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GUI Application for Voltage Regulation Improvement by Optimal Allocation of Multiple Type FACTS Using PSO

Mr. M. Vimalraj[1*], Mr. K. M. Mohamed Thoufiq[2$], Ms. P.Ramanathan[#]

[1]*Assistant Professor/EEE,Global Institute of Engineering & Technology,Vellore, TamilNadu, India*

[2]*PG Scholar/EEE, Mahabarathi Engineering College,Chinnasalem, TamilNadu, India*

[3]*Assistant Professor/EEE,Mahabarathi Engineering College,Chinnasalem, TamilNadu, India*

Abstract - Flexible AC transmission systems (FACTS) devices, can help reduce power flow on overloaded lines, which would result in an increased loadability of the power system, fewer transmission line losses, improved stability and security and, a more energy-efficient transmission system. This paper presents a graphical user interface (GUI) based on a Particle Swarm Optimization (PSO) which is shown able to find the optimal locations and sizing parameters of multi-type FACTS devices in large power systems. This toolbox, allows the user to pick a power system network, determine the PSO settings and select the number and types of FACTS devices to be allocated in the network. Three different FACTS devices are implemented: SVC, TCSC and TCPST . PSO method to solve the problem of optimal allocation and sizing of multiple type FACTS in a medium size power network (IEEE 14 bus system) in order to improve voltage profile, minimizing power system total losses and maximizing system loadability with respect to the size of FACTS.

Keywords: FACTS, Particle Swarm Optimization (PSO), optimal FACTS placement, OPF, power system loadability, power system security, Voltage Stability, SVC,TCSC,TCPST.

I. INTRODUCTION

Reactive power compensation is an important issue in electrical power systems and shunt flexible ac transmission system (FACTS) devices play an important role in controlling the reactive power flow to the power network and hence the system voltage fluctuations and stability [1]. Voltage collapse problems in power systems have been permanent concern since several major blackouts throughout the world have been directly associated with such mishaps. The collapse points are also known as maximum loadability points. Increased loading of power system, environmental restrictions, combined with a worldwide deregulation of the power industry, require more effective and efficient control means for power flow and stability control. The power flow control and static stability limits of power system can be considerably modified using the new reactive compensation equipment's [2]-[3].

At the present time, there is a consensus that the power grid has to be reinforced and to make it smart and aware, fault tolerant and self-healing, and dynamically and statically controllable. Flexible AC Transmission System (FACTS) devices, such as a STATCOM, a SVC, a SSSC and a UPFC can be connected in series or shunt (or a combination of the two) to achieve numerous control functions, including voltage regulation, system damping and power flow control[4-6].

In order to overcome these problems, Evolutionary Computation Techniques have been employed to solve the optimal allocation of FACTS devices. Different algorithms such as Genetic Algorithms (GA) [7], [8], and Evolutionary Programming [9] have been tested for finding the optimal placement as well as the types of devices and their sizes, with promising results.

Recently, Particle Swarm Optimization (PSO) has shown a great promise in power system optimization problems [10]. The PSO mimics the behaviors of individuals in a swarm to maximize the survival of the species. In PSO, each individual decides based on its own experience as well as other individual's experiences [11]. The algorithm searches a space by adjusting the trajectories of moving points in a multidimensional space. The individual particles are drawn stochastically toward the position of present velocity of each individual, their own previous best performance, and the best previous performance of their neighbors [12]. This paper introduces the application of PSO for the optimal allocation multiple types FACTS devices in order to improve voltage profile, minimizing power system total loss and maximizing system loadability considering the size of FACTS.

(a)Single-Type FACTS Device Allocation

The assumption here is that a single type of device is to be sited at a given number of optimally chosen locations. The FACTS placement procedure then starts to find the optimal locations and values for the selected device such as: SVC [6], STATCOM [14], TCSC [7], and UPFC [8], [9], [13], [16], [18].

(b)Multiple-Type FACTS Devices Allocation

Adopting a mix of different types of FACTS devices allows the benefits of each singular type to be included. For example, in some papers, three or four types of FACTS device such as TCSC, TCVR, TCPST, SVC [5], [15] were used together. In [10] and [11] the UPFC added to the other four FACTS above. In this context, the optimization procedure usually finds the optimal types, locations and values of the various FACTS devices simultaneously.

After these introductory remarks, we will now proceed to give an overall description of this paper. A MATLAB-based Graphical User Interface (GUI), called the FACTS Placement Toolbox, which uses the PSO as its optimization method, is presented. Using PSO puts this paper in the first category of allocation methods discussed above. Regarding the second categorization, we will perform the placement procedure for three types of FACTS devices simultaneously: SVC, TCSC and TCPST. The user has the opportunity to select the desired number and types among them. The power network also should be selected by the user from a large number of IEEE test networks. The optimization process will then find the optimal locations and values of the given number of FACTS in the selected power system network in order to maximize the power system loadability [5],[6], [14].

II.FACTS DEVICES INFLUENCES ON POWER FLOW

Based on the type of compensation, we could have three different categories for different types of FACTS devices:

- **Shunt controllers** such as SVC and STATCOM.
- **Series controllers** such as TCSC, TCPST and TCVR.
- **Combined shunt-series controllers** such as UPFC.

Each of the above FACTS devices has its own properties and could be used for a specific goal. The modeling of the FACTS devices presented in Fig. 1,which would be used for our power flow calculations in MATLAB. Here, we just consider the influence of FACTS devices presented in Fig. 2.1, separately, on the power transmitted on a line between two buses and. The active and reactive power flow equations transmitted on a line can be presented as (1) and (2) respectively:

$$\square_{\square\square} = -\square_{\square\square} = \frac{\square_{\square}\square_{\square}}{\square_{\square\square}} \square\square\,\square(\square_{\square} - \square_{\square})$$

(1)

$$\square_{\square\square} = \frac{1}{\square_{\square\square}}[\square_{\square}^{2} - \square_{\square}\square_{\square}\,\square\square\square(\square_{\square} - \square_{\square})$$

(2)

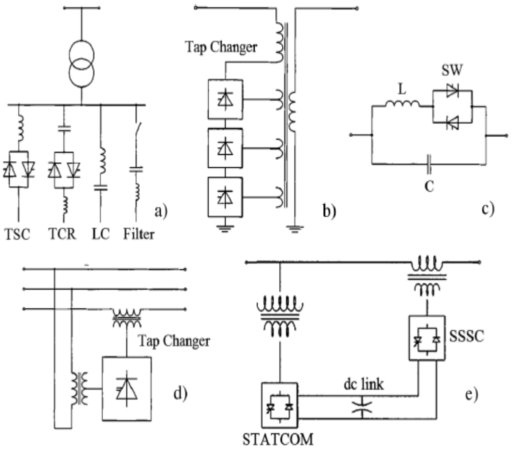


Fig. 2.1. FACTS devices: (a) SVC, (b) TCVR, (c) TCSC, (d)TCPST, (e) UPFC

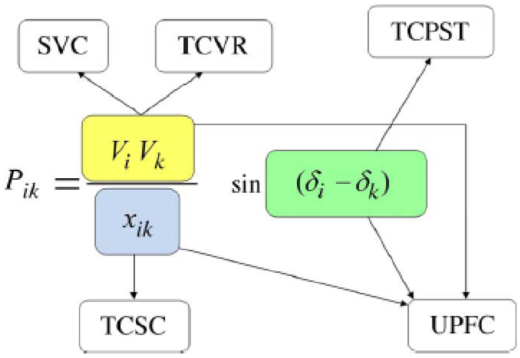


Fig. 2.2. Impacts of FACTS devices on the variables involved in the active power flow equation.

Where $\square_{\square}$and $\square_{\square}$are the voltage magnitudes of buses $\square$ and k, $\square_{\square\square}$ is the line reactance and $\square_{\square} - \square_{\square} = \square_{\square\square}$is the difference angle between phasor $\square_{\square}$and $\square_{\square}$. In normal power system operation, is small and the voltage magnitudes are typically 1.0 p.u.We can therefore easily decouple the active and reactive power controls from each other. While the active power flow is influenced by $\square_{\square\square}$ and $\square_{\square\square}$, the reactive power flow is related to the value of $\square_{\square} - \square_{\square}$ and $\square_{\square\square}$ Fig.2.2 shows the active power flow equation between two buses ‘i and ‘k it is the variables that can be controlled by each FACTS device.

III. OPTIMIZATION PROCESS

(a). Overview of the PSO:

Particle swarm optimization (PSO) is a novel optimization method developed by Kennedy and Eberhart [10]. It is a multi-agent search technique which traces its evolution to the emergent motion of a flock of birds searching for food. It uses a number of particles that constitute a swarm. Each particle traverses the search space looking for the global minimum (or maximum). To ensure convergence of PSO, Eberhart indicates that use of a constriction function may be necessary [18-22].

(b).Original Version with Inertia Weight:

The main purpose of a standard continuous optimization technique is to find the best of all feasible solutions to an optimization problem, usually, minimizing or maximizing a continuous function with respect to several constraints. In the case of minimization, mathematically, such a problem can be stated as:

$$\square\square\square\square\square\square\square\square \quad \square(\square),\ \square(\square): \square^{\square}, \ldots, \square$$

$$\square\square\square\square\square\square\square\ \square\square\ \square_{\square}(\square) \le 0, \square = 1, .., \square$$

$$h_{\square}(\square) = 0, \square = 1, .., \square$$

(3)

Where *f(x)* is called objective or fitness function and *gi(x)* and *hi(x)* respectively define the inequality and equality constraints. To solve these problems, PSO proposes a new approach by mimicking the movement behavior of some social groups encountered in nature with PSO particles acting as individuals in such a group.

According to the number typically ranges from 20 to 40 particles, depending on the problem's complexity and on the balance between number of calculations in each iteration of the algorithm and the number of iterations needed for the algorithm to converge.

The first one is the personal best solution achieved by each particle in the hyperspace until a particular moment. The set of coordinates values associated to this solution is named in this work $\square\square\square\square\square_{\square}$ for particle $\square$. The second one is the best solution achieved by all particles moving in the hyperspace. Consequently the value is shared by all particles. The set of coordinates values associated to this global best solution is called *Gbest*. Defining these criteria enables the laws of movement of the set of particles in the hyperspace to be constructed.

$$\square_{\square}(\square) = \square(\square)\square_{\square}(\square - 1) + \square 1\square_{1}[\square\square\square\square\square_{\square} - \square_{\square}(\square - 1)]$$

$$+ \square 1\square_{1}[\square\square\square\square\square_{\square} - \square_{\square}(\square - 1)](4)$$

The position of each particle, at iteration t is then determined by the sum of the previous position vector $\square_{\square}(\square - 1)$ and the updated velocity vector $\square_{\square}(\square)$ computed by equation(3). Interpreting the relationship between a position and a velocity demonstrated in equation(3) leads to conclusion that each iteration of the algorithm represents one unit of time in physical terms.

$$\square_{\square}(\square) = \square_{\square}(\square - 1) + \square_{\square}(\square)(5)$$

Fig.3.1 illustrates the movement of particle $\square$ in a two dimensional plane during one iteration of the PSO algorithm according to the laws of movement defined above.

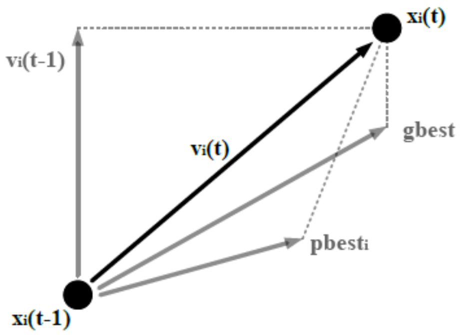


Fig.3.1: Movement of a PSO particle in a two dimensional plane

In this example, since the particle moves in a two dimensional space, the vectors x_i, v_i, *pbestiandgbest* would be defined as:

$$\square_{\square}, \square_{\square}, \square\square\square\square\square_{\square}, \square\square\square\square\square_{\square} \in \square^{2} \quad \square(\square): \square^{2} \to \square(6)$$

One option to describe this decrease in the inertia value is offered and it is described in equation (5) where $\square_{\square\square\square}$ and $\square_{\square\square\square}$are the boundaries of the range in which the inertia weight operates and tmax is the maximum iteration value.

$$\square(\square) = \square_{\square\square\square} - \frac{\square_{\square\square\square} - \square_{\square\square\square}}{\square_{\square\square\square}} \times \square(7)$$

In the beginning, this allows the algorithm to scatter the particles in the hyperspace with the aim of favoring global search and as the algorithm begins to approach the end, favoring local search by using a small inertia weight value.

(c).Constriction Factor Approach:

The new expression for the particle's velocity is shown in equation (6).

$$\square_{\square}(\square) = \square(\square_{\square}(\square - 1) + \square 1\square_{1}[\square\square\square\square\square_{\square} - \square_{\square}(\square - 1)]$$

$$+ \square 2\square_{2}[\square\square\square\square\square_{\square} - \square_{\square}(\square - 1)](8)$$

In this equation, the constriction factor, represented by K is defined as:

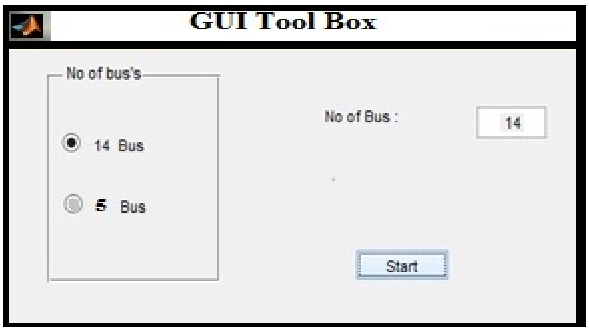
$$\square = \left[\frac{2}{2} - \square - \sqrt{\square^2 - 4\square}\right] \quad \square = \square 1 + \square 2, \square > 4 (9)$$

(d).Stopping Criteria:

In either variant of PSO, the main objective is to find the global optimum through the convergence of the swarm of particles to a particular point in the problem's hyperspace. However, to efficiently construct this algorithm, stopping criteria have to be properly defined. If the defined value is too small, it may result in error when obtaining the global optimum. On the other hand, when the value is too high, it leads to time being wasted in processing iterations when there is no need for it.

IV. GRAPHICAL USER INTERFACE DESCRIPTION: FACTS PLACEMENT TOOLBOX

To start, the user should choose between single and multiple type FACTS device allocation, followed by the type and number of FACTS to be allocated (SVC, TCSC, etc.). Finally, the user can pick a network among several IEEE test systems whose complexity at present ranges from four to 14 buses.The FACTS placement toolbox using GUI is shown in Fig. 4.1.The overall view of the implemented GUI is presented in Fig. 4.1.


GUI Tool Box

No of bus's

● 14 Bus

○ 5 Bus

No of Bus : 14

Fig. 4.1 FACTS devices placement toolbox for IEEE bus system using GUI

V. RESULTS OF FACTS PLACEMENT ON IEEE TEST NETWORKS

FACTS devices placement toolbox for the tested IEEE 14 bus system are shown in Fig.5.1The Performance characteristics of 14-bus system are shown in fig.6.

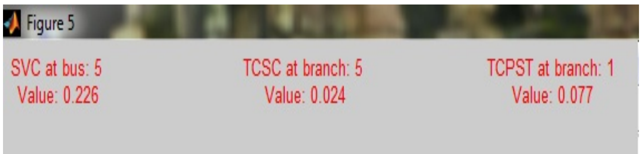


Figure 5

SVC at bus: 5 Value: 0.226

TCSC at branch: 5 Value: 0.024

TCPST at branch: 1 Value: 0.077

Fig. 5.1 FACTS devices placement toolbox for IEEE 14bus system

TABLE 1-FACTS PLACEMENT TOOLBOX RESULT

FACTS	Location	Rating	Value
SVC	Branch 5	0.226	0.98469MW
TCSC	Branch 5	0.024	-0.17431MVR
TCPST	Branch 1	0.077	0.21002MVR

a). Results Of Facts Placement On IEEE Test Networks:

In order to verify the performance of the implemented GUI, several combinations of FACTS devices were sited optimally on different IEEE test networks. The allocation results of a selected subset of the many scenarios studied are presented in Table 1. Based on with and without FACTS installation, the total loss minimization of the power system is presented in Table 2.The transmission line flow and loss of IEEE 14 bus system is tabulated in Table 3.

TABLE 2-TOTAL LOSS MINIMIZATION BASED ON WITH AND WITHOUT FACTS INSTALLATION.

Bus System	IEEE 14
Without FACTS	0.16022
With FACTS	0.15760

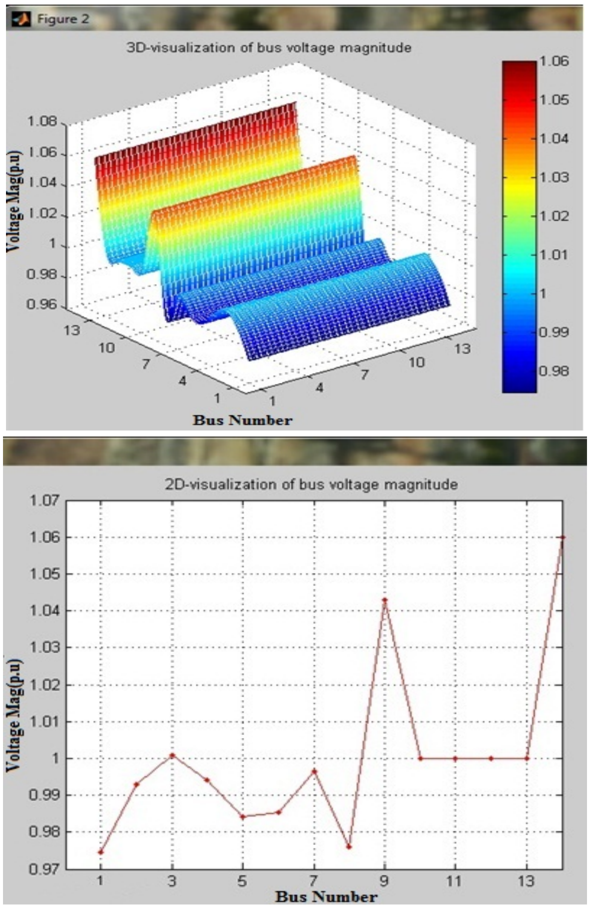


Fig.5.2.(a) 3D (b)2D Voltage magnitude characteristics of IEEE 14bus system

TABLE 3-TRANSMISSION LINE FLOW AND LOSS FOR IEEE 14 BUS SYSTEM

Bus From	**Bus To**	**Power Flow From - To**	**Power Loss**	
			MW	**Mvar**
1	2	1.619+j -0.189	0.046	0.077
1	5	0.691+j 0.153	0.024	0.037
2	3	0.640+j 0.245	0.021	0.039
2	4	0.938+j -0.066	0.047	-0.020
2	5	0.181+j 0.157	0.003	-0.024
3	4	-0.321+j 0.015	0.007	-0.014
4	5	-0.306+j 0.078	0.001	-0.009
4	7	0.070+j -0.012	0.000	0.001
4	9	0.331+j 0.110	0.000	0.010
5	6	0.461+j -0.013	0.000	0.009
6	11	0.094+j -0.038	0.001	0.002
6	12	0.066+j -0.005	0.001	0.002
6	13	0.196+j -0.054	0.003	0.009
7	8	-0.000+j 0.052	0.000	0.000

VI.CONCLUSION

This method is based on particle swarm optimizing (PSO).The algorithm is easy to implement and it is able to find multiple optimal solutions to the constrained multi-objective problem, giving more flexibility to take the final decision about the location of the FACTS units. The system loadability, bus voltage profile improvement, the power system loss reduction and size of device are employed as the measure of power system performance in optimization algorithm. For large power systems, the PSO algorithm could have a significant advantage compared to exhaustive search and other methods by giving better solutions with less computational effort. The Generic Graphical User Interface based on PSO to seek the optimal locations and values of a given set of FACTS devices for more efficient use of power system assets. The simulation results show that the FACTS placement toolbox is effectively applicable to find the optimal locations and values of the given multi-type FACTS devices mix in a given power system so as to maximize the system loadability under security constraints.

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BIOGRAPHIES

Mr. M. Vimalraj received B.E (Electrical & Electronics Engineering) from Ganadipathy Tulsi's Jain Engineering College, Vellore (TN), India and M.E (Power Systems Engg) from Kingston Engg College, Vellore (TN), India. Areas of interest are include Renewable Energy Resources, Electrical machines, FACTS, Power System operation & control, Soft Computing.

Mr.K.M.MohamedThoufiqreceived B.E (Electrical & Electronics Engineering) from Ganadipathy Tulsi's Jain Engineering College, Vellore (TN), India and currently pursuing M.E(Power Systems Engg) in Mahabarathi Engineering College (TN), India. Areas of interest are include Renewable Energy Resources, Electrical machines, FACTS, Power System operation & control, Soft Computing.

Mr. R. Ramanathan received B.E (Electrical & Electronics Engineering) from LCR Engineering College, Chennai (TN), India and M.E (PED) from from TB Engineering College, Chennai (TN), India. Areas of interest are include FACTS, Power System operation & control, Soft Computing.