optimization methods have constantly been established due to their high impacts and accomplishments, which continue to offer researchers, especially in designing and economics[5]. Thus, various intelligent techniques, including Differential Evolution[6], Jaya Algorithm[7], Particle Swarm Optimization [8], Bacteria Foraging Algorithm[9], Exchange Market Algorithm[10], Harmony Search Algorithm [11], and Seeker Optimization Algorithm[12], have been proposed to solve Optimal Power Flow(OPF) problem successfully. The gravitational search algorithm is one of the most strongly optimized algorithms (GSA). In solving various optimization problems, GSA has checked the high-quality performance during normal and contingency operations. GSA for solving different complex and nonconvex problems is included in several papers currently[١٣-١٤] .

The Optimal Power Flow Framework (OPF) defines the optimum location and size of TCSC devices, which solves technical challenges to minimize the cost of installing TCSC devices. On transmission networking, the GSA technique is used to locate the TCSC devices, As a nonlinear optimization problem with equality constraints and inequalities, it was conceived. To solve this problem, the GSA can be used of multi-target OPF in reactive power management. TCSC systems are optimally located to increase the transmission capacity, improve the voltage profile and raise reserve over thermal limits in the transmission line.

This paper discusses the multi-target function of reducing real and reactive losses of electric power, decreasing the voltage deviation, minimizing costs, and number of TCSC units during normal and contingency operations. Results showed that there is a good enhancement in the power flow of the loaded HV transmission lines, the loss of active and reactive power, and the load capacity when this TCSC is integrated into the IEEE 30 bus test system and 400 kV Iraqi Super High Voltage (SHV) gird system. The results of the simulation are consistent with previous research techniques to prove the performance of the GSA. Section 2 describes Thyristor-controlled series compensator modelling into the power grid. Section 3 defines 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 inference of the application of the selected GSA process.

2. Thyristor-Controlled Series Compensator

In the 1990s Kayenta substation between Glen Canyon and Shiprock (Arizona), the first TCSC installation (manufacturer called Advanced Series Capacitor) was used to increase power transmission capability[15]. The TCSC contains three main components: capacitor bank C, bypass inductor L, and bidirectional thyristors T1 and T2. The capacitor is directly inserted in the transmission lines and is mounted directly in parallel with the capacitor in the thyristor-controlled inductor. Therefore, no interface equipment is needed for high voltage transformers. This is much cheaper for TCSC than other competing FACT technologies[16]. With the thyristor firing control, the sensation part of the TCSC can be easily adjusted. There are several TCSC models, including the dynamic and steady-state models. For that, TCSC allows faster changes of transmission line impedance [17]. For static modeling, As an inductor or capacitor, TCSC can be used. Consequently, the transmission line reactance is limited in percentage. The reactance of TCSC (X_{TCSC}) is modeled as the transmission-line reaction function ($X_{T.L}$). The practical constraints of the required value to avoid overcompensation of transmission line can be calculated[12]:

$$-\ 0.8\, x_{T\cdot L} \leq\ x_{TCSC} \leq 0.2 x_{T\cdot L} \tag{1}$$

Figure (1) the equivalent circuit for the static modeling of the TCSC connected in series with transmission lines, X_{TCSC} It can be regulated that values are positive or negative, depending on the target and limitations under the permissible limit. There are several constraints where TCSC should be located; as selected TCSC devices, every transmission line may be placed, except for any two-generation bus connections. Furthermore, the transformers are not in series by the TCSCs. TCSC should not be installed on light loading lines as described in [16]. Besides, the total number of TCSCs in this research is optimized in severe contingencies for economic conditions. The model is used to eliminate transmission line overcompensation.

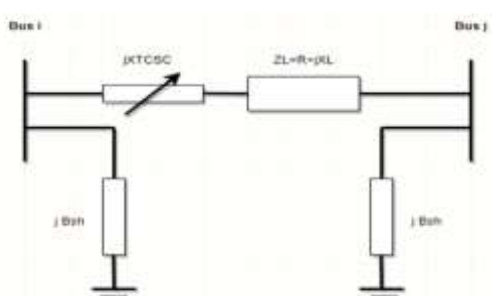

Figure 1. The description of a line between two buses with TCSC[12].

3. Problem Formulation

The proposed GSA is used to solve the issue of multi-target OPF incorporated into reactive power management. GSA technique can be used to find solutions for the fitness function of the proposed cases. By finding the best locations for TCSC devices and the level of compensation (sizing) to achieve the minimum values for the five proposed objectives.

$$Minnimize(Obj)\ = w_1 \times P_{losses} + w_2 \times |Q_{losses}| + w_3 \times VD + w_4 \times cost + w_5 \times NT \tag{2}$$

where, $w_1, w_2, \dots, w_5$ will be varied according to the priority of each objective function to satisfy the proposed cases. The weighting factors w_i for the i^{th} objective function demonstrating the relative value of the m targets. Where:

$$0 \leq w_i \leq 1, \sum_{i=1}^{m} \mathrm{w_i} = 1 \tag{3}$$

One of the goals of Equation (2) reduces real and reactive losses of power that are a function of the magnitude of the bus's voltage (V_i , V_j), mutual conductance and substance (G_{ij} , B_{ij}), and the phase difference (δ_{ij}) between the voltages of the buses i and j for a whole number of buses :

$$P_{losses}\ = \sum\nolimits_{i,j\in NB} G_{ij}(V_i^2 + V_j^2 - 2V_iV_j \cos\delta_{ij}) \tag{4}$$

$$Q_{losses}\ = \sum\nolimits_{i,j\in NB} B_{ij}(V_i^2 + V_j^2 - 2V_iV_j\, sin\,\delta_{ij}) \tag{5}$$

Another objective in Equation (2) is to improve the profile of voltage by reducing voltage deviations in buses by (6):

$$VD = \sum\nolimits_{i=1}^{NB} |V_i - V_{ref}| \tag{6}$$

Where V_i is the voltage in bus i and V_{ref} It is the reference voltage. Because TCSC devices are costly in the power grid, this cost in the objective role should be minimized. The cost can be calculated according to Equations (7-8) [18]:

$$C_{TCSC} = 0.0015 \times S_{TCSC}^2 - 0.713 \times S_{TCSC} + 153.75 \quad (7)$$

$$Cost = C_{TCSC} \times S_{TCSC} \quad (8)$$

The $costs$ here are TCSC's accumulated costs in line k, C_{TCSC} is the running cost of each TCSC unit in \$/MVAr, and S_{TCSC} is the TCSC capacity that has been installed in MVAr (Mega Volt-Amperes reactive), which can be determined by Equation (9):

$$S_{TCSC} = I_{Lmax}^2 \times x_{TCSC} \quad (9)$$

Where I_{Lmax} It is a nominal transmission line current through which TCSC is integrated. It is preferable to lessen the number of TCSC devices (NT), due to better system output from a few FACTS devices for monitoring and maintenance reasons, the goal function has improved. The main function of the objective in Equation (2) The power system subject to equity and inequality limits as follows:

3.1 Active/Reactive Balance of Total Power

To balance supply and demand, the constraint of power equality should be fulfilled. The total real and reactive of the power generated must be equal to the whole system demand added the power losses to be investigated by Equations (10–11):

$$\sum_{i=1}^{NG} PG_i = \sum_{i=1}^{NB} PD_i + P_{losses} \quad (10)$$

$$\sum_{i=1}^{NG} QG_i = \sum_{i=1}^{NB} QD_i + Q_{losses} \quad (11)$$

Where PG_i and QG_i are active and reactive power generation in unit , respectively. $PD_i$and QD_i Are active/ reactive power load at bus i .

3.2 Balance of Real/Reactive at Each Bus

Real and reactive power balance at each bus can be demonstrated as Equations (12-13):

$$PG_i = PD_i + \sum_{i=1}^{Ncl} PF_{ij} \quad (12)$$

$$QG_i = QD_i + \sum_{j=1}^{Ncl} QF_{ij} \quad \forall\, i \in NB, i \neq j \quad (13)$$

Where PF_{ij} and QF_{ij} The flow of active and reactive power on bus lines (Ncl).

3.3 Constrictions on Power Inequality and Voltage Generation Limits

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

$$PG_i^{min} \leq PG_i \leq PG_i^{max} \quad (14)$$

$$QG_i^{min} \leq QG_i \leq QG_i^{max} \quad (15)$$

$$VG_i^{min} \leq VG_i \leq VG_i^{max} \quad (16)$$

Here G_i^{max} , PG_i^{min} , QG_i^{max} and QG_i^{min} Are Active and reactive maximum and minimum power generation at bus i , respectively. Also VG_i^{max} and VG_i^{min} Are upper and lower limit of generation voltage at bus i.

3.4 Security Constraints

In this situation, the loading on the transmission line (Sl_i) should maintain within limits permitted for this issue and the load-bus voltages (VL_i) should also be limited by the lower and upper limits in agreement with Equations (17-18):

$$Sl_i^{min} \leq Sl_i^{max} \quad \forall\, i \in Nl \quad (17)$$

$$VL_i^{min} \leq VL_i \leq VL_i^{max} \quad \forall\, i \in NB \ni NG \quad (18)$$

Where Sl_i^{max} and Sl_i^{min} are transmission line loading at maximum and minimum levels at line . VL_i^{max} and VL_i^{min}Are maximum and minimum voltage values on loading bus i.

4. The Gravitational Search Algorithm

The stochastic search algorithm GSA is one among the most technologically advanced by Rashedi et al. [19]. This optimization process has a lot of potential for an optimization strategy because of the Newtonian law of gravity and mass interaction. In the GSA, agents are taken into account as objects and can calculate their performance by mass. The issue with this algorithm is that it has a solution (or part of a solution). All of these items are attracted to each other by gravity, and all of them will gravitate toward objects with heavier weights on a global scale. Because of their greater fitness, the heavy masses define optimal answers to problems and travel slower than lighter solutions.

In the selected algorithm, the four aspects of each mass are position, active gravitational mass (Mai), inertial mass (Mii), and passive gravitational mass (Mpi). For solving optimization problems with GSA firstly, the position of a system is defined with N masses (dimension of the search space) [14].

$$X_i = \left(X_i^1, \dots, X_i^d, \dots X_i^n\right), for\ i = 1,2, \dots, N \quad (19)$$

where N is the problem's space dimension, and X_i^d indicates the i^{th} agent's location in the d^{th} dimension. The agents of the Newton gravity solution are described alone, and at the time t is stated according to Equation (20), a gravitational force from mass j works mass i.

$$F_{ij}^d(t) = G(t)\frac{M_i(t) \times M_j\,(t)}{R_{ij}(t) + \varepsilon}\ (X_j^d\,(t) - X_i^d\,(t)) \quad (20)$$

where $M_j\,(t)$ is the mass of the target j , $M_i(t)$is the mass of the target i, ε a minor constant, $G(t)$the gravitational constant at time t and $R_{ij}(t)$ is the Euclidian distance between i and j objects defined as follows:

$$R_{ij}(t) = \ \|X_i(t), X_j(t)\|_2 \quad (21)$$

The whole force acting on the i^{th} the agent is considered computed by Equation:

$$F_i^d(t) = \sum_{j\in K_{best}, j\neq i}^{N} rand_j\, F_{ij}^d\,(t) \quad (22)$$

where $rand_j$ is a random number and K_{best} It is the set of first k agents with the biggest mass and the best fitness value. Based on Newton gravitation theory to observe the acceleration of the i^{th} agent, at t time in the d^{th} dimension, the motion law is used to calculate directly. Based on the above, there is an inverse relationship between the force acting on an agent and the mass of that agent. $a_i^d(t)$ can be calculated according to Equation:

$$a_i^d(t) = \frac{F_i^d(t)}{M_{ij}(t)} \quad (23)$$

The searching approach to this principle can also be used to locate an agent's following location and next velocity according to Equations.:

$$v_i^d(t+1) = rand_i \times v_i^d(t) + a_i^d(t) \quad (24)$$

$$x_i^d(t+1) = x_i^d(t) + v_i^d(t+1) \quad (25)$$

where $x_i^d(t)$ and $v_i^d(t)$ Are the position and velocity of an agent at t time in d dimension, respectively. $rand_i$ A random number between 0 and 1. G is a gravitational constant. Thus, it is utilized to manage the search accuracy, which is randomly initialized at the beginning and will decrease as the number of iterations of programs increases.

$$G(t) = G_0 e^{-\alpha\frac{t}{T}} \quad (26)$$

α is a constant defined by the user, T the sum of all iterations, and t 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 groups are modified as follows in the suggested algorithm:

$$M_{ai} = M_{pi} = M_{ii} = M_i, i = 1,2, \dots, N \quad (27)$$

$$m_i(t) = \frac{fit_i(t) - Worst(t)}{best(t) - Worst(t)} \quad (28)$$

$$M_i(t) = \frac{m_i(t)}{\sum_{j=1}^{N} m_j(t)} \quad (29)$$

Where $fit_i(t)$ indicates the agent′s fitness value i at time t. In each population, the $best\ (t)$ and $Worst\ (t)$ offers the most efficient and weakest fitness agent, based on Equations (30) and (31) was determined for the problem of minimum fitness:

$$best\ (t) = \min\ fit_j(t)\ , j \in \{1, \dots, N\} \quad (30)$$

$$Worst\ (t) = \max\ fit_j(t)\ , j \in \{1, \dots, N\} \quad (31)$$

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. One way to perform a good compromise between exploration and exploitation is to reduce the number of agents with a lapse of time. In this algorithm, only a set of agents with a more significant mass apply their force to the other [20].

An agent is placed in the search field to define a solution to the problem, minimizing the problem with the proposed algorithm at the beginning. The agents are then modified, and their following positions are determined according to Equations (24) and (25). The algorithm parameters such as the constant gravitational G, masses M, and acceleration a are calculated via Equation (26), (27), (28), (29), and (23) correspondingly, and are updated with each program iteration.

The GSA is used to solve the OPF problem, and the following steps are taken: Step 1: Initialize GSA parameters, such as the initial value of gravitational constantG_o, α, is a user-specified constant and the number of iteration. Step 2: The initial positions (i.e., control variables, such as generators' voltages, the locations for the TCSC places, and the compensation level set at Equations constraint (1),..) of each agent should be randomly selected while satisfying different equality and inequality constraints of OPF. Several numbers of agents, depending upon the agent size, are generated. Each set in the agent represents a potential solution to the problem. Step 3: Run the Newton–Raphson (NR) load flow program and determine Equation's objective function (2). Determine the different dependent variables, such as active power generation of the slack bus, load voltages, reactive power generations, and transmission line loadings. Step 4: Update (t), $be(t)$, $worst(t) and$ $Mi\ (t)$ for each set of agents. Step 5: The total force in various directions can be calculated using Equation (22). Step 6: Calculation of each agent's acceleration and velocity using Equations (23) and (24). Step 7: Updating agents' position and check constraints of Equations (10):(18). Step 8: continue iterative solution replay, save minimum fitness function and compare it to converge (2). To be able to meet the avoid criteria (that is, the number of iterations). Step 8: Rest.

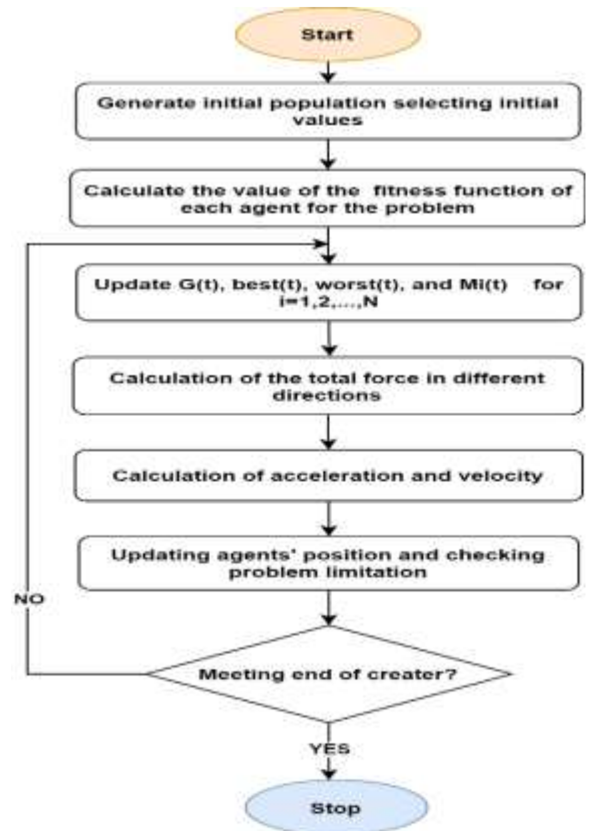

Figure 2. The Flowchart of The Implementing GSA technique.

5. Result and Discussion

Standard test systems IEEE 30-bus and 400 kV Iraqi Super High Voltage (SHV) gird system is selected for the study of the model proposed. All system details and diagrams on a single line are available in [21] and [22]. Figure (3) showing the single-line diagram of the IEEE 30 bus test system [16].

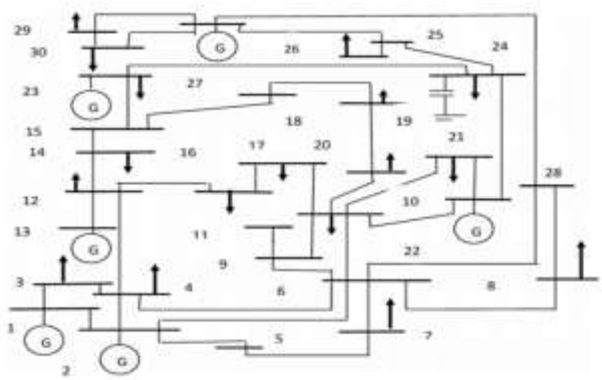

Figure 3. The single-line diagram of the IEEE 30 bus test system [16].

The GSA parameter setting for the normal study operation and emergency operations of the two test networks using MATLAB-based MATPOWER 6 software routines is set using Equation (26), where G_0 is set to 100, α is set to 10, and T is the total number of iterations. To arrive at an optimal solution, the maximum number of iterations for all case studies is 50. For the management of all objectives, the weighting factors for the objective function are set at multiple values.

The following three cases are used to demonstrate the research contribution:

Case 1: Initial system data normal operation.

Case 2: Outage of critical line.

Case 3: Increase the demand for the load on all buses or the specific bus.

- **IEEE 30-bus**

The first test 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 TCSC are presented in Table (1) compared to the GSA methods of DE [16] and APSOA [12].

The GSA process produces superior outcomes than the APSOA and DE procedures. shown in Table (1), Where the GSA system for the TCSC systems could minimize active power losses by 12.8% from 0.0242 to 0.0211, reactive power losses by 11.9% could be minimized from 0.0801 to 0. 0705. In the presence of TCSC, the real and reactive power losses for APSOA and DE techniques are greater than GSA. The GSA method of TCSC operation is less expensive than the DE algorithm in the normal operation of original systems data. Figure (4) showing the stable convergence characteristics of GSA in case 1.

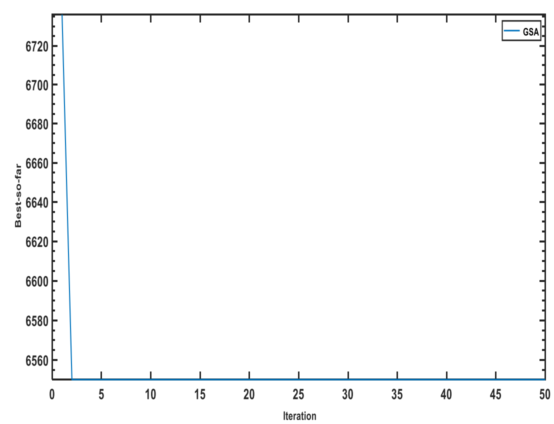

Figure 4. The stable convergence characteristics of GSA (case 1).

Table (2) summarizes cases 2 and 3. In case 2, a critical line and a service outage is line 36 (the line between bus 27 and bus 28). Its consequences are high losses of real/reactive power and the elimination of line 29 overflow under the total limit exposed in Figure (5). After injecting 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 realized from Table (2), when TCSC is used by the GSA technique, the losses of real or reactive power are reduced respectively from 0.0256, 0.0855to 0.0201, 0.0812, here lines 40, 26 are nominated for connecting TCSC units.

Table 1. The results of the GSA were compared to the DE and APSOA methods used in the IEEE 30-bus system (case 1).

Optimal value	Without TCSC			With TCSC		
	DE [16]	APSOA [12]	GSA	DE [16]	APSOA [12]	GSA
QG1(PU)	-0.01	-0.001	-0.0091	0.1129	0.0189	-0.009
QG2(PU)	0.32	0.335	0.38110	0.1096	0.3098	0.3386
QG22(PU)	0.3957	0.344	0.3063	0.2889	0.3417	0.2049
QG27(PU)	0.1054	0.091	0.1068	0.1644	0.0994	0.0095
QG23(PU)	0.0795	0.092	0.0772	0.0873	0.0908	0.0770
QG13(PU)	0.1135	0.129	0.1115	0.2355	0.1262	0.1110
TCSC Location	…	…	…	16,29	1,17	38,40
X Line (PU)	0.14,0.02	0.07,0.26	0.6,0.2	0.7,0.01	0.0803,0.3027	0.3838, 0.0945
***Compensation level (%)**	…	…	…	50,50	17.16,16.42	36,52,75
TCSC Cost($/h)	…	…	…	2.055×10^5	2.87×10^3	2.92×10^3
P losses (PU)	0.0245	0.023	0.0242	0.0225	0.02162	0.0211
Q losses (PU)	0.0899	0.076	0.0801	0.0802	0.0727	0.0705
V.D (PU)	0.0226	0	0	0.0186	0	0

Table 2. The results attained of the GSA for cases 1-3 (30-bus system).

	Case1		Case2		Case3.a		Case3.b	
23Optimal value	**Without TCSC**	**With TCSC**	**Without TCSC**	**With TCSC**	**Without TCSC**	**With TCSC**	**Without TCSC**	**With TCSC**
QG1(PU)	-0.0091	-0.009	0.0174	0.0172	-0.0266	-0.0468	-0.04633	-0.0497
QG2(PU)	0.38110	0.3386	0.3374	0.3371	0.4467	0.3540	0.4308	0.4190
QG22(PU)	0.3063	0.2049	0.3346	0.3351	0.4411	0.3979	0.4600	0.4017
QG27(PU)	0.1068	0.0095	0.0701	0.0701	0.0966	0.2597	0.0940	0.0936
QG23(PU)	0.0772	0.0770	0.1215	0.1213	0.1138	0.1047	0.0638	0.0597
QG13(PU)	0.1115	0.111	0.1193	0.1189	0.0127	0.1091	0.1333	0.1273
TCSC Location	…	38, 40	…	40, 26	…	26,34,36	…	24,28,40
Line Reactance (PU)	0.6,0.2	0.3838, 0.0945	0.2,0.08	0.08,0.07	0.08,0.38,0.4	0.0387,0.289,0.239	0.07,0.15,0.2	0.0823,0.0874,0.1474
***Compensation level (%)**	…	36, 52, 75	…	60, 12.5	…	51.6, 23.94, 40.25	…	17.5, 41.7, 26.5
TCSC Cost ($/h)	…	2.92×10^3	…	4.78×10^3	…	7.329×10^3	…	9.6×10^3
P Losses (PU)	0.0242	0.0211	0.0256	0.0201	0.03473	0.03017	0.0275	0.0268
Q Losses (PU)	0.0801	0.0705	0.0855	0.0812	0.1235	0.1004	0.1115	0.10745
Total V. D	0	0	0	0	0.007	0.001	0.015	0.001

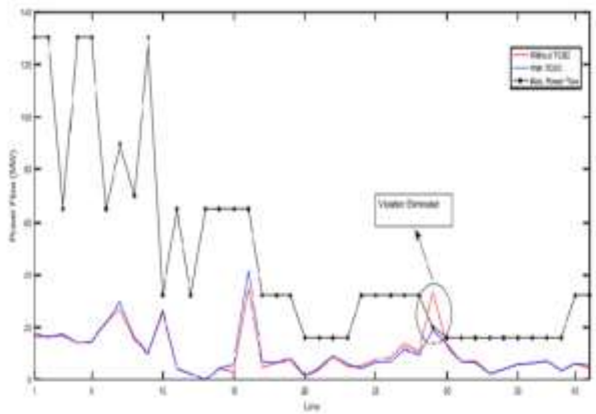

Figure 5. The improvement in power flow with the GSA (case 2).

Busload 8 increases by 50 % in the case of 3. a, As a result, real/reactive power losses and voltage variation are larger, and power flow on line 29 is at risk. The GSA method for TCSC systems could, in Table (2) after installing a TCSC device in case 3. a, mitigate active power loss of 13.12% from 0.03473 to 0.03017, then reactive power losses of 18.7% can be reduced from 0.1235 to 0.1004. For the installation of TCSC devices, lines 26, 34, and 36 are selected here.

In case 3. b, a new load (11MW+j11MVAr) is practical at bus 11. This did not provide good system performance than case 1, as exposed in Table (2), and overflowed in line 29. The real and reactive of the power losses and voltage deviation decreased by 0.0275, 0.1115, and 0.015, respectively, to 0.0268, 0.1074, and 0.001with the addition of TCSC in lines 24,28, and 40.

- **400 kV Iraqi Super High Voltage (SHV) gird system**

The 400 kV Iraqi super high voltage (SHV) grid is the second test system that comprises (36) bus bars, (22) generators, (24) load buses, (84) autotransformers, and (52) transmission lines. The (22) generators station are of different MW generation capabilities and MVAr generation/absorption; also, bus 20(KUTP) is the slack bus. The data were taken from Iraqi National Control Center (INCC) and represented the state of operation for the winter season on another date of Jan. 1, 2017. All data for the 400 kV Iraqi SHV gird system, such as buses data, machines data, line data, the single line diagram, …etc. It is given in [23].

The minimum limit of bus voltage magnitudes is (0.94 PU) while the maximum limit is (1.05 PU) at normal operation and emergency operation. Figure (6) shows the single line diagram of the 400 kV Iraqi SHV gird system [23].

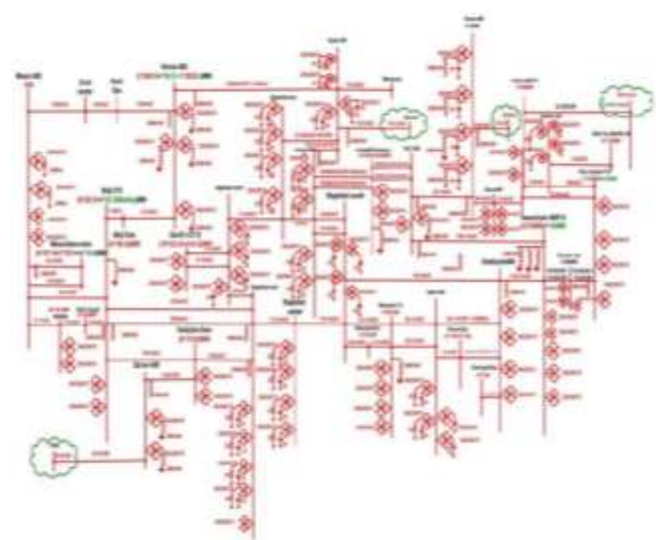

Figure 6. The single line diagram of the 400 kV Iraqi SHV gird [23].

The first case is a normal operation case, and the results of solving this case with and without inserting TCSC unites the GSA algorithm are shown in Table (3).

In case 1, after two TCSC units have been added in lines 41, 30 (a line between (BAB4-GKHER) and (AMN4-KUTP)), active and reactive of the power losses have been reduced to 29.23 MW

Table 3. The GSA obtained results for cases 1-3 (400 kV Iraqi (SHV) gird system).

Cases	**Case1**		**Case2**		**Case3.a**		**Case3.b**	
Method	**Without TCSC**	**With TCSC**	**Without TCSC**	**With TCSC**	**Without TCSC**	**With TCSC**	**Without TCSC**	**With TCSC**
TCSC Location	…	41, and 30	…	29, and 26	…	47, and 4	…	44, and 39
Line Reactance (PU)	0.0073, 0.022	0.0037, 0.0209	0.0135, 0.0078	0.0093, 0.0063	0.0110, 0.0343	0.0086, 0.0218	0.0348, 0.0067	0.0196, 0.0051
*Compensation level (%)	…	49.3, 5	…	25.6, 19.2	…	21.8,62.68	…	43.67,23.88
TCSC Cost ($/h)	…	12.659×10^4	…	16.08×10^4	…	5.422×10^4	…	6.988×10^4
P Losses (MW)	29.442	29.23	36.207	36.119	59.079	59.022	83.56	81. 21
Q Losses (MVAr)	257.741	241.621	321.655	316.34	525.70	524.46	749.15	745.38
Total V. D	0.002	0.001	0.021	0.01	0.14	0.11	0.23	0.19

and 241.62 MVAr. The GSA effects for active/reactive power losses are 29.442, 257.741, and 0.002, respectively, and the voltage deviation is obtained to 0.001. The comparative to the base case active and reactive power losses without installation TCSC units are 46.139MW,412.65 MVAr, respectively, indicate that the suggested GSA approach is highly effective in solving the normal operation of original systems data case 1.

In case 2, line 20 (BGS4 -BGC4) [23], a critical line is labeled, which causes higher system power losses and has been shut down. The activated and reactive power losses in this situation increase respectively to 36.207 MW and 321.655 MVAr. The TCSC units are reduced to 36.119 MW and 316.34 MVAr, respectively, when put in lines 29, 26 (the line between (AMN4-DAL4) and (BGE4-DAL4)). The voltage deviation is also reduced to 0.01, indicating better system performance.

In the next case, the load of all buses (case 3, a) increases by 10%, and line 20 is shut off (case2), leading to a significant violation of the system variables and higher system power losses. The whole power losses and the voltage deviation in that state are 59.079 and 525.70 MVAr, respectively, and 0.14. The GSA approach has increased the system's efficiency by adding TCSC units between lines 47 and 4 (the line between (AMR4-4QRN) and (MSL4-BAJP)). When the loss of active and reactive power is limited respectively to 59.022 MW and 524.46 MVAr, in this case, there are only two units of TCSC.

In case3 b, all buses' load is increased by 20%, and line 20 is an outage (case2) it does not provide enough system performance than case 1; as shown in Table (3), the real and reactive of the power losses and voltage deviation decreased by 83.56, 749.15, and 0.36, respectively, to 81. 21, 745.38, and 0.19 with the addition of the optimal location of the TCSC device in lines 44 and 39 (the line between (DWANG-KDS4) and (MUSP-BAB4)).

This reduction in the real and reactive of the power losses in all cases (1-3) will affect power generation. The decrease in reactive power generation with the GSA method is shown in Figure (7) for the 400 kV Iraqi Super High Voltage (SHV) gird system.

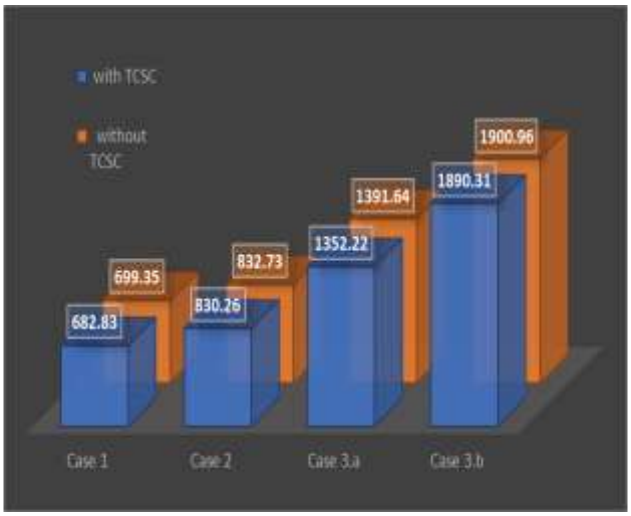

Figure 7. Reduction in the reactive power generation after adding the TCSC with GSA (case 1-3).

6. Conclusion

In this article, GSA algorithms are used for the optimal allocation of TCSC devices in IEEE 30 bus and 400 kV Iraqi Super High Voltage (SHV) grid system as a testing system. The static modeling of the TCSC devices was connected in a series of HVAC transmission lines that benefit from fast affected lines. The aim of solving the multi-target integration of the problem with TCSC was to reduce, under normal and emergency conditions, the active and reactive power loss, voltage deviation, including TCSC costs and TCSC unit numbers. The results of the GSA algorithm proposed are compared to the DE and APSOA processes. The study found that the voltage profile has been enhanced by minimizing the voltage deviation for all case studies. GSA has shown a high ability to mitigate independent variables for violation impact, especially in emergencies. The application of the algorithm has successfully established the optimum location and size of the TCSC, which is intended to optimize the transmission line productivity by reducing the active and reactive loss of power, increasing stability margin and transmission of capacity, as well as improving the voltage profile of all buses by reducing the voltage deviation and the reactive power limits of the generators. The results showed the TCSC device's role in improving the performance of transmission lines by reducing losses and rescheduling the power passing through the transmission lines. This GSA technique has the benefits of minimizing FACTS devices' size, switching processes, and controlling activities to enhance equipment's life cycle is an essential part of the Iraqi network.

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Conflict of interest

The authors of this article acknowledge that this article's publication causes no conflict of interest to anybody or institution.

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Appendix

*Compensation level (%) = [(Line reactance without TCSC- Line reactance with TCSC) / Line reactance without TCSC] × 100