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Optimum Power Flow With Multi-Types Of Facts By Using Particle Swarm Optimization (PSO)

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Abstract

In this paper, a Particle Swarm Optimization (PSO) approach is proposed to minimize the generator fuel cost in optimal power flow (OPF) control with multi-type flexible AC transmission systems (FACTS) devices. The optimal settings of FACTS parameters are searched for by the PSO approach and fixed flexible AC transmission system parameters are also searched for by the PSO. Particle Swarm Optimization (PSO) based OPF algorithm is developed in MATLAB 7.0. The optimum power flow using PSO with multi type FACTS devices such as TCSC, TCPS and UPFC for IEEE 26 bus system is done. The simulation results have demonstrate the fact that the proposed PSO based method yields better results.

Index Terms- *Thyristor-controlled series capacitor (TCSC), thyristor-controlled phase shifter (TCPS), Unified power flow controller (UPFC).*

1. Introduction

FACTS is one aspect of the power electronics revolution that is taking place in all areas of electrical energy. A variety of power semiconductor devices not only offer the advantage of high speed and reliability of switching but, more importantly, the opportunity offered by a variety of innovative circuits concepts based on these power devices enhance the value of electrical energy. The control of an AC power system in real time is involved because power flow is a function of the transmission line impedance, the magnitude of the sending end voltages, and the phase angle between the voltages. It is generally understood that AC transmission system could not be controlled fast enough to handle dynamic system conditions. In recent years, the development of semiconductor technology has led to the use of power electronics in electrical power devices. The advantages of these so-called Flexible AC Transmission System (FACTS) devices are primarily rapid response and enhanced flexibility. Flexible AC transmission systems (FACTS) devices are integrated in power systems to control power flow, increase transmission line stability limit and improve the security of transmission systems. FACTS controllers are used to enhance the system flexibility and increase system loadability. In addition to controlling the power flow in specific lines, FACTS devices could be used to minimize the total generator fuel cost in Optimal Power Flow (OPF) problem.

2. FLEXIBLE AC TRANSMISSION SYSTEMS (FACTS)

Introduction

The opportunities arise through the ability of FACTS controllers to control the interrelated parameters that govern the operation of transmission systems including series impedance, shunt impedance, current, voltage, phase angle and the damping of oscillation at various frequency below the rated frequency. These constrains cannot be over come, which maintaining the required system reliability, by mechanical means without lowering the useable transmission capacity. By providing added flexibility, FACTS controllers can enable a line to carry power closer to its thermal rating.

Importance of Reactive Power Control

A major cause of voltage fluctuations at buses is due to improper control of reactive power requirements of the network. Lagging VARs are required for magnetizing transformers, induction

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motors¸ etc. transmission line consumes lagging VARs (that varies with line current) in their series inductance and generates lagging VARs (that varies with the system voltage) in their shunt capacitance at any instance an improper balance in VARs generated and VARs absorbed in the network leads to undesirable deviations in voltages from their nominal values at some buses (voltages will be below their nominal values during peak load periods and above their nominal values during light load periods). Lack of fast and reliable control of reactive power are the problems with stability, inability to fully utilize transmission lines to their thermal limits power flowing through un-intended lines, higher losses, high or low voltages and recent voltages stability at some buses.

While HVDC transmission is the answer to some of this problem, it cannot be used on a broad basis because of the high converter costs and DC switchgear. Also these converters don't have over load capability and require reactive power (that varies with transmitted DC power support at the converter terminals). Moreover for a developing country, like India, HVDC transmission is not an immediate solution in the power sector.

THYRISTOR CONTROLLED SERIE CAPACITOR (TCSC)

Introduction

A capacitor reactance compensator, which consists of a series capacitor bank shunted by thyristor-controlled reactor in order to provide a smoothly variable series capacitive reactance.

Basic Operating Principles

TCSC consists of a capacitor connected in parallel with a thyristor-controlled reactor (TCR). The TCR circulates a current in the capacitor and helps to boost its voltage above that which could be obtained by line current alone. The TCSC voltage is non-sinusoidal where as the line current has a very small harmonic content. The use of thyristor control to provide variable series compensation makes it attractive to employ series capacitors in long lines. Each of the thyristors is triggered once per cycle and has a conduction period shorter that a half period of rated power frequency. By appropriately firing the thyristors it is possible to make the effective reactance of TCSC at fundamental frequency greater than that of the fixed capacitor (X_C) is shown Fig. 3.1.

STATIC MODEL OF TCSC

The effect of TCSC on the network can be modeled as a series reactance with control parameter X_s. The static model of the network with thyristor-controlled series capacitor (TCSC) is shown in Fig. 2.1.

The new line reactance of the transmission line can be formulated as

$$X_{new} = X_{ij} - X_s \quad (2.1)$$

The injected power is used to model the TCSC is shown in Fig. 3.2. The injected real and reactive power of TCSC at bus i and bus j are as follows.

$$P_{ij} = V_i^2 G_{ij} - V_i V_j (G_{ij} \cos \delta_{ij} + B_{ij} \sin \delta_{ij}) \quad (2.2)$$

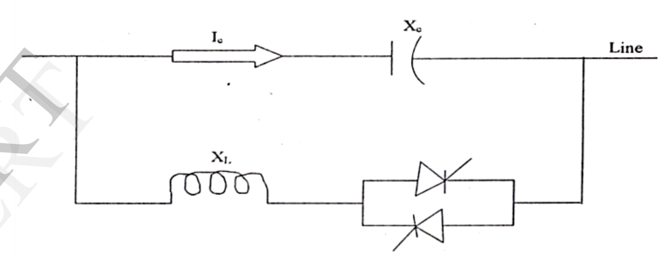
$$Q_{ij} = V_i^2 B_{ij} - V_i V_j (G_{ij} \cos \delta_{ij} + B_{ij} \sin \delta_{ij}) \quad (2.3)$$

$$P_{ji} = V_j^2 G_{ij} - V_i V_j (G_{ij} \cos \delta_{ij} + B_{ij} \sin \delta_{ij}) \quad (2.4)$$

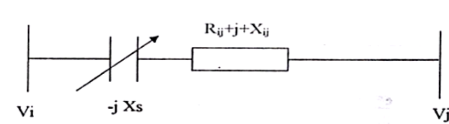
$$Q_{ji} = V_j^2 G_{ij} - V_i V_j (G_{ij} \cos \delta_{ij} + B_{ij} \sin \delta_{ij}) \quad (2.5)$$

Where , δ_{ij} is the voltage angle difference between bus i and bus jy

$$G_{ij}=\frac{Xnew}{R_{ij}^2+Xnew\ 2} \qquad B_{ij}=\frac{Xnew}{R_{ij}^2+X_{new}^2}$$



Static model of TCSC



Injected power model of TCSC

Application Of Tcsc:

1. To improve the static performance of the system such as cost and loss minimization.
2. Steady state voltage regulation and prevention of voltage collapse. And also it is used to damp low frequency oscillations.
3. TCSC with a suitable control strategy have the potential to significantly improve the transient stability as well as dynamic stability margin.
4. Secure operation of power system and increase the power transfer capability.

5.It allows increased utilization of existing network closer to its thermal loading capacity.

THYRISTOR CONTROLLED PHASE SHIFTER (TCPS)

Introduction

A phase shifting transformer adjusted by thyristor switches to provide a rapidly variable phase angle. In general, phase shifting is obtained by adding a perpendicular voltage vector in series with a phase. This vector derived from the other two phases via shunt-connected transformers. The perpendicular series voltage is made variable with a variety of power electronics topologies. A circuit concept that can handle voltage reversal can provide phase shift in either direction. This controller is also referred to as thyristor controlled phase angle regulator (TCPAR).

BASIC OPERATING PRINCIPLES

In Fig. 4.1 the equivalent circuit of TCPS is shown. The current through the magnetic transformer induces a voltages on the primary side of the booster transformer which is in quadrature with the phase voltages. The total reactance seen from the primary side of the booster transformer. The equivalent circuit can be considered as an ideal phase shifter in series with a line reactance. In practical phase shifters the φ dependent part of x, is small compared with x_{ij}.

STATIC MODEL OF TCPS

The effect of TCPS on the network can be modeled by a phase shifting transformer with control parameter φ. The model of the network with TCPS is shown in Fig. 4.1.

The power flow equation of the line can be derived as follows.

$$P_{ij} = V_i^2 G_{ij} / K^2 - V_i V_j / K (G_{ij} \cos(\delta_{ij} + \varphi) + B_{ij} \sin(\delta_{ij} + \varphi)) \quad (5.3)$$

$$Q_{ij} = V_i^2 G_{ij} / K^2 - V_i V_j / K (G_{ij} \cos(\delta_{ij} + \varphi) + B_{ij} \sin(\delta_{ij} + \varphi)) \quad (5.4)$$

$$P_{ji} = V_j^2 G_{ij} - V_i V_j / K (G_{ij} \cos(\delta_{ij} + \varphi) + B_{ij} \sin(\delta_{ij} + \varphi)) \quad (5.5)$$

$$Q_{ji} = V_j^2 G_{ij} - V_i V_j / K (G_{ij} \cos(\delta_{ij} + \varphi) + B_{ij} \sin(\delta_{ij} + \varphi)) \quad (5.6)$$

Where K = cos φ is the transformation co-efficient of the voltage magnitude.

The injected power is used to model TCPS as shown in Fig. 4.2. The injected real and reactive power of TCPS at bus i and bus j are as follows.

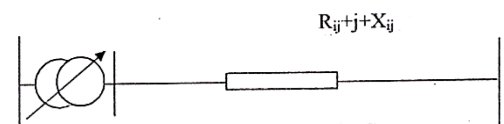
$$P_{is} = -V_i^2 t^2 G_{ij} - V_i V_j t (G_{ij} \sin(\delta_{ij}) - B_{ij} \cos(\delta_{ij})) \quad (5.7)$$

$$Q_{is} = -V_i^2 t^2 G_{ij} - V_i V_j t (G_{ij} \sin(\delta_{ij}) - B_{ij} \cos(\delta_{ij})) \quad (5.8)$$

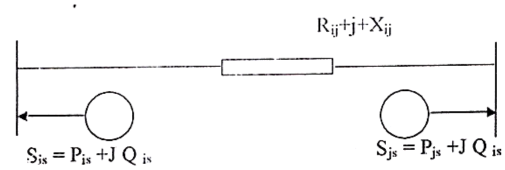
$$P_{is} = -V_i V_j t (G_{ij} \sin(\delta_{ij}) - B_{ij} \cos(\delta_{ij})) \quad (5.9)$$

$$Q_{is} = -V_i V_j t (G_{ij} \sin(\delta_{ij}) - B_{ij} \cos(\delta_{ij})) \quad (5.10)$$

Where t = tan φ.



Static Model Of TCPS



Injected power mode of TCPS

UNIFIED POWER FLOW CONTROLLER (UPFC):

Introduction:

The power transmitted over an AC transmission line is a function of the line impedance, the magnitude of sending end and receiving end voltages and the phase angle between these voltages. The unified power flow controller (UPFC) is a member of this latter family of compensators and power flow controllers, which utilize the synchronous voltage source concept for providing a uniquely comprehensive capability for transmission system control.

BASIC OPERATING PRINCIPLES

The UPFC is a generalized synchronous voltage source represented at the fundamental frequency by voltage phasor V_T with controllable magnitude V_T ($0 \le V_T \le V_{Tmax}$) and angle φ_T ($-\pi \le \varphi_T \le \pi$) in series with the transmission line, as illustrated for the usual elementary two machine system in Fig. 5.1. In this functionally unrestricted operation, which clearly includes voltage and angle regulation, the synchronous voltage source generally exchanges both reactive and real power with the transmission system. Since, as established previously an SVS is able to generate only the reactive power exchanged, the real power must be supplied to it, r absorbed from it, by a suitable power supply or sink. In the UPFC arrangement the real power exchange is provided by one of the end buses as indicated in Fig. 5.2.

STATIC MODEL OF UPFC

The effect of UPFC on the network can be modeled by a series inserted voltage source V_T and two tapped current I_T and I_q. The model of the network with UPFC is shown in Fig. 5.1.

UPFC can control three parameters, the magnitude (V_T) and phase angle (φ_T) of inserted voltage and the terminal voltage of shunt branch (V_i) using reactive current source I_q control. The power flow equation of the line can be derived as follows.

$$P_{ij} = (V_i^2 V_T^2) G_{ij} + V_i V_T G_{ij} \cos(\varphi_T - \delta_{ij}) - V_i V_T (G_{ij} \cos\varphi_T + B_{ij} \sin\varphi_T) + V_i V_j (G_{ij} \cos\delta_{ij} + B_{ij} \sin\delta_{ij}) \quad (5.1)$$

$$Q_{ij} = (V_i^2 V_T^2) G_{ij} + V_i V_T G_{ij} \cos(\varphi_T - \delta_{ij}) - V_i V_T (G_{ij} \cos\varphi_T + B_{ij} \sin\varphi_T) + V_i V_j (G_{ij} \cos\delta_{ij} + B_{ij} \sin\delta_{ij}) \quad (5.2)$$

$$P_{ji} = (V_i^2 G_{ij} + V_j V_T G_{ij} \cos\varphi_T - B_{ij} \sin\varphi_T) - V_i V_j (G_{ij} \cos\delta_{ij} - B_{ij} \sin\delta ij) \quad (5.3)$$

$$Q_{ji} = (V_i^2 G_{ij} + V_j V_T G_{ij} \cos\varphi_T - B_{ij} \sin\varphi_T) - V_i V_j (G_{ij} \cos\delta_{ij} - B_{ij} \sin\delta ij) \quad (5.4)$$

The injected power is used is used to model the UPFC is shown in Fig. 5.4. The injected real and reactive power of UPFC at bus i and bus j are as follows.

$$P_{is} = -V_T^2 G_{ij} - 2 V_i V_T G_{ij} \cos(\varphi_T - \delta_{ij}) + V_j V_T (G_{ij} \cos\varphi_T + B_{ij} \sin\varphi_T) \quad (5.5)$$

$$Q_{is} = V_T I_q + V_i V_T (G_{ij} \sin(\varphi_T - \delta_{ij}) + B_{ij} \sin\varphi_T) \quad (5.6)$$

$$P_{is} = V_j V_T (G_{ij} \cos\varphi_T - B_{ij} \sin\varphi_T) \quad (5.7)$$

$$Q_{is} = V_j V_T (G_{ij} \cos\varphi_T - B_{ij} \sin\varphi_T) \quad (5.8)$$

5.5 APPLICATION OF UPFC

1. To improve the static performance of the system such as cost and loss minimization.
2. To maximize the use of existing transmission facilities within the applicable reliability criteria.
3. Sub-synchronous resonance.
   Improved dynamic behaviour of transmission system (Stability problem).

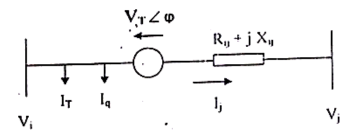


Fig. 5.1 Basic configuration of UPFC

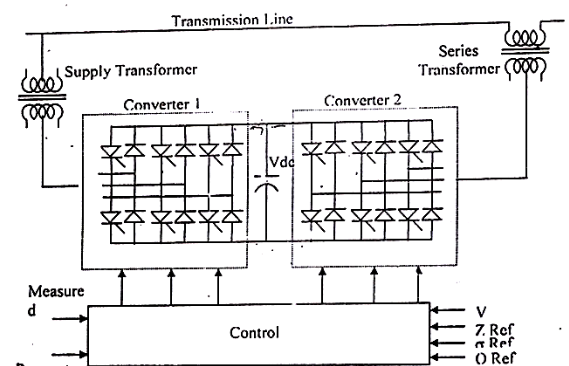


Fig. 5.2 Implementation of the UPFC by two back to back voltage source converters

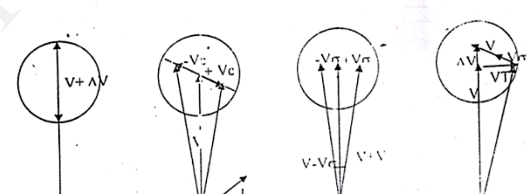


Fig. 5.3a Voltage Regulation Fig. 5.3b Line Impedance Compensation Fig. 5.3c Phase shifting Fig. 5.3d Simultaneous of voltage, impeda and angle

Fig. 5.3 Basic UPFC Power Flow Control Functions

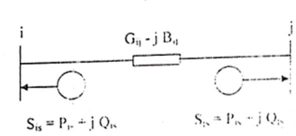


Fig. 5.4 Injection model of UPFC

PARTICLE SWARM OPTIMIZATION (PSO)

Introduction

The term particle swarm optimization (PSO) refers to a relatively new family of algorithms that may be used to fine optimal (or near optimal) solutions to numerical and qualitative problems. It is easily implemented in most programming languages and has proven both very effective and quick when applied to a diverse set of optimization problems. PSO shares many similarities with evolutionary computation techniques such as genetic algorithm (GA). The system its initialized with a population of random solutions and searches for optima by updating generations. However, unlike GA, PSO has no evolution operators such as crossover and mutation. In PSO, the potential solutions, called particle, fly through the problem space by following the current optimum particles.

The PSO Implementation PSO based approach was implemented using the MATLAB language and the developed software program was executed on a 1GHz Pentium IV PC. Initially, several runs have been done with different values of the PSO key parameters such as the initial inertia weight and the maximum allowable velocity. In our implementation the, the following parameters are selected. To demonstrate the effectiveness of the proposed approach different cases with various objectives are considered in this study.

ALGRITHM FOR PARTICLE SWARM OPTIMIZATION (PSO)

Step 1: Initial searching points and velocities are randomly generated within their limits

Step 2: Pbest is set to each initial searching points. The best-evaluated value among Pbest is set to g_{best}.

Step 3: New velocities are calculated using the equation

$$V_{id}^{(t+1)} = w.\ V_{id}^{t} + c_1 * rand(\ ) * (pbest_{id} - x_{id}^{(t)}) + c2 * rand(\ ) * (gbest_d - x_{id}^{(t)})$$

Step 4:If $V_{id}^{(t+1)} < V_{d\ min}$ the $V_{id}^{(t+1)} = V_{d\ min}$ and if $V_{id}^{(t+1)} > V_{d\ max}$ then $V_{id}^{(t+1)} = V_{d\ max}$.

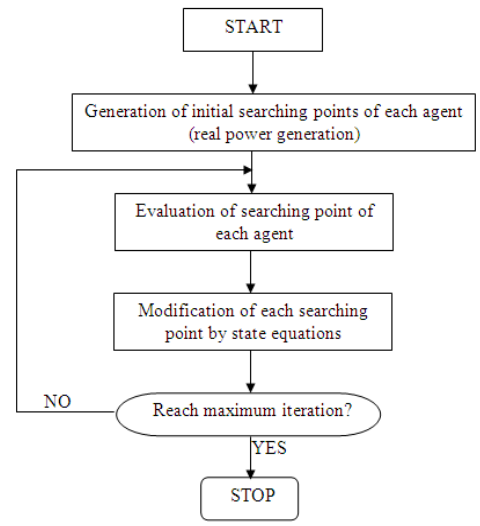
Step5:New searching points are calculated using the equation

$$X_{id}^{(t+1)} = x_{id}^{(t)} + v_{id}^{(t+1)}$$

Step 6:Evaluate the fitness values for new searching point. If evaluated values of each agent is better than previous P_{best} the set to P_{best}. If the best P_{best} is better than g_{best} then set to g_{best}.

Step 7: If the maximum iteration is reached stop the process otherwise go to step 3.

GENERAL FLOWCHART OF PSO



OPTIMAL REAL POWER FLOW

7.1 INTRODUCTION

The main purpose of ORPF is to determine the optimal operation state of power system while meeting some specified constraints. Several methods were proposed to solve the optimal real power flow without FACTS devices, with TCSC, with TCPS and with UPFC devices.

OPTIMAL REAL POWER FLOW WITHOUT FACTS DEVICES

The optimal real power flow is to determine the generation outputs of units that minimize the operating cost while satisfying a set of constraints.

7.2.1. Problem Formulation

The optimal real power flow problem is formulated as follows.

Objective function

$$\text{Min} \sum_{i \in NG} (a_i P_{Gi}^2 + b_i P_{Gi} + c_i) \qquad (7.1)$$

Constrains

$$P_{Gi} - P_{di} - \sum_{j \in N} V_i V_j Y_{ij} \cos(\theta_{ij} + \delta_j - \delta_i) = 0 \qquad \forall i \in N \qquad (7.2)$$

$$Q_{Gi} - Q_{di} - \sum_{j \in N} V_i V_j Y_{ij} \sin(\theta_{ij} + \delta_j - \delta_i) = 0 \quad \forall i \in N \qquad (7.3)$$

$$P_{Gi,min} \le P_{Gi} \le P_{Gi,max} \quad \forall i \in NG \qquad (7.4)$$

$$Q_{Gi,min} \le Q_{Gi,max} \quad \forall i \in NG \qquad (7.5)$$

$$V_{Gi,min} \le V_{Gi} \le V_{Gi,max} \quad \forall i \in N \qquad (7.6)$$

OPTIMAL REAL POWER FLOW WITH MULTI-TYPE OF FACTS DEVICES

In this section, multi-type of FACTS devices such as TCSC, TCPS and UPFC is integrated in ORPF by using the static model. For ORPF control, multi-type of FACTS devices such as TCSC, TCPS and UPFC devices are used to minimize the total generator fuel cost subject to power balance constraint, real and reactive power generation limits, voltage limits, transmission line limits, TCSC, TCPS and UPFC parameter limits.

7.3.1 Problem formulation

$$\text{Min} \sum_{i \in NG} (a_i P_{Gi}^2 + b_i P_{Gi} + c_i) \qquad (7.7)$$

Constrains

$$P_{Gi} - P_{is} - P_{di} \sum V_i V_j Y_{ij} \cos(\theta_{ij} + \delta_j - \delta_i) = 0 \quad \forall i \in N, \; J \in N \qquad (7.8)$$

$$Q_{Gi} - Q_{is} - Q_{di} \sum V_i V_j Y_{ij} \sin(\theta_{ij} + \delta_j - \delta_i) = 0 \quad J \in N \quad \forall i \in N \qquad (7.9)$$

$$P_{Gi,min} \le P_{Gi} \le P_{Gi,max} \quad \forall i \in NG \qquad (7.10)$$

$$Q_{Gi,min} \le Q_{Gi} \le Q_{Gi,max} \quad \forall i \in NG \qquad (7.11)$$

$$V_{Gi,min} \le V_{Gi} \le V_{Gi,max} \quad \forall i \in N \qquad (7.12)$$

$$0 \le \varphi \le 0.1 \quad \forall i \in NU \qquad (7.13)$$

$$0 \le V_T \le V_{T,max} \quad \forall i \in NU \qquad (7.14)$$

$$-\pi \le \varphi_T \le \pi \quad \forall i \in NU \qquad (7.15)$$

$$0 \le I_q \le I_{q.max} \quad \forall i \in NU \qquad (7.16)$$

4 CASE STUDIES

There are five case studies.

Case 1 is ORPF without FACTS device is used as a reference case.

Case 2 is ORPF with one TCPS at line 14-15.

Case 3 is ORPF with one TCSC at line 2-3

Case 4 is ORPF with one UPFC at line 14-15.

Case 5 is ORPF with one TCPS and one TCSC at line 2-3.

Table 7.1 Minimum and Maximum Limits of Control Variables for IEEE 26-bus system

Bus No.	Real Power Generation	
	Min (mw)	Max (Mw)
1	100	500
2	50	200
3	80	300
4	50	150
5	50	200
26	50	120

Table 7.2 Cost Co-efficient

Bus No.	A	B	c
1	0.00 70	7.0	340
2	0.00 95	10.0	300
3	0.00 90	8.5	320
4	0.00 90	11.0	300
5	0.00 80	10.5	320
26	0.00 75	12.0	290

RESULTS

Table7.4. Optimal Values of Case 1 to Case 5 for IEEE 26-Bus System Using PSO

BUS	CASE 1	CASE 2	CASE 3	CASE 4	CASE 5
PG1	416.510	336.150	373.360	393.5637	387.750
PG2	158.451	161.022	240.627	162.4230	219.856
PG3	204.159	283.984	227.251	264.6000	242.758
PG4	236.192	149.311	138.727	146.7358	110.319
PG5	215.180	202.388	227.420	174.4482	151.592
PG6	48.0365	68.6694	71.1375	92.7536	69.5758
Sys. Loss (MW)	15.53	15.526	15.524	15.5243	15.158
Cost($/hr)	15190.	15137.6	15135.8	15028.1	15002.8

RESULT AND DISCUSSION

To verify the feasibility of the proposed PSO method, an IEEE 26 bus system was taken as a test system and the proposed PSO method was tested on it. This ensures that the PSO method yields better quality of solution. Thus the above said fact reveals the superior properties of PSO. Thus the proposed PSO method can yield high quality solutions.

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