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A Nature Inspired Algorithm for location and Performance analysis of UPFC

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Abstract: The paper presents a PSO based approach for optimal location of UPFC in transmission system. Two objectives reduction of power loss and improving the bus voltages are considered in this paper. In this regard the power flow injection model of UPFC is derived and injected into load flow studies. In this work the effect of placement of UPFC at optimal location on the system parameter is studied. The effectiveness of the method is tested on IEEE 30 bus system. The results obtained shoe that the proposed method is capable of finding the optimal location and improving the system stability.

1. Introduction

There is a vast increase in the power flow transactions due to power system restructuring. High cost and environmental are major hurdles for expansion of power transmission network, which provokes the need for study of unused potential of the transmission system capacity. FACT devices can increase power transfer capability reduce system losses, and stability. There are many advanced approaches proposed in the literature for optimizing location FACT devices and their parameter settings.

Unified Power Flow Controller (UPFC), Phase Shifting Transformer (PST) and Optimal UPFC can be utilized to control the power flow in the lines by changing their parameters to achieve various objectives. FACTS devices can control steady state power flow as well as system parameters in dynamic state [1-4]. Without changing the generation schedule and topology of power system network, the power flow can be controlled by placing the FACTS devices in appropriate locations [5]. There is an increased interest in FACTS due to the development in modern power electronic devices [6] combined with deregulation of power industry. The power flow control is a cost-effective means of dispatching specified power transactions. FACTS devices can relieve the system from congestion and help in utilizing the maximum capacity of the transmission network without threatening the stability and network security. There are several methods to find optimal locations of specified type of FACT device. However, there is no generalized approach for placement of any type of FACT device. This paper presents a generalized method to determine ideal location for placement of any FACT device with a fixed parameter set. According to the proposed method, the objective function is differentiated with respect to the parameter of the corresponding FACT device to be optimized. The basic concept of the generalized method is initially identifying the control parameters of the respective FACT devices and then to determine sensitivity index with FACT device located in each line. Sensitivity index is obtained by differentiating the objective function with respect to device parameters. The parameter that influences power flow in a line is the angle of injected voltage of the series converter. The generalized approach cannot be applied to the systems where analytical model of the FACTS device is not available.

The proposed method is tested on a 5 Bus and IEEE14 Bus systems for placement of three devices, viz., UPFC and IPFC respectively. The rest of the paper is organized as follows. Section II contains the static model of UPFC and STATCOM, section III contains optimal location of FACTS devices. Section IV gives the result analysis and Section V gives the conclusions.

2. Modelling of UPFC

UPFC is designed by combining the series compensator (SSSC) and shunt compensator (STATCOM) coupled with a common DC capacitor. It provides the ability to simultaneously control all the transmission parameters of power systems, i.e. voltage, impedance and phase angle. It consists of two converters – one connected in series with the transmission line through a series inserted transformer and the other one connected in shunt with the transmission line through a shunt transformer. The DC terminal of the two converters is connected together with a DC capacitor. The series converter control to inject voltage 7 magnitude and phase angle in series with the line to control the active and reactive power flows on the transmission line. Hence the series converter will exchange active and reactive power with the line.

The UPFC can perform the function of STATCOM and SSSC and phase angle regulator. Besides that, the UPFC also provides an additional flexibility by combining some of the function above. UPFC has also a unique capability to control real and reactive power flow simultaneously on a transmission system as well as to regulate the voltage at the bus where it's connected [7].

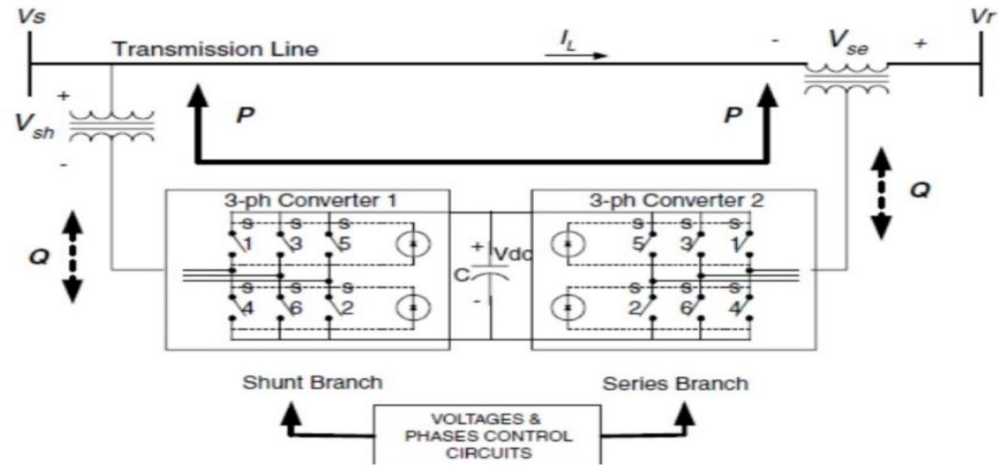

Figure 1. Power flow model of UPFC

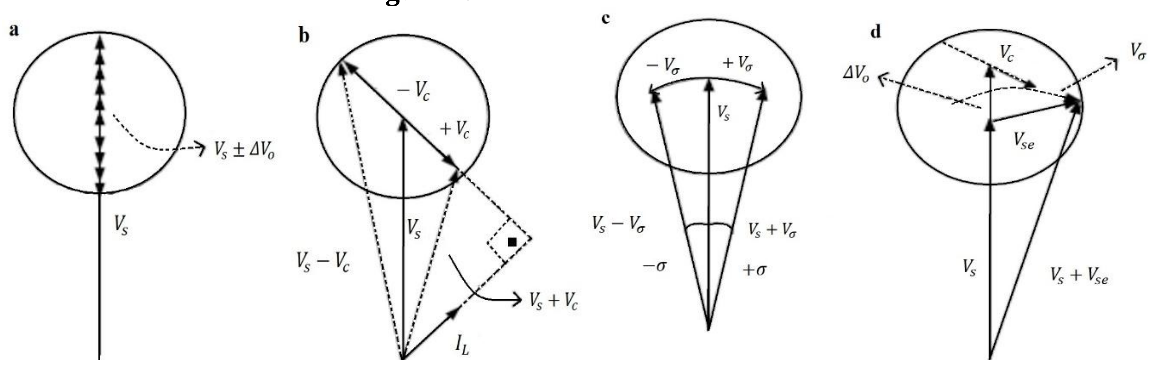

Figure 2. Functional capabilities of UPFC (a) Terminal voltage regulation (b) Series reactive compensation (c) Phase angle shifting (d) multi-function control mode

The steady-state UPFC mathematical model is developed by replacing voltage source V_s by a current source I_s parallel with the transmission line [8], where

$$b_s = \frac{1}{x_s} \tag{1}$$

$$I_s = -jb_sV_s \tag{2}$$

The detailed model of UPFC is given in [9]

The complete steady state model of UPFC is given by the following equations

$$P_{i,upfc} = rb_sV^2{}_i sin\,\gamma - rb_sV_iV_j\,sin(\theta_i - \theta_j + \gamma) \tag{3}$$

$$P_{j,upfc} = rb_sV_iV_j\,sin(\theta_i - \theta_j + \gamma) \tag{4}$$

$$Q_{i,upfc} = -rb_sV^2{}_i cos\,\gamma \tag{5}$$

$$Q_{j,upfc} = rb_sV_iV_j\,cos(\theta_i - \theta_j + \gamma) \tag{6}$$

General nodal power flow equations and linearized power system model can be expressed in rectangular form by the following equations:

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix}^n = \begin{bmatrix} H & N \\ J & L \end{bmatrix}^n \begin{bmatrix} \Delta\theta \\ \Delta V/V \end{bmatrix}^n \tag{7}$$

where P and Q are vectors of real and reactive nodal power injections, which are function of nodal voltages, (V\h), and network conductance and susceptance, (G and B), respectively. (ΛP = Pspe _ Pcal) is the real power mismatch vector and (ΛQ = Qspe _ Qcal) is the reactive power mismatch vector. (ΛV and Λh) are vectors of incremental changes in nodal voltages. H, N, J, and L denote the basic elements in the Jacobian matrix. Derived injected power model can be incorporated into a general NR power flow algorithm by modifying the related elements in the normal Jacobian matrix and the corresponding power mismatch equations as well [10].

3. Optimal location of UPQC

PSO is an evolutionary computation technique developed by Eberhart and Kennedy in 1995 and was inspired by the social behavior of bird flocking and fish schooling. PSO has its roots in artificial life and social psychology as well as in engineering and computer science. It utilizes a population of individuals, called particles, which fly through the problem hyperspace with some given initial velocities. In each iteration, the velocities of the particles are stochastically adjusted considering the historical best position of the particles and their neighborhood best position; where these positions are determined according to some predefined fitness function. Then, the movement of each particle naturally evolves to an optimal or near-optimal solution [11-14]. The name of "swarm" comes from the irregular movements of the particles in the problem space, more similar to a swarm of mosquitoes rather than flock of birds or school of fish.

The following equation represents the fundamental PSO

$$V_i^{k+1} = w\,V_i^k + c_1\,rand_1(\ldots) \times (p\,best_i - s_i^k) + c_2\,rand_2(\ldots) \times (gbest - s_i^k)$$

Where v_i^k: velocity of agent i at iteration k, w: weighting function, c_j: weighting factor, rand: uniformly distributed random number between 0 and 1, s_i^k : current position of agent i at iteration, $pbest_i$: pbest of agent i, gbest: gbest of the group.

Algorithm for optimal location is given as below

A. Because UPFC are expensive, therefore the minimum device installed is searched for economic efficiency reasons.

B. Generator buses where voltages are regulated by the generator do not need UPFC installation.

C. Each bus is limited to the installation of one device. Installing more does not represent a significant effect.

D. If the bus voltage is above 0. 95p.u then UPFC is not installed.

The algorithms applied for IEEE 30 bus system and results are obtained as follows

4. Results and analysis

A 30-Bus test system is used for this paper. The test system consists of 5 generators and 24 PQ bus (or load bus). The problem to be addressed consists of finding the optimal location and power rating of UPFC with power flow injection model (PFI). In this case the PSO is able to find different options for capacity of the UPFC with the PFI model [15].

TABLE I. Optimal location of UPFC

UPFC Bus	V (pu)	Theta (Degree)	P (pu)	Q (pu)
18	1.0000	-16.4708	0.9343	0.9206
27	1.0000	-15.5960	0.9343	0.9206

TABLE II. Power flow with UPFC

Bus No.	V (pu)	Angle degree	P Flow (pu)	Q Flow (pu)
1	1.0600	0.0000	0.9451	0.9314
2	1.0430	-5.3585	0.9421	0.9283
3	1.0189	-7.5267	0.9377	0.9239
4	1.0094	-9.2798	0.9360	0.9223
5	1.0100	-14.1846	0.9361	0.9224
6	1.0086	-11.0506	0.9359	0.9221
7	1.0014	-12.8653	0.9346	0.9208
8	1.0100	-11.8277	0.9361	0.9224
9	1.0366	-14.0831	0.9409	0.9271
10	1.0166	-15.7094	0.9373	0.9235
11	1.0820	-14.0831	0.9491	0.9353
12	1.0466	-15.1839	0.9427	0.9289
13	1.0710	-15.1839	0.9471	0.9333
14	1.0276	-16.0515	0.9393	0.9255
15	1.0194	-16.0117	0.9378	0.9240
16	1.0266	-15.6766	0.9391	0.9253
17	1.0142	-15.9128	0.9369	0.9231
18	1.0000	-16.4708	0.9343	0.9206
19	0.9972	-16.6961	0.9338	0.9200
20	1.0012	-16.5100	0.9346	0.9208
21	1.0028	-16.2514	0.9348	0.9210
22	1.0060	-16.0166	0.9354	0.9216
23	1.0029	-16.2595	0.9349	0.9211
24	0.9917	-16.3227	0.9329	0.9191
25	0.9914	-16.0447	0.9328	0.9190
26	0.9732	-16.4871	0.9295	0.9157
27	1.0000	-15.5960	0.9343	0.9206
28	1.0056	-11.6790	0.9354	0.9216
29	0.9796	-16.8850	0.9307	0.9169

The results in the above table show that placing the UPFC at bus 18 or 27 the voltage profile of the system is improved and the voltages at all buses is more than 1.0 p.u which is in the stable region. The results in table III show that the power loss also greatly reduced from 0.2p.u to 0.002116 p.u there by increasing the power flow.

TABLE III. Power loss with and without UPFC

Total power loss	Without UPFC (p.u)	With UPFC (p.u)
	0.2 p.u	0.002116

Analysis of Results of results is divides between voltage profile and power loss

A. Voltage profile

The results show that wit out UPFC majority of the buses are facing under voltage problem i.e below 0.95 p.u. When UPFC is injected at optimal location using PSO all the buses are in stable voltage region and is above 1.0 p.u value. The active and reactive power flow at each bus is also improve and can be seen from table 1. The results also show that the placements of UPFC with proposed algorithm has improved the system performance.

B. Power loss

The optimal location of UPFC with the proposed algorithm has reduced the total power loss in the system. The power loss obtained without UPFC is 0.2 p.u. When the UPFC is placed in optimal location the power loss is drastically reduced to 0.002116 p.u as shown in table III. Hence the placement of UPFC not only increased the power flow but also reduced the power loss to an acceptable limit.

5. CONCLUSIONS

In this paper a PSO algorithm is proposed for the optimal location of UPFC.A power flow injection model of UPFC is also derived to incorporate this model into load flow studies. The results show that the optimal location of UPFC increases the voltage profile and reduces the power loss. The power flow capability of the system is also improved and is observed from the results obtained. The proposed algorithm can also be extended for advanced FACTS devices like DPFC in the presence of contingencies and its security.

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