Comparative Evaluation of Optimum Power Flow with and without FACTS Devices by using Particle Swarm Optimization

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***Abstract*— In this paper, a Particle Swarm Optimization (PSO) approach is proposed to minimize the losses and generator fuel cost in optimal power flow (OPF) control with& without flexible AC transmission systems (FACTS) devices. The optimal settings of FACTS parameters are searched by the PSO approach. Particle Swarm Optimization (PSO) based OPF algorithm is developed in MATLAB 7.0.The optimum power flow using PSO with FACTS devices such as TCSC and UPFC in IEEE-26 bus system is done. The simulation results have tabulated with& without FACTS devices. The comparison of with &with FACTS devices, The optimum with UPFC by using PSO serves better results.**

Keywords*— Thyrisyor controlled series capacitor (TCSC) *Unified power flow controller (UPFC).

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.

1.0 FLEXIBLE AC TRANSMISSION SYSTEMS (FACTS)

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 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.

2. 0 THYRISTOR CONTROLLED SERIES CAPACITOR

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. The TCSC figure 3.1. is based on thyristor without the gate turn-off capability. It is a very important FACTS controller. A variable reactor such as a Thyristor-Controlled Reactor (TCR) is connected across a series capacitor. When the TCR firing angle is 180 degrees, the reactor becomes non conducting and the series capacitor has its normal impedance increases. At the other end, when the TCR firing angle is 90 degrees, the reactor becomes fully conducting, and the total impedance becomes inductive, because the reactor becomes fully conducting, and the total impedance becomes inductive, because the reactor impedance is designed to be much lower than the series capacitor impedance. When 90 degrees firing angle, the TCSC helps in limiting fault current. The TCSC may be a single, large unit, or may consist of several equal or different sized smaller capacitors in order to achieve a superior performance

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. Most applications of TCSC technology involve relatively smooth control of reactance, which is needed to securely damp power swings or to regulate power flow on adjacent transmission 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.

Series capacitors have been successfully used for many years in order to enhance be stability and loadability of high voltage transmission networks. The principles is to compensate the inductive voltage drop in the line by an inserted capacitive voltage or in other words to reduce the effective of the transmission line.

The inserted voltage provided by a series capacitor is in proportion to and in quadrance with the line current. Thus the generated reactive power provided by the capacitor is proportional to the square of the current. This means that a series capacitor has a self-regulating impact. When the loading of the system increases, the generated reactive power from the series capacitor also increases.

CONVENTIONALTRANSMISSION CONTROL CAPABILITIES

The TCSC is able to directly schedule the real power flow through a typically selected line and allow the system to operate closer to the line limits. More importantly because of its rapid and flexible regulation ability, it can improve transient stability and dynamic performance of the power system. Particularly, in systems with large bulk transfer of power and long transmission lines it can be used to increase the power transfer capability, damp low frequency oscillations.

The main consideration for the structure of the internal control operating the power circuit of the TCSC is to ensure immunity to sub synchronous resonance. Present approaches follow two basic control philosophies. One is to operate the basic phase-locked-loop (PLL) from the fundamental component of the line current. In order to achieve this, it is necessary to provide substantial filtering to remove the super- and, in particular, the subsynchronous components from the line current and, at thesame time, maintain correct phase relationship for proper synchronization. A possible internal control scheme of this arrangement the conventional technique of converting the demanded TCR current into the corresponding delay angle, which is measured from the peak (or, with a fixed 90 degree shift, from the zero crossing) of the fundamental line current, is used. The reference for the demanded TCR current is, usually provided by a regulation loop of the external control, which compares the actual capacitive impedance or compensating voltage to the reference given for the desired system operation. The second approach also employs a PLL, synchronized to the line current, for the generation of the basic timing reference. However, in this method the actual zero crossing of the capacitor voltage is estimated from the prevailing capacitor voltage and line current by an angle correction circuit. The delay angle is then determined from the desired angle and the estimate correction angle so as to make the TCR conduction symmetrical with respect to the expected zero crossing. The delay angle of the TCR, and thus the compensating capacitive voltage, as in the previous case, is controlled overall by a regulation loop of the external control in order to meet system-operating requirements. This regulation loop is relatively slow, with a bandwidth just sufficient to meet compensation requirements (power flow adjustments, power oscillation damping, etc.,). Thus, from the standpoint of the angle correction circuit, which by comparison is very first(correction takes place in each half cycle), the output of the phase shifter is almost a steady-state reference. Although control circuit performances are usually heavily dependent on the actual implementation, the second approach is theoretically more likely to provide faster response for those applications requiring such response.

STATIC MODEL OF TCSC

$$P_{ij}=V_i^2\ G_{ij}-V_i\ V_j(G_{ij}\ \text{COS}\ \delta_{ij}+B_{ij}\ \ \sin\delta_{ij})$$

$$Q_{ij}=V_i^2\ G_{ij}-V_i\ V_j(G_{ij}\ \text{COS}\ \delta_{ij}+B_{ij}\ \ \sin\delta_{ij})$$

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

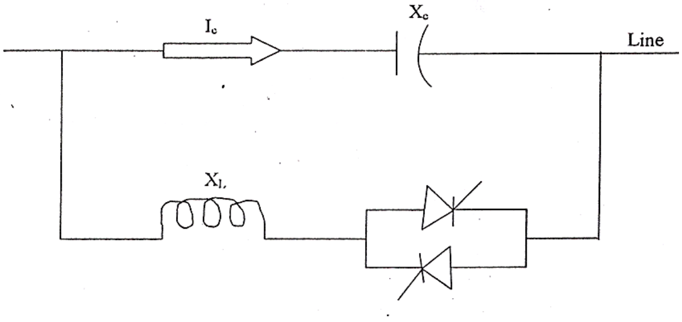
$$Q_{ji}=V_j^2\ G_{ij}-V_i\ V_j(G_{ij}\ \text{COS}\ \delta_{ij}+B_{ij}\ \ \sin\delta_{ij})$$

Where

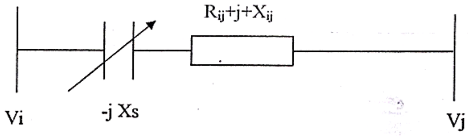
δ_{ij} is the voltage angle difference between bus i and bus j.

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, and thus avoiding the need to construct new transmission lines.



Static model of TCSC



Injected power model of TCSC

3.UNIFIED POWER FLOW CONTROLLER (UPFC):

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 $\psi_T(-\Pi \le \psi_T \le \Pi)$ 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 bothreactive 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.s

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 (ψ_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.

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

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

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

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

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.

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

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

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

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

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).

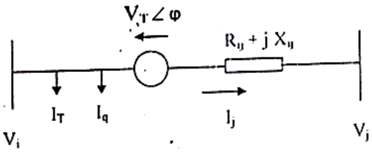


Fig. 5.1 Basic configuration of UPFC

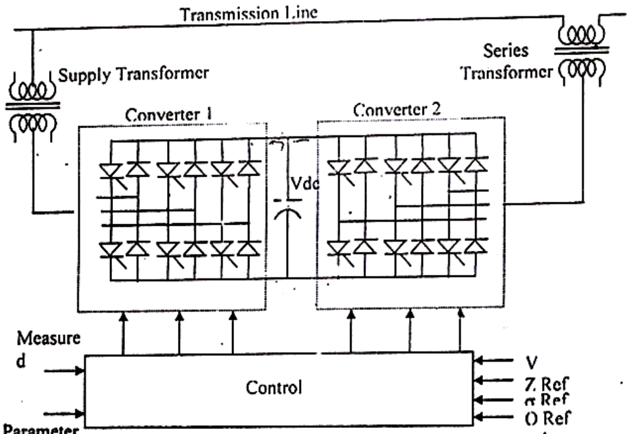


Fig. 5.2 Implementation of the UPFC by two back to back voltage source converters

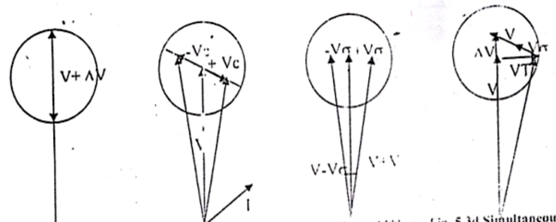


Fig. 5.3a Voltage Regulation Fig. 5.3b Line Impedance Compensation Fig. 5.3c Phase shifting Fig. 5.3d Simultaneous of voltage, impeda and angle

Fig. 5.3 Basic UPFC Power Flow Control Functions

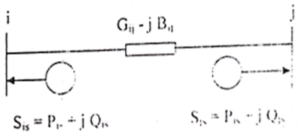


Fig. 5.4 Injection model of UPFC

4.0PARTICLE SWARM OPTIMIZATION (PSO)

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

$Vid^{(t+1)}$ = w. Vid^{t}+c1*rand( )*(pbestid-xid(t))+ c2*rand( )*(gbestd-xid(t))

Step 4:If $Vid^{(t+1)}$ < Vd min the $Vid^{(t+1)}$ = Vd min and if $Vid^{(t+1)}$ > Vd max then $Vid^{(t+1)}$ = Vd max.

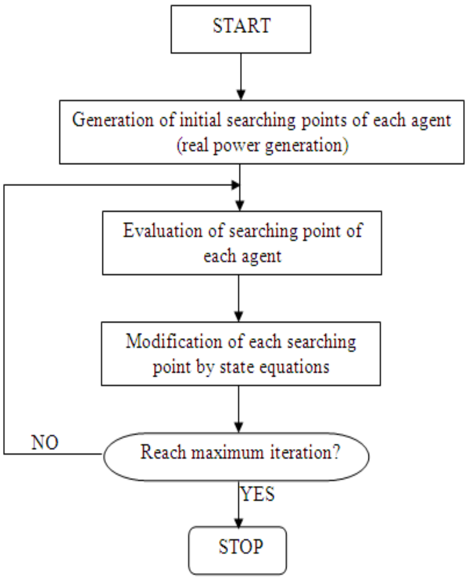
Step5:New searching points are calculated using the equation

$Xid^{(t+1)}=xid^{(t)}+vid^{(t+1)}$

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



5.0 OPTIMAL REAL POWER FLOW

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 device 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.

Problem Formulation

The optimal real power flow problem is formulated as follows.

Objective function

$$\text{Min} \sum_{i\epsilon NG} a_i\, PGi^2 + b_i P_{Gi} + C_i$$

Constrains

$$P_{Gi} - P_{di} - \sum_{J\epsilon N} V_i V_j Y_{ij} cos(\theta_{ij} + \delta_j - \delta_i) = 0$$

$$Q_{Gi} - Q_{di} - \sum_{J\epsilon N} V_i V_j Y_{ij} sin(\theta_{ij} + \delta_j - \delta_i) = 0$$

$$P_{Gi,}\text{min} \le P_{Gi} \le P_{Gi}\text{,max} \quad \forall i \in NG$$

$$Q_{Gi}, min \le Q_{Gi} \le Q_{Gi}\text{,max} \quad \forall i \in NG$$

$$V_{Gi}\text{,min} \le V_{Gi} \le V_{Gi}, max \quad \forall i \in N$$

OPTIMAL REAL POWER FLOW WITH OF FACTS DEVICES

In this section, FACTS device such as UPFC is integrated in ORPF by using the static model. For ORPF control, FACTS devices such as UPFC device 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 and UPFC parameter limits.

Problem formulation

$$\text{Min} \sum_{i\epsilon NG} a_i \, PGi^2 + b_i P_{Gi} + C_i$$

Constrains

$$\boldsymbol{P_{Gi} - P_{si} - P_{di} \sum_{J\epsilon N} V_i V_j Y_{ij} cos(\theta_{ij} + \delta_j - \delta_i) = 0}$$

$$\boldsymbol{Q_{Gi} - Q_{si} - Q_{di} \sum_{J\epsilon N} V_i V_j Y_{ij} sin(\theta_{ij} + \delta_j - \delta_i) = 0}$$

$$P_{Gi}, \text{min} \leq P_{Gi} \leq P_{Gi}, \text{max} \quad \forall i \in NG$$

$$Q_{Gi}, min \leq Q_{Gi}, \text{max} \quad \forall i \in NG$$

$$V_{Gi}, \text{min} \leq V_{Gi} \leq V_{Gi}, max \quad \forall i \in N$$

Table 5.1 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 5.2 Cost Co-efficient

Bus No.	**A(\$/Mw^{2}hr)**	**B(\$/Mwhr)**	**C(\$)**
1	0.0070	7.0	340
2	0.0095	10.0	300
3	0.0090	8.5	320
4	0.0090	11.0	300
5	0.0080	10.5	320
26	0.0075	12.0	290

6.0 RESULTS:

Case Studies

There are three case studies.

Case 1 is ORPF without FACTS device is used as a reference case.
Case 2 is ORPF with one TCSC at line 2-3.

Case 3 is ORPF with one UPFC at line 14-15.

BUS	CASE 1	CASE 2	CASE 3
PG1	416.5103	336.1501	373.3609
PG2	158.4516	161.0224	240.6273
PG3	204.1592	283.9844	227.2511
PG4	236.1924	149.3114	138.7274
PG5	215.1800	202.3887	227.4205
PG6	48.0365	68.6694	71.1375

LOSS MINIMIZATION:

S.NO	CASES	SYSTEM LOSS(MW)
1	CASE 1	15.53
2	CASE 2	15.5246
3	CASE 3	15.5123

COST MINIMIZATION:

S.NO	CASES	COST($/hr)
1	CASE 1	15190.4
2	CASE 2	15135.8
3	CASE 3	15028.1

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.

7.0 CONCLUSION

Particle Swarm Optimization (PSO) based optimal power flow algorithm is developed in MATLAB 7.0. PSO approach is effectively and successfully implemented to minimize the losses and total generator fuel cost in OPF control with FACTS (devices. The algorithm is compared with FACTS and without FACTS devices. The PSO approach achieves better on the IEEE 26 bus system with FACTS devices fixed at the given locations.

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