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RESEARCH ARTICLE

MPSO BASED SOLUTION FOR OPF PROBLEM INCORPORATING VARIOUS FACTS DEVICES FOR IEEE STANDARD BUS SYSTEMS

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MPSO-Modified Particle Swarm Optimization;
FACTS-Flexible A.C. Transmission Systems**;**
OPF-Optimal Power Flow.

ABSTRACT

This paper proposes an approach for optimal power flow (OPF) problem in order to improve the power system stability because Stability is one of the important constraints in a power system operation. Often trial and error heuristics methods are used to improve the stability of the power system, but that can be costly and imprecise. A new methodology that eliminates the need for repeated simulation to determine a transiently secure operating point is presented. The methodology involves a stability constrained Optimal Power Flow (OPF). Particle swarm optimization (PSO) algorithm is adopted to realize the OPF process. The method is programmed in MATLAB and implemented to a fourteen-bus test power system. The results show the ability of the proposed method to find optimal (or near optimal) operating points in different cases. This paper proposes this novel approach to solve OPF problem with improvement in the power system stability also.

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INTRODUCTION

NY physical system that is designed or operated to perform certain pre-assigned tasks in a steady state must, in addition to performing those functions in satisfactory manner, be stable at all times for sudden disturbances with a margin of safety. When the physical system is large and complex such as a typical modern interconnected system, investigation of stability requires analytical sophistication in terms of techniques employed and practical experience in interpreting the results properly. The ability of a power system to reestablish the initial state (or one practically identical) after any disturbance or interruption manifested as a deviation from the initial parameter values for the system's operation. A distinction is made between static and dynamic stability, that is, between the ability to reestablish the initial state after small and strong disturbances, respectively. Stability is a necessary condition for the reliable operation of a power system.

In reality the stability problem appears to be an OPF-like problem, in which stability can be viewed as a constraint in addition to the normal OPF voltage and thermal constraints. The concept of optimal power flow, introduced by Dommel and Tinney in the early 1960's, has received great attention since its early application to power systems analysis. OPF is a nonlinear optimization problem, where a specific objective function must be optimized while satisfying operational and physical constraints of the electric power system. Active power loss in the transmission system is to be minimized as the objective function, while Automatic Voltage Regulator (AVR) operating values, On-Load Tap Changer (OLTC) positions and number of reactive power compensation equipments are selected as control variables. This paper proposes an OPF problem which is realized by means of Particle Swarm Optimization algorithm. Particle Swarm Optimization (PSO) is a population based stochastic optimization technique developed by Dr. Eberhart and Dr. Kennedy in 1995, inspired by social behavior of bird flocking or fish schooling. PSO optimizes a problem by having a population of candidate solutions, here dubbed particles, and moving these particles around in the search-space according to simple mathematical formulae over the particle's position and velocity.

Load Flow Calculations

The load flow calculation is important to compute the power flow between the buses. In our method Newton raphson method is used for load flow calculation.

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Newton raphson method is commonly used technique for load flow calculation. The real and reactive power in each bus is computed using equation 1 & 2.

$$P_i = \sum_{k=1}^{N} V_i * V_k \left(G_{ik} * \cos\theta_{ik} + B_{ik} * \sin\theta_{ik}\right)$$
……………………..(1)

$$Q_i = \sum_{k=1}^{N} V_i * V_k \left(G_{ik} * \sin\theta_{ik} - B_{ik} * \cos\theta_{ik}\right) \qquad \text{……………………..(2)}$$

where, N is the total number of buses, V_i & V_k are the voltage at i & k bus respectively, θ_{ik} is the angle between i & k bus, G_{ik} & B_{ik} are the conductance and susceptance value respectively. After computing the power flow between the lines, the amount of power to be generated for the corresponding load with low cost is identified using PSO. In our method, there are two stages of PSO and a neural network is used. Here, PSO is used for generating training dataset to train the neural network. In the first stage, the amount of power generated by each generator for a particular load is computed using PSO and in the second stage, the bus where the FACTS controller is to be connected is identified and using this data, the neural network is trained. From the output of neural network, the amount of power to be generated by each generator for the given load and the location of FACTS controller to be connected are obtained.

Stage 1: Computation of Power to be generated for P_{Gi}

The amount of power to be generated by each generator is estimated using PSO. The process that takes place in PSO is generation of initial particle, evaluation function and updating the particles. The first step is generating the initial particle by PSO.

Generating Initial Particle

First the total number of generators connected in the system is identified and then the amount of power generated by each generator is calculated by satisfying two constraints. The initial particles to be generated by using PSO are $\{P_{G1}, P_{G2}, \ldots\ldots. P_{GD}\}$. The two constraints that must be satisfied for generating the particle are given below.

Constraint1: $\sum_{i=1}^{D} P_{Gi} = P_d + P_l$ ……………………..(3)

where, P_{Gi} is the total power generated, P_d is the total power demand, P_l is the total power loss, D is the total number of generator.

Constraint2 : $P_{Gi}^{\min} \le P_{Gi} \le P_{Gi}^{\max}$ ………………………(4)

where, $P_{Gi}^{\min}$ and $P_{Gi}^{\max}$ is the minimum and maximum real power to be generated by i^{th} generator.

The initial particles are generated by satisfying the above two constraints and after generating the initial particle, the next step is evaluation function.

Evaluation Function

The evaluation function is used to evaluate the initial particle generated in the above step. Here, the cost function is taken as the evaluation function.

Evaluation function, $C = F + E$ ………………………….(5)

Where

Fuel cost, $F = \sum_{i=1}^{D} (a_i + b_i * P_{Gi} + c_i * P_{Gi}^{2})$ ………………………….(6)

EmissionCost

$$E = \sum_{i=1}^{D} \left(\alpha_i * P_{Gi}^{2} + \beta_i * P_{Gi} + \gamma_i\right) \qquad \text{………………………..(7)}$$

where, a_i, b_i and c_i are the cost coefficients of the i^{th} generator, P_{Gi} is the real power of the i^{th} generator, and α_i, β_i and γ_i are the coefficients of the i^{th} generator emission Characteristics.

Updating Initial Particles

Updating the particles is an important process in PSO. In this stage, the initial particles generated in section 3.2.1 are updated and then the fitness values are calculated. The particles are updated using the equation given below.

$$v[\,] = v[\,] + c1 * rand(\,) * (\text{pbest}[\,] - \text{present}[\,]) + c2 * rand(\,) * (gbest[\,] - present[\,]) \qquad \text{.....................(8)}$$

$$present[\,] = present[\,] + v[\,] \qquad \text{.....................(9)}$$

$v[\,]$ is the particle velocity, $present[\,]$ is the current particle, $pbest[\,]$ and $gbest[\,]$ are best fitness value and best value from any particle in the population respectively, $rand(\,)$ is the random number between $(0,1)$ and $c1$, $c2$ are learning factors. By using the above equation, initial particles are updated and a new particle is generated. The total number of new particles is generated based on the number of iterations applied. Then, the evaluation function is applied to the newly generated particles and the particle with low cost is selected as the best particle.

Repeat the above process by randomly generating new set of generator values and the process are repeated for n times, so that n set of data is generated. The n set of data generated from PSO are as follows.

$$S = \begin{bmatrix} P_{G11} & P_{G12} & \cdots\cdots & P_{G1D} \\ P_{G21} & P_{G22} & \cdots\cdots & P_{G2D} \\ . & & & \\ . & & & \\ P_{Gn1} & P_{Gn2} & \cdots\cdots & P_{GnD} \end{bmatrix} \begin{bmatrix} C_1 \\ C_2 \\ . \\ . \\ C_n \end{bmatrix} \qquad \text{.....................(10)}$$

From the above generated data, the minimum cost function is taken as the power generated by the generator with low cost.

Placement of Facts Controllers

FACTS controllers are used to improve the power flow between the lines. There are different types of FACTS controllers are used. Here, UPFC is used to improve the power flow between the lines, and the amount of voltage and angle to be injected due to the addition of UPFC controllers are calculated using PSO. Due to the addition of UPFC, some real and reactive power is added to the buses where the UPFC needs to be connected. The real and reactive power injected due to the addition of UPFC is calculated using the equations 11, 12, 13 & 14.

$$\Delta P_i = -V_k * V_{inj}\left[G * \cos(\delta_k - \delta_{inj}) - B * \sin(\delta_k - \delta_{inj})\right] + G^{new} * V_{inj}^{\;2} + 2 * V_i * V_{inj} * G^{new} * \cos(\delta_k - \delta_{inj}) \qquad \text{.........................(11)}$$

$$\Delta Q_i = V_k * \left[G^{new} * \sin(\delta_i - \delta_{inj}) - B^{new} * \cos(\delta_i - \delta_{inj})\right] - V_i * I_q \qquad \text{.........................(12)}$$

$$\Delta P_k = -V_k * V_{inj}\left[G * \cos(\delta_i - \delta_{inj}) - B^{new} * \sin(\delta_i - \delta_{inj})\right] \qquad \text{.........................(13)}$$

$$\Delta Q_k = -V_k * V_{inj}\left[G * \sin(\delta_i - \delta_{inj}) - B * \cos(\delta_i - \delta_{inj})\right] \qquad \text{.........................(14)}$$

where, ΔP_i, ΔP_k, ΔQ_i, ΔQ_k are the real and reactive injecting powers from and to bus respectively, I_q is the transformer reactive current, V_{inj} and δ_{inj} are the injecting voltage and angle respectively,

$$G^{new} = gik + G\,, \quad B^{new} = bik + B\,. \qquad \text{.........................(15)}$$

The above real and reactive power injected values are added to the starting and ending buses where the UPFC is connected, respectively in 1 &2. In the second stage, the voltage and angle to be injected are calculated by using PSO.

Optimal Settings of facts devices

In this paper UPFC is modeled as combination of a TCSC in series with the line and SVC connected across the corresponding buses between which the line is connected. After fixing the location, to determine the best possible settings of FACTS devices for all possible single and multiple contingencies, the optimization problem will have to be solved using Fuzzy Controlled Genetic Algorithm technique.

The objective function for this work is, Objective = minimize {SOL and IC}

$$SOL = \sum_{C=1}^{M} \sum_{k=1}^{n} a_k (P_k / P_{k^{\max}})^4 \qquad \text{……………………(16)}$$

where,
m- Number of single contingency considered
n- Number of lines
ak- weight factor=1.
Pk- real power transfer on branch k.
Pk^{max}- maximum real power transfer on branch k.
IC - Installation cost of FACTS device
SOL **-** Represents the severity of overloading

$$C_{TCSC} = 0.0015S^2 - 0.71S + 153.75(US\$/\ KVAR) \qquad \text{……………………(17)}$$

$$C_{UPFC} = 0.0003S^2 - 0.2691S + 188.22(US\$/\ KVAR) \qquad \text{……………………(18)}$$

where, S - Operating range of UPFC in MVAR $S = |Q_2 - Q_1|$ ……………………(19)

Q1 – MVAR flow through the branch before placing FACTS device.
Q2 - MVAR flow through branch after placing FACTS device.
The objective function is solved with the following constraints

Voltage Stability Constraints

VS includes voltage stability constraints in the objective function and is given by,

$$VS = \begin{cases} 0 & if\ 0.9 < Vb < 1.1 \\ 0.9 - Vb & if\ Vb < 0.9 \\ Vb - 1.1 & if\ Vb > 1.1 \end{cases} \qquad \text{……………………(20)}$$

Vb - Voltage at bus B

FACTS Devices Constraints

The FACTS device limit is given by,

$$-0.5X_L < X_{TCSC} < 0.5X_L \qquad \text{……………………(21)}$$

$$-200MVAR \leq Q_{SVC} \leq 200MVAR \qquad \text{……………………(22)}$$

Where,
X_L - original line reactance in per unit
X_{TCSC} - reactance added to the line where UPFC is placed in per unit
Qsvc- reactive power injected at SVC placed bus in MVAR

Power Balance Constraints

While solving the optimization problem, power balance equations are taken as equality constraints. The power balance equations are given by,

$\Sigma P_G = \Sigma P_D + P_L$ ……………………(23)

Where, ΣP_G– Total power generation
ΣP_D– Total power demand
PL – Losses in the transmission network

$$P_i = \sum \frac{\overline{E_i}}{} / E_k / \left[G_{jk} cos(\theta_i - \theta_k) + B_{ik} sin(\theta_i - \theta_k) \right] \qquad \text{……………………(24)}$$

$$Q_i = \sum/E_i/\,/E_k/[G_{jk}sin(\theta_i - \theta_k) + B_{ik}cos(\theta_i - \theta_k)] \qquad \ldots\ldots\ldots\ldots\ldots\ldots(25)$$

where

Pi – Real power injected at bus i.

Qi– Reactive power injected at bus i.

θ_i ,θ_k– The phase angles at buses i and k respectively.

E_i,E_k– Voltage magnitudes at bus i and k respectively.

G_{ik}, B_{ik}– Elements of Y – bus matrix.

RESULTS AND DISCUSSION

The proposed technique was implemented in the working platform of MATLAB 7.11 and tested using both IEEE 14 & 30 bus systems. The IEEE 14 bus system used in our proposed method is shown in Figure 1.

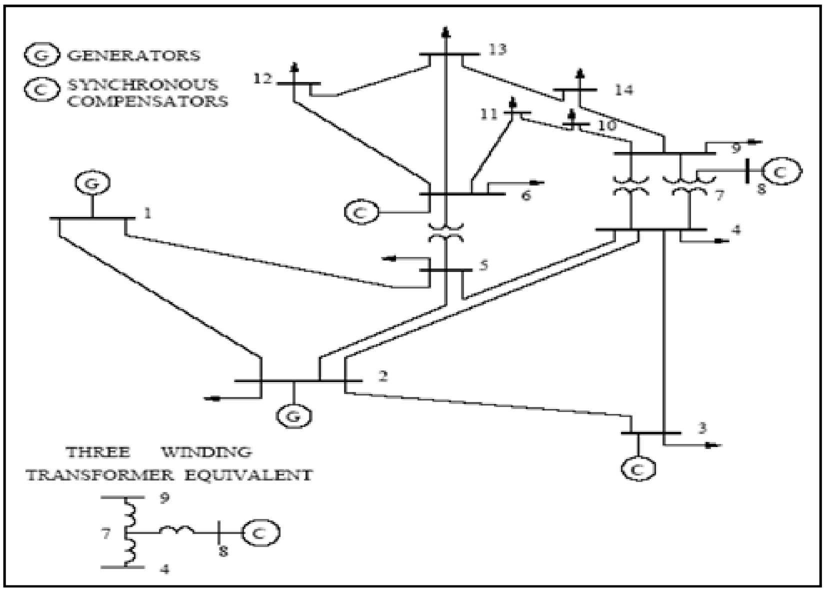

Fig.1. IEEE standard 14 bus system

The IEEE 30 bus system used in our proposed method is shown in Figure 2.

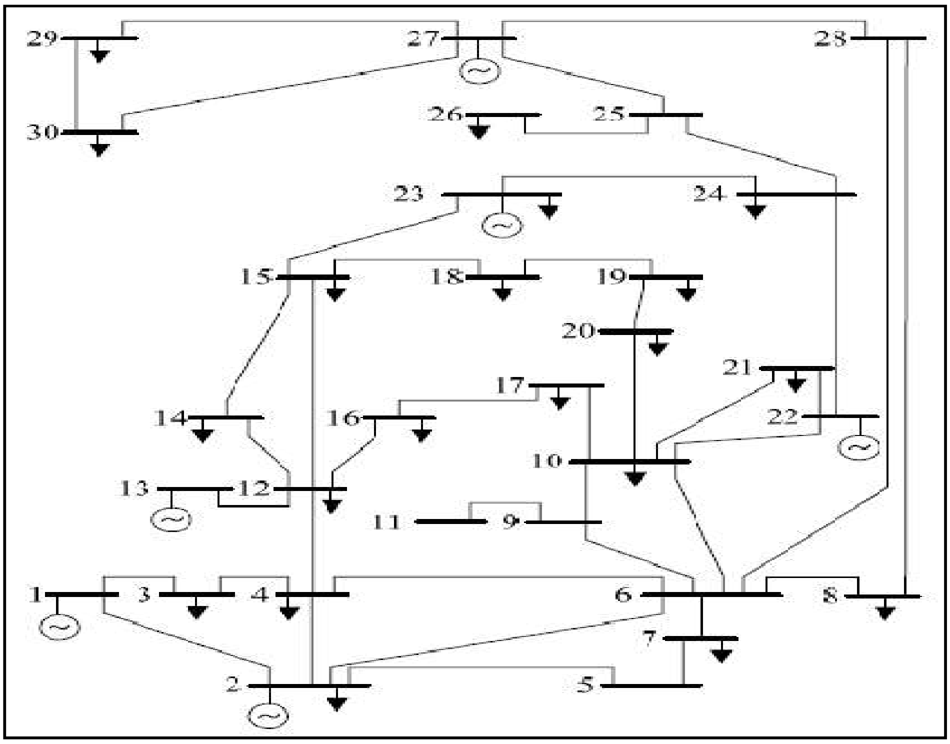

Fig. 2. IEEE standard 30 bus system

Line Data

Table 1. Line Data

Bus No.	Bus code	Voltage magnitude	Angle degree	Load		Generator				Injected MVAR
		P.u.	Degree	MW	MVAR	MW	MVAR	Q_{max}	Q_{min}	
1	1	1.06	0	0	0	0	0	0	0	0
2	2	1.043	0	21.7	12.7	40	0	-40	50	0
3	0	1	0	2.4	1.2	0	0	0	0	0
4	0	1.06	0	7.6	1.6	0	0	0	0	0
5	2	1.01	0	94.2	19	0	0	-40	40	0
6	0	1	0	0	0	0	0	0	0	0
7	0	1	0	22.8	10.9	0	0	0	0	0
8	2	1.01	0	30	30	0	0	-10	60	0
9	0	1	0	0	0	0	0	0	0	0
10	0	1	0	5.8	2	0	0	-6	24	19
11	2	1.082	0	0	0	0	0	0	0	0
12	0	1	0	11.2	7.5	0	0	0	0	0
13	2	1.071	0	0	0	0	0	-6	24	0
14	0	1	0	6.2	1.6	0	0	0	0	0

Bus Data

Table 2. Bus Data

Bus No.	Bus No.	R (p.u.)	X (p.u.	1/2 B (p.u.	Line code = 1 for lines > 1 or < 1 tr. tap at bus No.
1	2	0.0192	0.0575	0.0264	1
1	3	0.0452	0.1852	0.0204	1
2	4	0.057	0.1737	0.0184	1
3	4	0.0132	0.0379	0.0042	1
2	5	0.0472	0.1983	0.0209	1
2	6	0.0581	0.1763	0.0187	1
4	6	0.0119	0.0414	0.0045	1
5	7	0.046	0.116	0.0102	1
6	7	0.0267	0.082	0.0085	1
6	8	0.012	0.043	0.0045	1
6	9	0	0.208	0	0.978
6	10	0	0.556	0	0.969
9	11	0	0.208	0	1
9	10	0	0.11	0	1
4	12	0	0.256	0	0.932
12	13	0	0.14	0	1
12	14	0.1231	0.2559	0	1

Comparison with & without UPFC

Table 3. Comparison with & without UPFC

		Total power loss (MW)	Total cost (fuel cost + UPFC cost) ($/hr)
Newton Raphson method		10.809	809.7812
Proposed method without UPFC		9.7451	804.8386
Proposed method with UPFC connected at	2-5	7.3721	989.5896
	3-4	9.2101	976.6951
	2-4	9.418	991.9066
	2-5	7.2968	993.13
	5-7	8.1359	988.5793
	8-28	9.3983	991.78
	9-10	9.7263	992.051
	10-17	9.1633	985.535
	14-15	9.2339	991.633
	10-17	9.138	986.0894
	19-20	8.6614	985.9431
	21-23	8.0017	977.1855
	24-25	9.4722	992.0179
	25-27	9.229	989.6654

Conclusion

IEEE 14 &30 bus systems and FACTS controller used in our method is SVC, TCSC and UPFC. In this paper, the proposed method was tested for IEEE 30 bus system and FACTS controller used in our method is UPFC. The proposed method is compared with Newton raphson method and proposed method without UPFC controller. In Newton raphson method power loss is 10.809 MW and cost is 809.7812 $/hr, but in our method (UPFC connected between bus 2 & 5) power loss is 7.3721 MW and cost is

989.5896 $/hr, in our method cost increases because due to the installation of UPFC in the system. From the above results it is clear that our method has reduced the power losses as well as the total cost in the system.

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