Scientific
Research
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Hybrid Swarm Algorithm for Multiobjective Optimal Power Flow Problem

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Abstract

Optimal power flow problem plays a major role in the operation and planning of power systems. It assists in acquiring the optimized solution for the optimal power flow problem. It consists of several objective functions and constraints. This paper solves the multiobjective optimal power flow problem using a new hybrid technique by combining the particle swarm optimization and ant colony optimization. This hybrid method overcomes the drawback in local search such as stagnation and premature convergence and also enhances the global search with chemical communication signal. The best results are extracted using fuzzy approach from the hybrid algorithm solution. These methods have been examined with the power flow objectives such as cost, loss and voltage stability index by individuals and multiobjective functions. The proposed algorithms applied to IEEE 30 and IEEE 118-bus test system and the results are analyzed and validated. The proposed algorithm results record the best compromised solution with minimum execution time compared with the particle swarm optimization.

Keywords

Multiobjective, OPF, Optimization, Hybrid

1. Introduction

The power system is an interconnected electric network, which has generating plant and loads that are connected through transmission and distribution networks. It is a complicated network and it has many objectives to be solved. The reliable result of the objectives is obtained using optimal power flow. Optimized solution for the objective functions is attained by satisfying the power flow equations and constraints of the entire power system network. Various control variables are also influenced to achieve an

optimal solution. Many conventional techniques are applied to solve the optimal power flow problem. They are quadratic programming [1], interior programming [2], linear programming [3], gradient method [4] and newton's method [5]. The drawback of these methods is that it is a local solver only. The solutions from these classical methods are not the most reasonable for nonlinear, discrete and continuous functions with constraints.

In order to overcome the drawbacks of classical methods, many computational methods are used to solve the optimal power flow problem. Particle Swarm Optimization (PSO) [6] inspires the school of fishes and a flock of birds and trapped in local optima. Genetic algorithm [7] [8] solves the optimal power flow problem using a random selection of starting values of voltage angles, but it has no control over global and local investigation. Evolutionary programming [9] algorithm solves the problem by enhancing the gradient of the function, and it has the problem of long computational time. Tabu search [10] solves the optimal power flow problem which is more composite for classical method. These manuscripts give the optimal solution for individual objective. Conversely the real world problem needs a concurrent optimal solution for all the objectives.

Multiobjective optimal power flow problem is solved by differential evolution, for active and reactive power dispatch [11] and fuel cost, voltage profile, and voltage stability enhancement [12]. The drawback of this technique is that the convergence time is more. Enhanced genetic algorithm [13] solves the problem with the combination of new developed quadratic load flow and its demerit is that it gets trapped in local optima. Self adaptive evolutionary programming [14] combines the evolutionary programming and random search technique and it has the problem of long computational time. As particle swarm optimization is improved [15], the particles avoid being trapped in local optima. Harmony search algorithm [16] inspires the analogy with music improvisation which has solved the problem with slow convergence. These techniques solve the problem with the long computation time and being trapped in local optima.

In the weighted sum method [17], different objectives are formatted into a single function. In this method, the demerit is to run the problem with multiple time to desire the optimal solution. Voltage security costs [18] are optimized using a penalty method which has the drawback of deciding the suitable penalty. The importance of each objective is not preserved while merging all the objective function into a single objective function. In order to maintain the significance of each objective pareto optimal method is adopted.

In the PSO algorithm, if the particles are small, local minimum problem will occur and the outcome could be evaluated in multiple runs. If the particles are too large, the global solution is obtained in each run and it reduces the speed of the algorithm. In order to overcome these difficulties and to increase the efficiency of PSO in this paper, a new hybrid technique technique is proposed by combining the particle swarm optimization and ant colony optimization with chemical communication signal.

In this paper cost, loss and Voltage Stability Index (VSI) objectives are analyzed using enhanced PSO with the multiobjective optimal power flow by pareto optimal method. The multiobjective optimization of these objectives is practiced through three

cases. In the first case, all the objective functions are simulated individually. In the second case, two objectives are considered simultaneously for optimization such as cost-loss, cost-VSI, loss-VSI and in the third case three objectives are considered concurrently as cost-loss-VSI. These objectives are optimized using the proposed technique with the IEEE 30 and IEEE 118-bus test system. A short introduction of an optimal power flow system has been presented in this section. This paper is planned as a tag on the section. In Section 2, the optimal power flow problem is formulated and discussed. Section 3 explains the central concepts of PSO, Ant colony Optimization (ACO) and Hybrid Swarm Optimization. Section 4 presents the simulated results with discussions of PSO, ACO and hybrid PSO. The conclusion is dealt in the Section 5.

2. Problem Formulation for OPF Solution

In this paper the cost, transmission loss, voltage stability index are optimized, which is satisfying equality and voltage, generator, shunt VAR and transformer constraints.

2.1. Problem Objectives

1) Minimization of Fuel Cost:

This objective is to minimize the cost. The total fuel cost can be expressed as

$$\text{Minimization} \sum_{i=1}^{n} F_i\left(P_i\right) \tag{1}$$

$$F_i\left(P_i\right) = a_i P_i^2 + b_i P_i + c_i \tag{2}$$

$$P_i^{\min} \leq P_i \leq P_i^{\max} \tag{3}$$

a_i, b_i, c_i is the cost coefficients of the ith generator, P_i is the real power output of the ith generator.

2) Minimization of Transmission Loss:

This objective is to minimize the real power transmission loss. The transmission loss can be stated as

$$TL = \sum_{k=1}^{n} g_k \left[V_i^2 - V_j^2 - \left(2V_iV_j \cos\left(\theta_i - \theta_j\right)\right) \right] \tag{4}$$

V_i is the voltage at the ith line, V_j is the voltage at the jth line, g_k conductance.

3) Minimization of Voltage Stability Index:

This objective is to minimize the voltage stability index. The voltage level ought to maintain below critical level. If the voltage level greater than the critical limit the entire system becomes unstable. The fast voltage stability index expressed as

$$FVSI_{ij} = 4Z_{ij}^2 Q_j \big/ V_i^2 X_{ij} \tag{5}$$

Z_{ij} is the impedance of line between i and j, X_{ij} is the reactance of line between i and j, V_i is the sending end voltage, Q_i is the receiving end reactive power.

2.2. Problem Constraints

1) Voltage Constraint:

The bus voltage maintained the maximum and minimum level. The voltage limit conveyed as

$$V_i^{\min} \le V_i \le V_i^{\max} \tag{6}$$

$V_i^{\min}$, $V_i^{\max}$ Minimum, maximum values of voltage magnitudes at bus i.

2) Generation Constraints:

The real and reactive power of generation sustained the maximum and minimum limit. The generation level of real and reactive power is expressed as

$$P_{Gi}^{\min} \le P_i \le P_{Gi}^{\max} \tag{8}$$

$$Q_{Gi}^{\min} \le Q_i \le Q_{Gi}^{\max} \tag{9}$$

$P_{Gi}^{\min}$, $P_{Gi}^{\max}$ Minimum, maximum values of real power allowed at bus i.

$Q_{Gi}^{\min}$, $Q_{Gi}^{\max}$ Minimum, maximum values of reactive power allowed at bus i.

3) Transformer Constraints:

The transformer tap setting values are maintained within the maximum and minimum level. The transformer tap setting limit is expressed as

$$T_i^{\min} \le T_i \le T_i^{\max} \tag{10}$$

$T_i^{\min}$, $T_i^{\max}$ Minimum, maximum values of transformer tap settings allowed at bus i.

4) Shunt VAR Constraints:

The shunt VAR restricted the maximum and minimum level. The shunt VAR limit is stated as

$$Q_{Ci}^{\min} \le Q_i \le Q_{ci}^{\max} \tag{11}$$

$Q_{Ci}^{\min}$, $Q_{ci}^{\max}$ minimum, maximum values of Shunt VAR allowed at bus i.

5) Equality Constraints:

The equality constraints are expressed as

$$P_{Gi} - P_{Di} - V_i \sum\nolimits_{j=1}^{n} V_j \left[G_{ij} \cos\left(\delta_i - \delta_j\right) + B_{ij} \sin\left(\delta_i - \delta_j\right) \right] = 0 \tag{12}$$

$$Q_{Gi} - Q_{Di} - V_i \sum\nolimits_{j=1}^{n} V_j \left[G_{ij} \cos\left(\delta_i - \delta_j\right) + B_{ij} \sin\left(\delta_i - \delta_j\right) \right] = 0 \tag{13}$$

n: Number of buses.

P_G, Q_{Gi} Real, reactive power generation at bus i.

P_D, Q_{Di} Real, reactive load demand at bus i.

V_P, V_j Voltage magnitudes at bus i and j respectively.

G_{ip}, B_{ij} Transfer conductance and susceptance between bus i and j respectively.

δ_P, δ_j Voltage angle at bus i and j respectively.

3. Concepts of Swarm Intelligence

3.1. Basics of PSO

Particle swarm optimization (PSO) is a population based optimization technique which is motivated by group manners of birds or fishes. Each particle has its own experience and neighbor particle experience. According to that particle adjusts its position, within

the bounded area. Each particle has its local best (lbest) or a personal best. The best position brings into being by all neighbours particles in the specific solution is global best (gbest). The optimal solution is acquired in the specific solution in the course of its current velocity and the experience.

The formation of individual best is

$$Pbest_i = \left(x_{i1}^{pbest}, \cdots, x_{in}^{pbest} \right) \tag{14}$$

The pattern of global best is

$$Gbest_i = \left(x_{i1}^{gbest}, \cdots, x_{in}^{gbest} \right) \tag{15}$$

The velocity and the positions are updated in the each iteration. The updating of velocity is

$$V_i^{k+1} = \omega V_i^k + c_1 \, rand_1 \times \left(Pbest_i^k - X_i^k \right) + c_2 \, rand_2 \times \left(Gbest_i^k - X_i^k \right) \tag{16}$$

The updating of position of the particle is

$$X_i^{k+1} = X_i^k + V_i^{k+1} \tag{17}$$

V_i^k current velocity of individual i at iteration k, V_i^{k+1} Modified velocity of individual i at iteration $k+1$, X_i^k Current position of individual i at iteration, ω Inertia weight parameter, c_1, c_2 Acceleration factors, $rand_1$, $rand_2$ Random numbers between 0 and 1, $Pbest_i^k$ Best position of individual i until iteration k, $Gbest_i^k$ Best position of the group until iteration k.

3.2. Ant Colony Optimization

Ant colony optimization (ACO) is an evolutionary and adaptive algorithm inspired by the behavior of real ant colonies. The ant when searching food and find food sources, it deposits a chemical called pheromone as a trail during the return path. Based on the quantity and quality of the food available the quantity of pheromone deposited. The pheromone trails allow the ants to identify the shortest path between the ant nest and the food source. Ant colony optimization algorithm updates pheromone values in order to update solutions during run time [19].

The pheromone trail updating equation is stated as

$$T_{ij} \left(t + \Delta t \right) = \left(1 - \alpha \right) T_{ij} \left(t \right) + \Delta T_{ij} \tag{18}$$

α is the pheromone trails evaporation co-efficient, which lies between 0 and 1, ΔT_{ij} is the increment of edge for the period Δt.

To enhance the tempo of search in the optimal power flow problem, the chemical communication between the insects will help. It is the signal of wasp which produces alarm pheromone to the inspiration of anxiety in the colony. This increases the speed of search in the problem area.

The chemical communication signal is expressed as

$$A = \left(B / 2D\Pi r \right) comperr \left(r / \sqrt{4Dt} \right) \tag{19}$$

A is the chemical signal, B is the emission rate, D is the diffusion coefficient, r is the radius of the active space, t is the time from the beginning of emission, *Comperr* is the complementary error function.

3.3. Hybrid Swarm Intelligence

ACO not suitable for large optimization problems because it takes long time to search the result and premature convergence. To overcome of finding the best solution with large search space, combine with another algorithm (PSO) which has a better solution. In the hybrid PSO-ACO, the PSO algorithm is used for pheromone update of ACO. This improves the global exploration capabilities of ACO algorithm. This also improves convergence performance of ACO.

The velocity updating equation is expressed as

$$\Delta T_{ij} = A + \sum_{k=1}^{n} \Delta T_{ij}^{k} + c_1\, rand_1 \times \sum_{k=1}^{n} \Delta T_{ij}^{local_k} + c_2\, rand_2 \times \Delta T_{ij}^{global} \tag{20}$$

A is the chemical communication signal, ΔT_{ij}^{k} is the increment of pheromone trails laid on the edge by ant between t and $t + \Delta t$, $\Delta T_{ij}^{local_k}$ is the local update value of ant k, ΔT_{ij}^{global} is the global update value of edge.

3.4. Fuzzy Approach

In the proposed method, the aim is to achieve a set of solution of the multiobjective optimal power flow problem. In the optimal power flow problem with conflicting objectives the single optimal solution does not determine the real solution. The Pareto optimal approach, it is feasible to find the set of solution instead of the single optimal solution. From the set of solution, the best solution is obtained from the fuzzy approach. The equation for the fuzzy approach for best solution is expressed as

$$\mu^{l} = \sum_{i=1}^{j} \mu_{i}^{l} \left/ \sum_{l=1}^{x} \sum_{i=1}^{j} \mu_{i}^{l} \right. \tag{21}$$

x total number of non-dominated solutions.

$\mu_{i}^{l} = 0$ when the objective function is greater than the maximum value of ith objective function.

$\mu_{i}^{l} = 1$ when the objective function is greater than the minimum value of ith objective function.

3.5. Proposed Hybrid Algorithm for the Optimal Power Flow Problem

Step 1: Read input data include equality and inequality constraints.
Step 2: Initialize the population.
Step 3: Calculate the objective function.
Step 4: Apply Pareto optimal method to get the set of solution.
Step 5: Update the velocity using hybrid velocity updating equation.
Step 6: Update the position using position updating equation.
Step 7: Check for stopping criteria. If the iteration reaches the maximum iteration

stop else go to step 5.

Step 8: Apply Pareto method and determine the non-dominated solution.

Step 9: Find the best solution using fuzzy approach.

4. Simulation Results

The proposed system has been tested to IEEE 30-bus test system. The 30-bus IEEE test system has 41 transmission lines, six generators and four transformers (T6-9, T6-10, T4-12 and T27-28). The transformer taps are set between 0.9 to 1.1. The proposed algorithm has the particles of 30.

Case 1: Single objective optimization.

The proposed algorithms analyzed with the various values of acceleration factors (c_1 and c_2) individually. This analysis assists to achieve the suitable value of the acceleration factor for the further process. This optimal power flow problem was simulated with the acceleration factor (c_1) varied from 1 to 3, using hybrid algorithm. The best value is obtained at $c_1 > 2.5$. **Table 1** shows the best values of the cost, loss and VSI for $c_1 = 2.5$ are $801.7/hr, 5.21 MW and 0.14 p.u. respectively. The hybrid algorithm also simulated with the various values of the acceleration factor (c_2). The best value is obtained at $c_2 > 2$. **Table 2** shows the best values of the cost, loss and VSI for $c_2 = 2$ are, $801.72/hr, 5.24 MW and 0.13 p.u. respectively.

Table 3 shows the single objective optimized values with the control variables using the algorithms of PSO, ACO and Hybrid algorithm respectively. It shows that, the reliable generation cost of PSO, ACO and Hybrid are $802.15/hr, $804.86/hr and $801.54/hr respectively. **Figure 1** displays the generation cost convergence characteristics of a single objective optimization of IEEE 30 test bus system using PSO, ACO and Hybrid algorithm. **Figure 2** indicates the reduction of transmission loss using PSO, ACO and Hybrid algorithms is 5.974 MW, 9.42 MW and 5.208 MW respectively. **Figure 3** indicates the voltage stability of PSO, ACO and Hybrid algorithms are 0.1307 p.u., 0.142 p.u. and 0.13 p.u. respectively. These results show that, hybrid algorithm results are distributed.

Table 1. Best optimized values of different C_1 using hybrid algorithm.

Acceleration factor	1	1.5	2	2.5	3
Cost ($/hr)	803.7	802.4	801.9	801.7	801.9
Loss (MW)	5.41	5.322	5.24	5.21	5.91
VSI (p.u.)	0.151	0.15	0.149	0.14	0.153

Table 2. Best optimized values of different C_2 using hybrid algorithm.

Acceleration factor	1	1.5	2	2.5	3
Cost ($/hr)	803.89	802.75	801.72	801.76	801.78
Loss (MW)	5.319	5.27	5.24	5.25	5.254
VSI (p.u)	0.131	0.129	0.13	0.132	0.131

Table 3. Single objective optimized values of cost, loss and VSI using PSO, ACO and Hybrid algorithms.

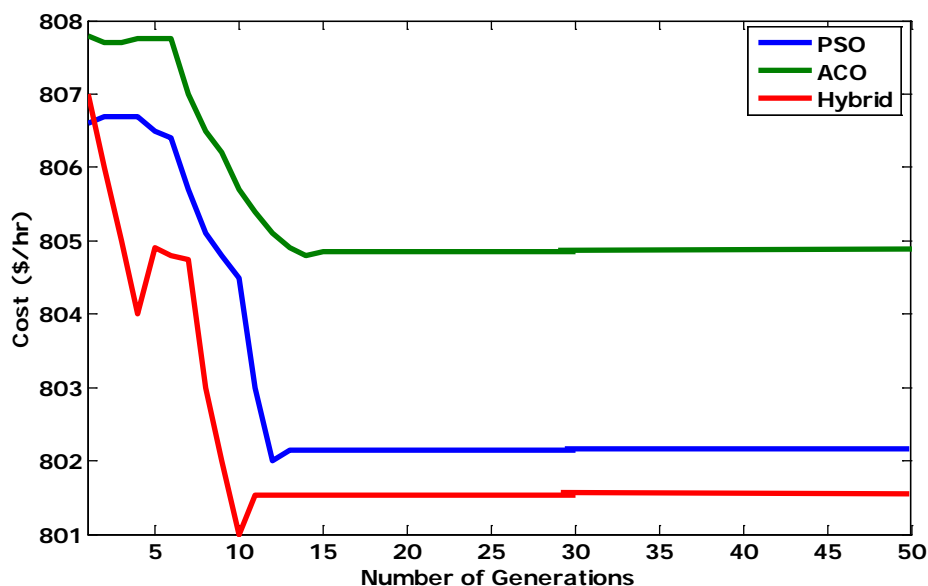|	PSO	ACO	Hybrid
P_{g1} (MW)	177.132	176.901	176.7
P_{g2} (MW)	48.12	49.932	48.89
P_{g3} (MW)	21.356	21.125	21.4719
P_{g4} (MW)	22.878	21.468	21.6423
P_{g5} (MW)	10.121	10.116	12.0878
P_{g6} (MW)	12	12	12.00
V_{g1}	1.05	1.045	1.045
V_{g2}	1.0442	1.043	1.043
V_{g3}	1.446	0.998	0.998
V_{g4}	1.0408	1.009	1.009
V_{g5}	0.9601	1.014	1.014
V_{g6}	1.05	1.047	1.047
$T_{6\text{-}9}$, (p.u.)	1.01	1.012	1.012
$T_{6\text{-}10}$, (p.u.)	0.99	0.971	0.971
$T_{4\text{-}12}$, (p.u.)	1.01	1.023	1.023
$T_{27\text{-}28}$, (p.u.)	1.02	1.014	1.014
Cost ($/hr)	802.15	804.86	801.54
Loss (MW)	5.974	9.42	5.208
VSI (p.u)	0.1307	0.142	0.13

Figure 1. The generation cost convergence characteristics of a single objective optimization of IEEE 30 test bus system using PSO, ACO and hybrid algorithm.

The accuracy of the proposed system is measured using the mean and standard deviation. Table 4 indicates the mean and standard values of the PSO, ACO and Hybrid algorithms. It is obvious that the proposed hybrid algorithm can achieve better result in the best solution search. The convergence time for the cost optimization using a hybrid technique is 1.05 s, which is a faster than the PSO and ACO methods (1.24 s and 1.12 s
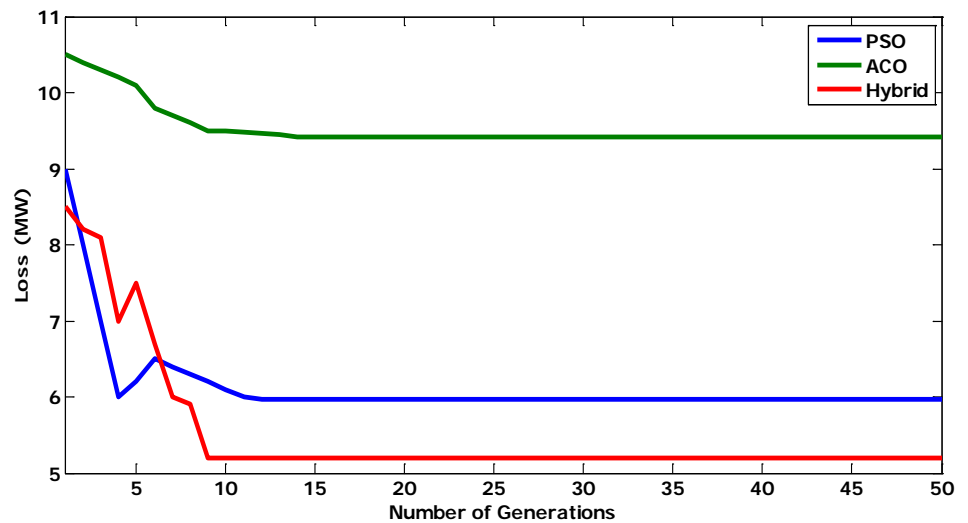

Figure 2. The transmission loss convergence characteristics of a single objective optimization of IEEE 30 test bus system using PSO, ACO and Hybrid algorithm.
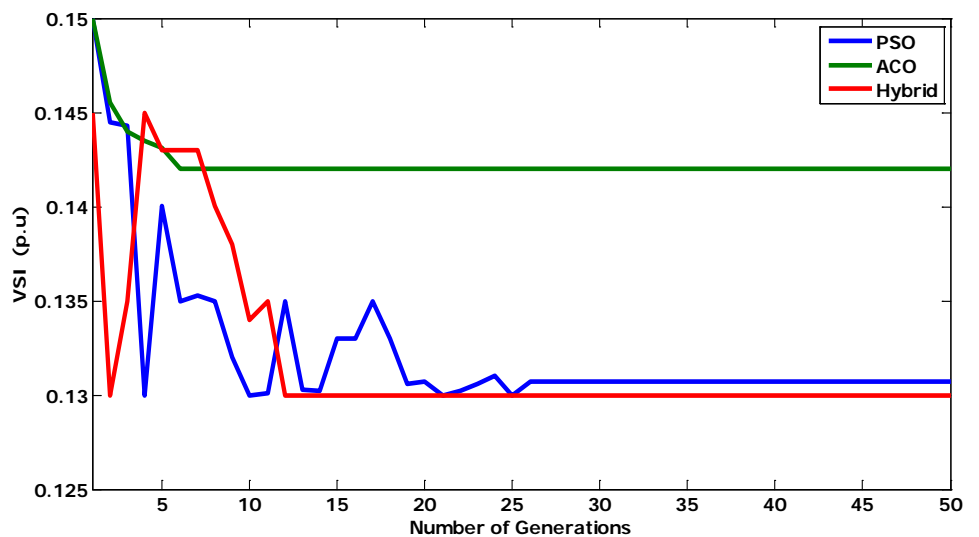

Figure 3. The voltage stability index convergence characteristics of a single objective optimization of IEEE 30 test bus system using PSO, ACO and hybrid algorithm.

Table 4. Performance measure of PSO, ACO and hybrid algorithms.

	ACO	PSO	Hybrid
Mean	0.212	0.234	0.259
STD	0.042	0.036	0.024

respectively). The convergence time taken for the hybrid technique is less. The accuracy and speed of convergence of hybrid are more than the ACO and PSO. Because the hybrid algorithm overcome the drawback in local search such as stagnation and premature convergence by the local experience of the ant and it processed in parallel. This enhances the chance of locating the finest solution in rapidity. The global search increased by the divergence of the pheromone tracks and also with the chemical communication signal. This leads the particle move the quickly to reach the solution. The global utilization, speed up the search and it support to acquire the best solution.

This optimal power flow problem was worked out using P4, 3 GHz. To evaluate the difficulty of the proposed system, the IEEE 14 bus is chosen to solve this OPF problem. The convergence time for this optimization in IEEE 14 bus system of hybrid method is 0.63 s. The convergence time for the hybrid technique is for IEEE 30 bus test system is 1.05 s The convergence speed of the IEEE 30 bus system is twice the times of IEEE 14 bus test system. This will persuade to carry on the proposed technique in higher buses.

Case 2: Two objective optimization.

In a real world, the problems involve simultaneous optimization of several objective functions. These functions are non commensurable and conflicting objective functions. It gives rise to a set of optimal solutions, instead of one optimal solution. The reason for the optimality of many solutions is that no one can be considered to be better than any other with respect to all objective functions. Table 5 shows the optimized values of two

Table 5. Optimal solution for objective functions with different algorithms.

	Cost-Loss			Cost-VSI			VSI-Loss		
	PSO	ACO	Hybrid	PSO	ACO	Hybrid	PSO	ACO	Hybrid
Pg1, MW	136.467	132.374	134.717	178.167	179.232	178.12	177.458	172.486	169.451
Pg2, MW	49.396	51.585	48.856	46.544	47.54	45.421	45.425	49.581	46.859
Pg3, MW	32.826	27.847	31.471	21.412	21.324	21.433	23.192	21.247	22.294
Pg4, MW	21.686	32.694	30.642	16.234	17.415	16.574	17.497	19.782	18.482
Pg5, MW	18.085	28.878	19.078	12.201	13.127	12.401	12.108	13.875	12.158
Pg6, MW	26.011	27.200	26.002	14.704	12.332	12.228	14.704	13.229	12.759
Vg1	1.035	1.0265	1.045	1.049	1.056	1.045	1.049	1.056	1.045
Vg2	1.034	1.023	1.043	1.04	1.034	1.043	1.082	1.034	1.043
Vg3	0.998	0.948	0.998	0.890	0.998	0.998	1.089	0.998	0.998
Vg4	1.090	1.089	1.009	1.000	1.005	1.009	1.002	1.005	1.009
Vg5	1.0154	1.014	1.014	1.022	1.034	1.014	1.212	1.034	1.014
Vg6	1.0347	1.0477	1.047	1.057	1.064	1.047	1.057	1.064	1.047
T6-9, pu	1.0152	1.016	1.012	1.019	1.023	1.012	1.019	1.023	1.012
T6-10, pu	0.9671	0.9598	0.971	0.980	0.992	0.971	0.980	0.992	0.971
T4-12, pu	1.0123	1.002	1.023	1.034	1.039	1.023	1.034	1.039	1.023
T27-28, pu	1.0124	1.0133	1.014	1.034	1.045	1.014	1.034	1.045	1.014
Cost ($/hr)	825.15	831.72	821.72	809.54	815.65	802.5			
Loss (MW)	5.376	5.637	5.003				5.2574	5.117	5.113
VSI (p.u)				0.1094	0.1096	0.1092	0.1047	0.1052	0.1007
Execution time (s)	1.4815	1.675	1.4167	1.598	1.679	1.5297	1.4298	1.4972	1.4475

objective optimization such as cost-loss, cost-VSI and loss-VSI using PSO, ACO and Hybrid algorithm. It is not easy to pinpoint the correct concert solution from a single run for the corresponding objective. So, to get the appropriate solution 30 numbers of pare to solution sets are obtained from 30 generations.

In the cost-loss minimization, objectives contrasts to each other. The cost-loss divergence optimization, the cost and loss for the PSO, ACO and Hybrid techniques are $825.15/hr, $831.72/hr, $821.72/hr and 5.376 MW, 5.375 MW, 5.043 MW respectively. The reduction of cost and loss in hybrid is 1.12% and 11%higher than PSO and ACO techniques. Figure 4 indicates the compromised solution of cost and loss are $821.72/hr and 5.43 MW obtained using hybrid algorithm. It shows that, the cost-loss multiobjective optimization, the hybrid solution is best in cost and less reduction.

To avoid the stability problem in the system, the VSI should be maintained below critical limit. In addition to the VSI, cost also to be reduced. The cost-VSI conflict optimization, the cost and VSI for the PSO, ACO and Hybrid techniques are $809.54/hr, $815.65/hr, $802.5/hr and 0.1094 p.u, 0.1096 p.u., 0.1092 p.u, respectively. The reduction of cost and VSI of hybrid technique is 1.63% and 0.36% respectively. Figure 5 shows that the best compromised solution of cost and VSI are $802.5/hr and 0.1092 p.u, obtained using hybrid algorithm. The execution time of the hybrid technique for the cost-VSI divergence optimization is 1.5297 s, which is a faster than the PSO and ACO methods (1.598 s and 1.679 s respectively).

In the loss-VSI case, the loss is minimized with the voltage stability, which is maintained below critical limit. The loss-VSI contrast optimization, the loss and VSI for the PSO, ACO and Hybrid techniques are 5.2574 MW, 5.117 MW, 5.113 MW and 0.1047 p.u, 0.1052 p.u., 0.1007 p.u, respectively. It shows that the reduction of loss in the ACO technique is less than the PSO technique Figure 6 indicates the divergence of hybrid is
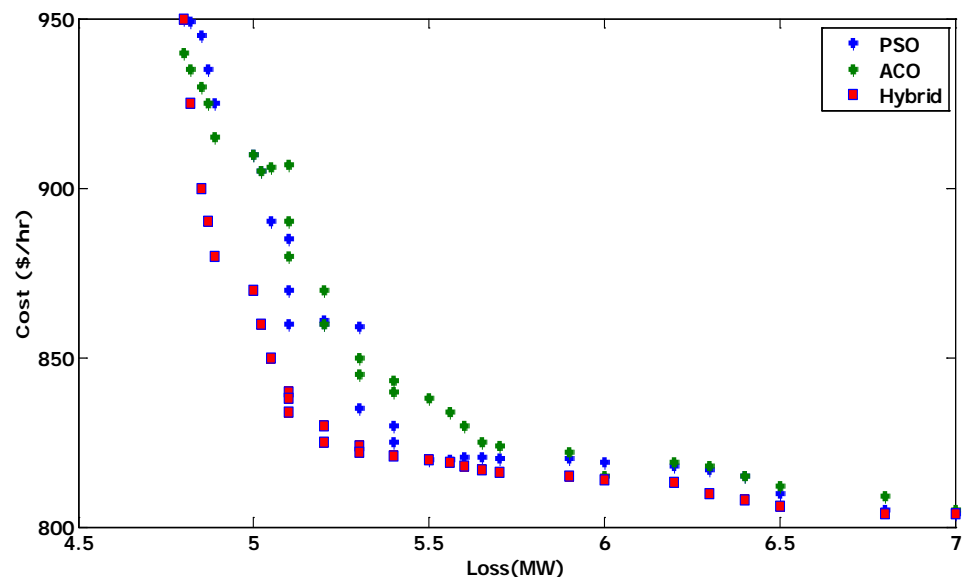

Figure 4. Loss-Cost optimization using PSO, ACO and hybrid algorithms of IEEE 30 test bus system.
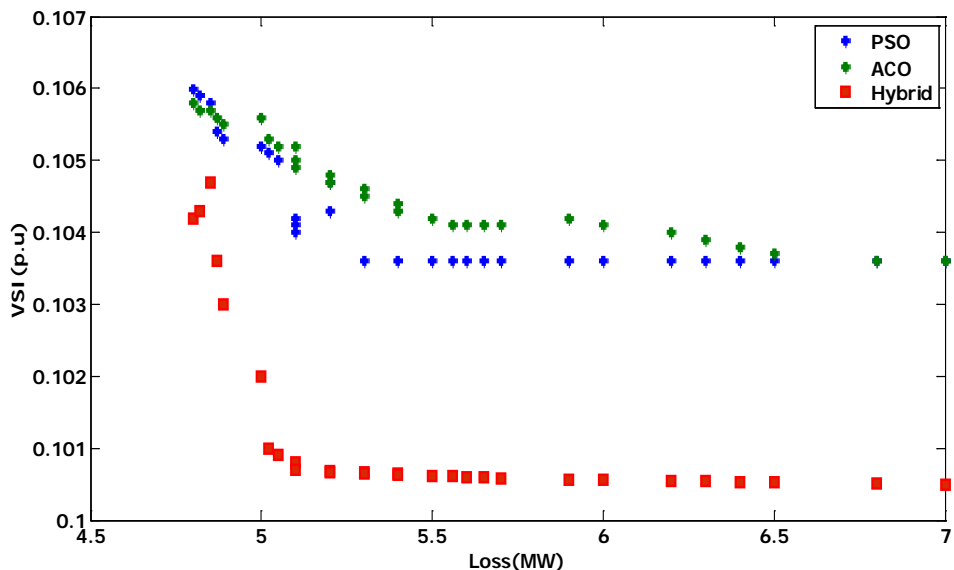
Figure 5. Loss-voltage stability index optimization using PSO, ACO and hybrid algorithm of IEEE 30 test bus system.
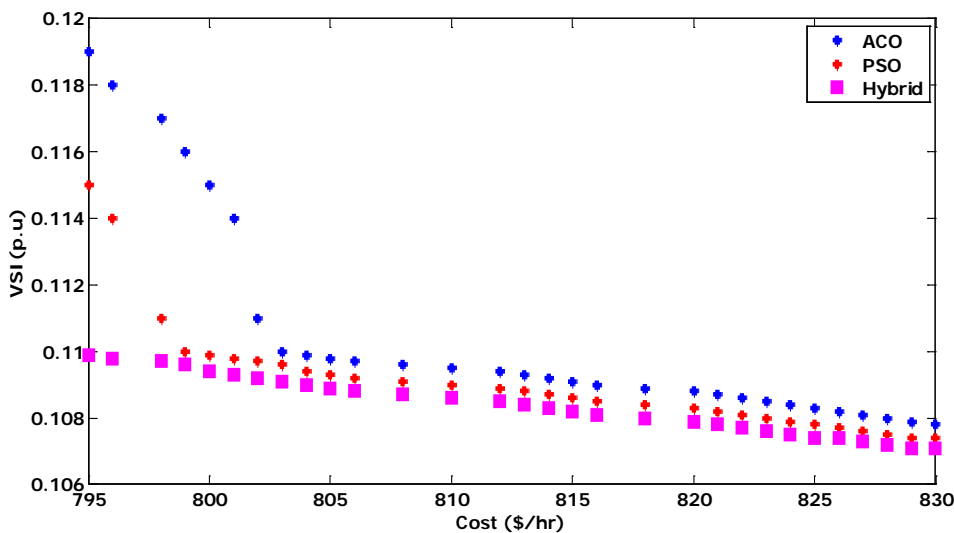

Figure 6. Voltage stability index-cost optimization using PSO, ACO and hybrid algorithm of IEEE 30 test bus system.

more than the ACO and PSO. The best compromised solution of loss and VSI are 5.113 MW and 0.1007 p.u, obtained using SPPSO algorithm. This result indicates the hybrid optimized result from the loss-VSI multiobjective optimization is better compared to the PSO and ACO techniques.

From the two objective optimization the reduction of cost is more in cost-VSI than the cost-loss optimization. The loss is optimized more in cost-loss multiobjective than the loss-VSI. Optimizing two objectives will give the dissimilar result for the same objective function. It initiates the objectives which are considered for the optimal power flow should be optimized simultaneously.

Case 3: Three objective optimization.

Table 6 indicates the optimal values of the three objectives such as cost-loss-VSI, using PSO, ACO and Hybrid algorithms. The cost of the three objective optimization using PSO, ACO and Hybrid algorithms are $814.76/hr, $815.6/hr and $805.5/hr respectively. In this, the cost reduced in the hybrid 1% more than the ACO and PSO techniques. The loss of the three objective optimization of the PSO, ACO and Hybrid techniques are 9.924 MW, 9.98 MW and 6.321 MW respectively. The loss reduction of hybrid technique is 57% higher than the PSO and ACO. The VSI of the PSO, ACO and Hybrid for the multi objective optimization are 0.1407 p.u, 0.1482 p.u and 0.1127 p.u respectively. The hybrid algorithm results, 24% more reduction in VSI than the PSO and ACO techniques. Table 6 shows, the hybrid technique results the better accuracy compare to the PSO and ACO algorithm for multiobjective optimization problem.

In order to confirm the performance of the proposed algorithm in large systems, hybrid algorithm applied in IEEE 118 test bus system. The particles are increased to 50. To get the appropriate solution, 30 numbers of pareto solution sets are obtained from 30 generations. Table 7 indicates the optimal solutions for the cost, loss and VSI optimized with a single objective, two objectives and three objective function using a hybrid

Table 6. Multiobjective optimal solution for Cost-Loss-Voltage Stability Index with different algorithms.

Variables	PSO	ACO	Hybrid
P_{g1}, MW	168.163	167.937	105.71
P_{g2}, MW	46.232	45.827	74.445
P_{g3}, MW	23.957	23.211	38.329
P_{g4}, MW	15.328	18.185	35.517
P_{g5}, MW	18.541	17.248	19.278
P_{g6}, MW	23.789	25.157	12.248
V_{g1}	1.065	1.074	1.045
V_{g2}	1.054	1.063	1.043
V_{g3}	0.9002	0.9098	0.998
V_{g4}	1.100	1.104	1.009
V_{g5}	1.017	1.019	1.014
V_{g6}	1.066	1.078	1.047
T_{6-9}, pu	1.015	1.019	1.012
T_{6-10}, pu	0.980	0.998	0.971
T_{4-12}, pu	1.034	1.045	1.023
T_{27-28}, pu	1.016	1.017	1.014
Cost ($/hr)	814.76	815.6	805.4
Loss (MW)	9.924	9.98	6.321
VSI (p.u)	0.1407	0.1482	0.1127
Execution time (s)	1.4724	1.6245	1.5348

Table 7. The optimal solution of single objective and multi objective functions using hybrid algorithm for IEEE 118 test bus system.

Objectives	Single objective			Two objectives			Three objectives
	Cost	Loss	VSI	Cost-loss	Cost-VSI	Loss-VSI	Cost-loss-VSI
Cost ($/hr)	128945	152014	149156	131992	131129		131119
Loss (MW)	139.5	123.3	138.6	115.4		125.12	143.5
VSI (p.u.)	0.47	0.479	0.412		0.431	0.429	0.442
Execution time (s)				35.487	35.897	35.127	48.087

algorithm for IEEE 118 test bus system. It indicates the values of cost, loss and VSI of the single objective optimization are less when compared to the multiobjective optimization. It states that while considering more objective function, the optimized value and execution time are increased concurrently. Because of nonlinearity in large system the front is less consistent comparing to the smaller system.

5. Conclusion

In this paper optimal power flow problem has three objectives with constraints, and it works out in the multiobjective optimization approach. This multiobjective problem is solved by single objective, two-objective optimization such as cost-loss, cost-voltage stability index, loss-voltage stability index, and three-objective optimization of cost-loss-voltage stability index using PSO, ACO and hybrid techniques. Hybrid swarm intelligence is used to avoid the stagnation of global and local search and get the best solution by fuzzy approach. The simulation results show that the hybrid swarm optimization provides better results and faster convergence compared to the ant colony optimization and particle swarm optimization. The proposed technique gives better results with less convergence time and it will help to choose the sensible solution to the multiobjective optimization problem in IEEE 30 & IEEE 118 test bus system.

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