INTERNATIONAL JOURNAL OF
ELECTRICAL AND POWER ENGINEERING
Journal Home Page: https://medwelljournals.com/journalhome.php?jid=1990-7958

Improvement of Transmission Line Loadability using Multi Type Facts Devices

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Key words: Gbest guided gravitational search algorithm, optimal power flow, Static VAR Compensator (SVC), system loadability limits, Thyristor Controlled Series Compensator (TCSC), voltage stability margin

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Page No.: 56-60
Volume: 13 Issue 04, 2019
ISSN: 1990-7958
Internation Journal of Electrical Power and Engineering

Abstract: In this study, Flexible AC Transmission System (FACTS) devices are optimally located in a power network to maximize the system loadability. FACTS devices are used in transmission system to control the system performance. The location of FACTS devices and the setting of their control parameters are optimized by gbest Gravitational Search Algorithm (GGSA) to improve the performance of the power network. The FACTS devices namely SVC (Static VAR Compensator) and TCSC (Thyristor Controlled Series Compensator) is considered to maximize the system loadability. The proposed system is used to control the main parameters namely voltage, phase angle and impedance which is affecting AC power transmission. Proposed algorithm is tested on IEEE 30 bus system for optical location and sizing of multi type FACTS devices and the system loadability gets improved and the transmission line losses are reduced.

INTRODUCTION

Now a days power systems are developed and widely interconnected, the operation of power system becomes more complex because of increasing load demand. In many cases, generation is far away from the load and critical to transmit a power to huge loads on long distance (Baghaee *et al*., 2008; Parolekar *et al*., 2013). Enhancement of transmission line loadability is essential because of stable power supply for many industries in daily operation. The development of power electronics, Flexible AC Transmission System (FACTS) devices has been implemented in power systems (Ghahremani and Kamwa, 2013; Sarda *et al*., 2012; Bhattacharya and Goswami, 2011). FACTS devices namely Thyristor Controlled Series Compensator (TCSC), Static VAR Compensator (SVC), Static Compensator (STATCOM), Unified Power Flow Controller (UPFC), etc. These devices can provide more flexible operation of power system (Gerbex *et al*., 2001; Belazzoug and Boudour, 2010; Barzadeh, 2004).

Series compensation device namely Thyristor Controlled Series Compensator (TCSC) and shunt compensation devices such as Static VAR Compensator (SVC) and Static Synchronous Compensator (STATCOM). Unified Power Flow Controller (UPFC) can provide both series and shunt compensation (Lu *et al*., 2007; Sirjani *et al*., 2011; Karthik and Arul, 2013). The FACTS devices are optimally located by using optimization techniques. The system loadability can be improved by optimal location and sizing of FACTS devices (Singh *et al*., 2006; Mondal *et al*., 2012; Saravanan *et al*., 2007). In this study, GGSA technique is used to find the optimal location and sizing of multi type FACTS devices. SVC and TCSC devices are considered to improve the transmission line loadability. TCSC can change the line resistance by connecting a variable resistance in series with the line. It may reduces the real power losses. The Static VAR Compensator (SVC) can inject or generate the reactive power on the transmission line. Simulations are carried out on IEEE 30-bus systems and the results are discussed.

MATERIALS AND METHODS

Modelling of FACTS devices: The two types of FACTS devices are considered namely Static VAR Compensator (SVC) and Thyristor Controlled Series Capacitor (TCSC).

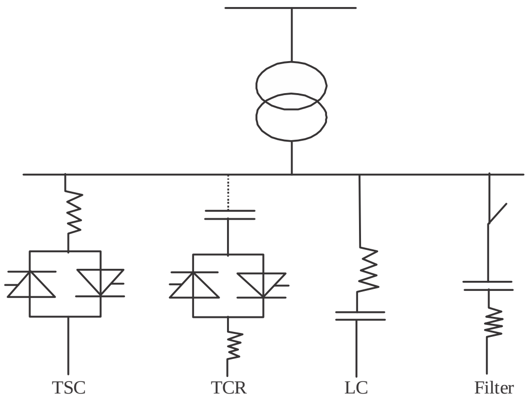

Fig. 1: Static VAR compensator

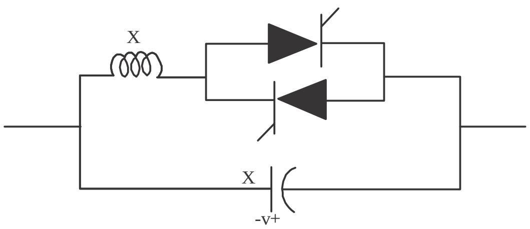

Fig. 2: Thyristor controlled series capacitor

Static Var Compensator (SVC): SVC consists of a Thyristor Controlled Rectifier (TCR) in parallel with a bank of capacitor. It regulates voltage terminals by controlling the amount of reactive power injection or absorption. The reactive power generation or absorption depends on the system voltage level low or high, respectively (Fig. 1).

Thyristor Controlled Series Capacitor (TCSC): Thyristor Controlled Series Capacitor (TCSC) is a series compensation device which control the reactacnce in the transmission line. The TCSC have two characteristics such as capacitive or inductive, corresponding to the reactance of the line, $X_{line,}$ decreasing or increasing, respectively. The capacitance or inductance value of the TCSC is denoted as X_{TCSC} (Fig. 2):

$$X_{ij} = X_{line} + X_{TCSC} \tag{1}$$

Where:

X_{TCSC} : Compensation factor of TCSC
X_{line} : Reactance of transmission lines

where, X_{line} is reactance of transmission line. Rating of TCSC is depended on transmission line where it is located.

Problem formulation

Objective function: The objective function is to maximize system loadability. It can be achieved by load factor (λ) of the system will be increased in an iterative process. Initial condition load factor is equal to 1($\lambda_0 = 1$):

$$g(x, v) = 0 \tag{2}$$

Where: x = System variable vector:

$$x = [V\,\theta]^T \tag{3}$$

v = Control variable vector:

$$v = [P_g C_r F]^T \tag{4}$$

Subject to the both equality and inequality constraints:

Equality constraints: The equality constraints g (x, u) are the nonlinear power flow Eq. 5 and 6:

$$P_{Gi} = P_{Di} + V_i \sum_{j=1}^{N_i} V_j \left(G_{ij} \cos\theta_{ij} + B_{ij} \sin\theta_{ij}\right) \quad i = 1, ..., N_0 \tag{5}$$

$$Q_{Gi} = Q_{Di} + V_i \sum_{j=1}^{N_i} V_j \left(G_{ij} \sin\theta_{ij} + B_{ij} \cos\theta_{ij}\right) \quad i = 1, ... , N_{PQ} \tag{6}$$

Inequality constraints: The inequality constraints h (x, u) are limits of control variables and state variables:

$$P_{Gi}^{min} \leq P_{Gi} \leq P_{Gi}^{mix} \tag{7}$$

$$Q_{Gi}^{min} \leq Q_{Gi} \leq Q_{Gi}^{mix} \tag{8}$$

$$V_{Gi}^{min} \leq V_{Gi} \leq V_{Gi}^{mix} \tag{9}$$

Where:

P_{gi} : Real Power Generation at bus i
Q_{gi} : Reactive power Generation at bus i
V_{gi} : Voltage at Generator bus i

Optimal location and sizing of SVC: The SVC can be used to control reactive power in the system. It may be installed at midpoint of the transmission interconnections or in load areas. It can be used for both inductive and capacitive compensation:

$$lo_{min} \leq lo_{SVC} \leq lo_{max} \tag{10}$$

$$Q_{min} \leq Q_{SVC} \leq Q_{max}; \ -100 \leq Q_{SVC} \leq 100 \tag{11}$$

Where:

Q_{min} : Minimum reactive power of SVC
Q_{max} : Maximum reactive power of SVC
lo_{svc} : Optimal location of SVC to be place
Q_{SVC} : Optimal size of SVC

Optimal location and sizing of tcsc: The TCSC can allow rapid and continous changes of the transmission line impedance. It can provide continuous control of power on the ac line over a wide range. The line reactance values between -0.8-0.2:

$$lo_{min} \le lo_{TCSC} \le lo_{max} \tag{12}$$

$$X_{min} \le X_{TCSC} \le X_{max};\ -0.8 \le X_{TCSC} \le 0.2 \tag{13}$$

Where:

X_{min} : Minimum value of TCSC reactance
X_{max} : Maximum value of TCSC reactance
lo_{TCSC} : Optimal location of TCSC to be place
X_{TCSC} : Optimal size of TCSC

gbest Guided Gravitational Search Algorithm (GGSA): The Gravitational Search Algorithm (GSA) is based on the law of gravity and law of motion. The search process of an algorithm starts with an initial population as a set of solution. The process has two main phases such as exploration and exploitation to find the global optimum. Exploration in the first iteration to search the problem in space broadly whereas exploitation in the final iteration to converge the best solution from promising solutions found in the exploration phase.

Each objects attracted each other by their gravitational force and these force causes an object moves towards the heavier mass of the object. This heavier mass is close to the global optimum, attracts the other masses in proportion to their distances. The slow movement of heaviest mass significantly decrease the speed of converge. Therfore, that GSA suffers slow search speed in exploitation phase and doesn't have enough memory to saving the global solution.

The proposed algorithm provide the location of best mass to speed up the exploitation phase and also provide enough memory to save the global solution. The g best element applies an additional velocity to the best mass.

An algorithm has three group of functions: Unimodal, multimodal, composite functions (Mirjalili and Lewis, 2014).

Unimodal: The unimodal functions have one global solution without any local optimal. This function is suitable for examining exploitation (Fig. 3).

Multimodal: The multimodal functions have many local minima with the number increasing exponentially with dimension. It is suited to test the exploration capability.

Composite function: The composite functions have many local minima with complex structure. These functions are suitable to test both exploration and exploitation.

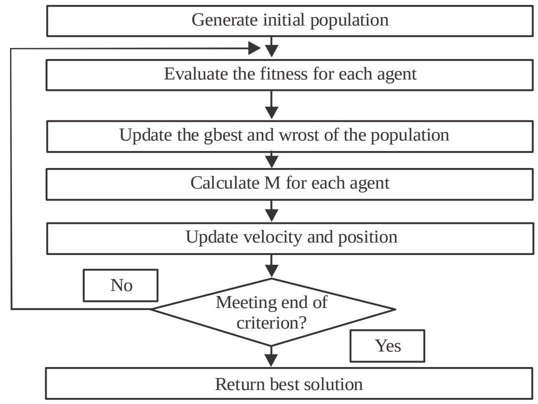

Fig. 3: Flowcahrt of GGSA

Algorithm 1; The procedure for the GGSA:

Step 1: Start the program

Step 2: Generate initial population
Position of N no of agents
$X_i = X_i^1, \dots, X_i^d, \dots, X_i^n$ for I = 1, 2, ..., N
X_i^d = Position if i^{th} agent in the d^{th} dimension
n= Space dimension

Step 3: Gravitational Constant (G) Computation:
Gravitational constant $G(t) = G_o\, e^{(-\acute{a}/T)}$
T-Total No. of iterations
G_o and α-intialized at the beginning and reduced with time to control the search accuracy T

Step 4: Gravitational and resultant forces:

$$F_{ij}^d(t) = G(t)\frac{M_{pi}(t)\times M_{aj}(t)}{R_{ij}(t)+\varepsilon}\left(x_j^d(t)-x_I^d(t)\right) \tag{14}$$

$$R_{ij}(t) = X_i(t)-X_j(t) \tag{15}$$

Where:

G(t) : Gravitational constant
$M_{pi:}$: Passive gravitational mass related to agent 'i'
$M_{ai:}$: Active gravitational mass related to agent 'i'
ε : Small constant
$R_{ij}(t)$: Distance between two agents i and j

Step 5: Velocity and Position of agents computation. V and P of the agents at next iteration (t+l) are based on

$$V_i(t+l) = rand*V_i(t)+c_1'*ac_i(t)+c_2'*\left(gbest-X_i(t)\right) \tag{16}$$

$$X_i(t+l) = X_i(t)+V_i(t+l) \tag{17}$$

Where:

$V_i(t)$: Velocity of agent i at iteration t
c_1, c_2 : Accelerating coefficients
rand : Random number between 0 and 1
$ac_i(t)$: Acceleration of agent i at iteration t

RESULTS AND DISCUSSION

The proposed algorithm is tested on IEEE 30 bus system. The system contains 6 generator buses, 24 load buses and 41 transmission lines. Transmission lines 6-9,

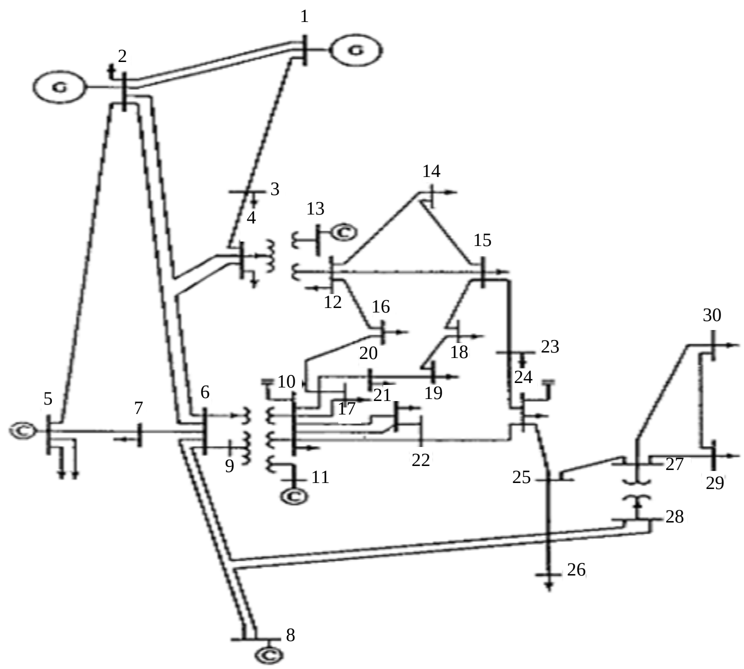

Fig. 4: IEEE 30 bus system

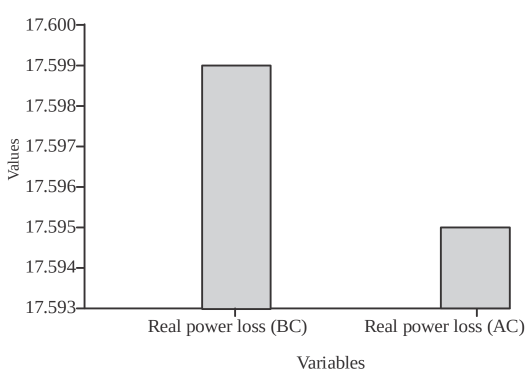

Fig. 5: Comparison of real power loss

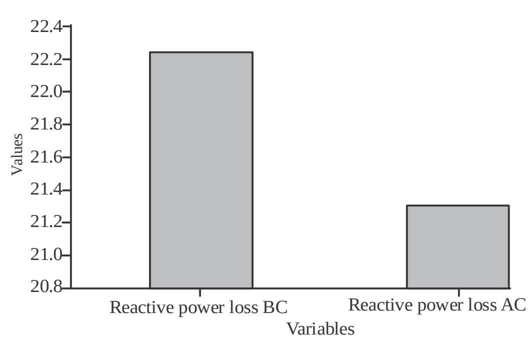

Fig. 6: Comparison of reactive power loss

6-10, 4-12 and 28-27 have tap changer transformers except these lines are suitable for locate the TCSC. SVC can be placed on the bus through the shunt connection. The location and sizing of SVC and TCSC have been found by using GGSA (Fig. 4-7).

Table 1: Real and reactive power losses without and with FACTS devices

Device	Real power loss (MW)	Reactive power loss (MVAR)
Without facts device	17.599	17.595
With facts device	22.244	21.703

Table 2: Optimal location and size data of multi type facts device

Facts devices	Optimal locaton	Optimal sizing (p.u)
SVC1	Bus 12	0.3121 (MVAR)
SVC2	Bus 14	0.0227 (MVAR)
TCSC1	Branch19-21	-0.2020 (reactance)
TCSC2	Branch 25-26	-0.2887 (reactance)

Comparison of power losses before and after compensation: Power losses are tabulated and compared with before and after compensations that can be seen in following Table 1. The real power losses has been reduced to 17.595 from 17.599 MW, after the devices are located at appropriate place. Thus, same, the reactive power losses are reduced to 22.244 from 21.703 MVAR, the devices have been located at the appropriate place.

Optimal location and size of multi type facts devices: The optimal location and sizing of multi type FACTS devices have been achieved by GGSA. TCSC is a series controller have been placed on branch 19-21 with optimal size of -0.2020 (reactance in p.u) and branch 25-26 with optimal size of 0.2887 (reactance in p.u). SVC is a shunt controller and have been placed on 12 and 14th bus with optimal size of 0.3121 (MVAR in p.u) and 0.0227 (MVAR in p.u), respectively (Table 1 and 2).

CONCLUSION

This study made to find the optimal location and sizing of SVC and TCSC devices to maximize the transmission line loadability. SVC can improve the voltage profile and TCSC can reduces the real power losses. By using the GGSA, the given devices can be located at optimal place and sizing on the power system to reduces power losses and to maintain system voltage at rated level. The proposed method has been tested for IEEE 30 bus system. The voltage profile has been improved at 1.001 p.u and real and reactive power losses has been reduced 17.595 MW and 21.703 MVAR, respectively and compare to the initial condition.

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