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Regular paper

Combined Heuristic and Evolutionary approach for Reactive Power Planning Problem

In this paper authors have used mixed heuristic and evolutionary technique for solving the reactive power problem. In doing so, power system control variables are treated as planning & dispatch variables. All the variables of the reactive power optimization problem do not involve cost. The variables which does not involve cost treated as dispatch variable and those involve cost are treated as planning variable. Heuristic method is used for installation of capacitor's on weak buses and evolutionary programming approach is used for setting of transformer tap positions and reactive generations of the Generator's.

Keywords: Heuristics, Evolutionary techniques, Planning, Dispatch.

1. INTRODUCTION:

In this paper, the main concern is proper planning and co-ordination of control variables which are either transformer tap changers, shunt capacitors, Generators reactive VAr's in an interconnected power system such that real power loss becomes minimum. The problem of reactive power planning in a power system can be shown to be a combinatorial optimization problem though a number of methods have been proposed to solve the problem using the classical optimization techniques [1-5]. Optimal Power flow method is used for VAr placement [6]. Security constrained reactive power dispatch is discussed in [7]. Reactive power planning tool was described in [8]. Simulated Annealing technique [9, 10] is applied for the capacitor placement problem. Fuzzy logic, found its application for handling reactive power problem in [11-12]. Expert system [13], and AI method [14] is also used for solving the reactive power problem. Heuristic approach was used to get the solution of reactive power problem in [15-17]. Genetic Algorithm [18-25] is used as an optimization technique for capacitor placement and also for solving reactive power planning and dispatch problem. Evolutionary programming, Evolutionary strategies [26-31] were applied for reactive power problem. Particle Swarm optimization (PSO) [32] is used as a technique to deal reactive power problem. Differential Evolution and the Hybrid Evolutionary approaches [33-38] are recent trends to handle reactive power optimization problems.

In the present paper, the authors propose a new approach to the solution of the reactive power problem based on heuristics for the capacitor placements and Evolutionary Algorithms such as GA(Genetic Algorithm), PSO(Particle Swarm Optimization), DE(Differential Evolution) methods for controlling reactive generations of Generators and transformer tap positions of an inter connected power system. Shunt capacitors which is treated as planning variable are installed at candidate buses using heuristic approach considering loss sensitivity at that bus. Evolutionary method then applied for optimal

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setting of transformer tap positions and reactive VAr's Generated by the Generator's . The results obtained by each of these mixed heuristics and Evolutionary methods are compared with the results obtained by using each of the Evolutionary (GA, PSO and DE) methods.

2. THE PROPOSED APPROACH

The method has been developed for solving the reactive power planning problem though it may be used for the dispatch problem as well. Installation of the generators and tap changing transformers in a power system require considerations of the aspects beyond the reach of the reactive power optimization problem. On the other hand, the decision of installing new capacitors is solely guided by the reactive power considerations. As the capacitor installation involves costs, it is expected that the decision for the installations of new capacitors will be taken after the best possible utilization of the existing sources only. This gives rise to the idea that capacitor installation problem has to be solved after solving the reactive power dispatch problem for the generators and the tap changing transformers only. In such a case the capacitor installation problem has to be solved separately so as to minimize the additional cost to be incurred in the new capacitors. On the other hand, treatment of the complete problem simultaneously, as in conventional way (i.e entirely either by classical optimization or by evolutionary programming) will demand unnecessary searches requiring long time to generate the optimal solution. The above stated idea motivated the development of a heuristic technique for the solution of the capacitor installation problem and an evolutionary approach for solving the generator and tap changer dispatch problem.

2.1. PROBLEM FORMULATION

Reactive power optimization problem is nothing but minimization of transmission losses utilizing the available sources in the system.

Mathematically, the problem may be expressed as minimizing the power loss

$$P_{LOSS} = \sum_{k=1} \left(V_i^2 + V_j^2 - 2V_iV_j \cos\theta_{ij} \right)$$

Subject to the nodal reactive power balance

$$Q_{ni}^{\min} \le Q_{ni} \le Q_{ni}^{\max}$$

And Voltage magnitude constraints: $V_i^{\min} \le V_i \le V_i^{\max}$

OLTC tap constraints $t_k^{\min} \le t_k \le t_k^{\max}$

And the existing nodal reactive capacity constraints: $Q_{gi}^{\min} \le Q_{gi} \le Q_{gi}^{\max}$

The planning problem solves an enlarged set of equations including the investment costs of the components. The objective function to be minimized is

$$CP = \sum_{i=1}^{N} \left(Q_{n1}C_n + C_{o1} \right) + C_e \sum_{k=1}^{L} \left(V_i^2 + V_j^2 - 2V_iV_j \cos\theta_{ij} \right)$$

The constraint set consists of those mentioned above for the dispatch problem plus the additional constraint due to the new Var sources $Q_{ni}^{\min} \le Q_{ni} \le Q_{ni}^{\max}$

In the above:

L = total number of lines in the system.
ij = end buses of line k.
θ_{ij} = phase angle difference between buses i & j.
t_k = tap setting of the kth transformer.
Ce = cost of energy loss.
Cn = cost per Kvar of new reactive source.
N = Number of locations of new Var sources.
Superscripts min, max= minimum and maximum limits of the variables.

2.2. THE HEURISTIC TECHNIQUE FOR THE CAPACITOR INSTALLATION PROBLEM

The installation of a new capacitor is justified by two related responses of the systems. The cost reduction due to reduced power loss and the improvement of the voltage profile.

Given the loss equation of a power system

$P_{loss} = \sum_k v_i^2 + v_j^2 - 2v_i v_j \cos\delta_{ij}$, and assuming that change in the VAr generations has negligible effect on the voltage phase angle such that voltage magnitudes only will be changed, loss sensitivity with respect to node voltages may be used to judge where new sources are to be introduced or old sources are to be made richer.

For changes in the bus voltages, incremental change in the power loss is given by

$$\Delta P_{loss} = \left[\frac{\partial P_{loss}}{\partial v_1} \frac{\partial P_{loss}}{\partial v_2} .... \frac{\partial P_{loss}}{\partial v_n} \right] \quad \left[\Delta v_1 . \Delta v_2 ...... \Delta v_n \right]^T$$

The implication of the above relation is that loss reduction can be achieved by increasing the voltages at those nodes where loss sensitivity to voltage has a negative value and reducing the voltages of those nodes where loss sensitivity value is positive. Maximum reduction in the loss is possible where the product $\frac{\partial P_{loss}}{\partial v_i}.\Delta v_i$ is most negative and this node should first be selected for additional VAr support. In the planning problem, simply reducing the loss may not reduce the overall cost of the system as reduction has to be achieved by paying for additional capacitors to be installed. Moreover, operational constraint for system voltage also has to be maintained. To be on the safe side, therefore, it is decided to select that node as the first candidate for capacitor installation where the product of $\frac{\partial P_{loss}}{\partial v_i}.\Delta v_i$ is most negative and at the same time voltage is outside the permissible lower and upper limits. The amount of capacitor VAr addition however has to be justified before taking an installation decision. The verification of cost reduction requires a load flow to be performed. A decoupled load flow is used here. A further gain in solution speed of the load flow is achieved by recognizing the fact that, addition of VAr generation will not change the active power flow pattern. Thus, after the addition of the VAr source only the Q-equation of the fast decoupled load flow has to be solved in order to assess the cost benefit. Still greater reduction in solution time is achieved by modeling the capacitor as a constant Var source. This eliminates the necessity of updating the B" matrix and simple forward and backward substitutions only serve the purpose.

The heuristic algorithm for capacitor location identification is as given below:

1. Determine the loss sensitivities at all the nodes of the system.
2. Determine maximum possible voltage adjustments $\Delta v_i = v^{\lim it} - v_i$
3. Determine the product $\frac{\partial P_{loss}}{\partial v_i} . \Delta v_i$, i = 1,…..n.
4. Identify the nodes having a negative value of the product.
5. Order the nodes with decreasing values of the product.
6. Select the first node of the list as the capacitor location.
7. Apply the minimum size of capacitor, at the selected location.
8. Perform only the Q-solution of the decoupled load flow.
9. Determine the loss reduction.
10. Compare with the capacitor cost.
11. If cost reduction is possible, install the capacitor and go to step –1. Otherwise go to the next step.
12. All nodes in the list exhausted? If yes go to step 14. Otherwise go to the next step.
13. Select the next node in the list as the capacitor location and go to Step 7.
14. End of the heuristic step 7.

2.3. THE EVOLUTIONARY SOLUTION

As already mentioned, the evolutionary approach is used in this algorithm to know the optimum dispatch only. For this, capacitors selected by the heuristic algorithm are assumed to be fixed in the evolutionary process and the generator reactive outputs and the tap changer ratios are used as variables. The evolutionary algorithm is allowed to run to get optimum setting of the reactive sources presented with in a string. The string is shown in fig 1.It is to be mentioned here that for the load flows to be performed during the execution of the evolutionary algorithms, capacitors need not be modeled as constant Q-source. Rather an admittance model this time is preferred to have a better result.

Q_{g1}	Q_{g2}	……	Q_{gn}	t_1	t_2	……	t_n

Generator's Var   Transformer Taps

Fig 1: Solution String for Evolutionary Algorithm:

2.4. THE MIXED HEURISTIC AND EVOLUTIONARY ALGORITHM

Because of the sequential solutions of the two part of the problem, a one step solution will seldom be the optimum. An iterative approach is therefore necessary. The complete solution algorithm is as given in the flowchart of Fig. 2.

3. APPLICATION RESULTS

The proposed mixed heuristic and evolutionary approach has been applied to solve the reactive optimization problems of IEEE 14 and 30 bus test systems.

In IEEE 14 bus system the first four elements of the string are for Generator's reactive VAr's the next three positions are for transformer tap positions and as the weak buses are selected by heuristics, the string length has reduced to seven.

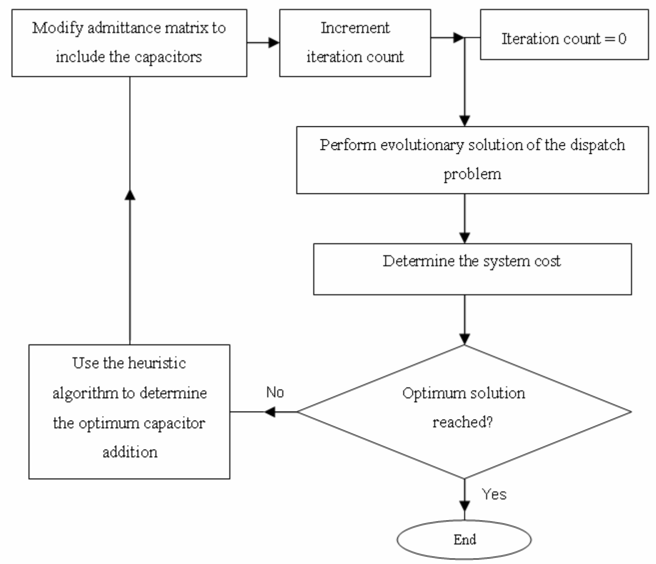

Fig 2: Flowchart of the Heuristic-Evolutionary process

Transformer taps are in line 8, 9 and 11 of the IEEE 14 bus system, since Bus number 2, 3, 6, 8 are PV buses, generator VAr's are controlled at these four buses. Heuristically 10th , 13th and 14th buses are determined as weak buses. Hence Shunt capacitors are installed at these locations. Transformer taps are in line 11, 12, 15 and 36 of the IEEE 30 bus. Here 1st five positions are assigned for Generator's reactive VAr's in the string as bus 2, 5, 8, 11 and 13 are the PV buses of the 30 bus system and 6th to 9th position are kept transformer tap positions. So string length is nine and hence string length is reduced as Shunt capacitor's are not taken inside the string. By Heuristic analysis 21st, 26th and 30th buses are found as candidate buses for installation of shunt capacitors. The heuristic approach has been applied along with the GA, PSO and DE algorithms and the results obtained are reported in the following tables.

Table 1 –shows the result obtained by Heuristic – GA technique and comparison of this result with GA, PSO and DE technique for IEEE 14 and IEEE 30 bus.

Table 2 – shows the result obtained by Heuristic – PSO method and comparison of this result with that obtained by GA, PSO and DE method.

Table 3 – shows the result obtained by Heuristic – DE method and comparison of this method with that of GA, PSO and DE method for IEEE 14 and IEEE 30 bus.

Various cost data is taken from [9] are as follows:

Energy cost= 0.06 $/KWh, fixed installment cost of capacitor =1000 $ and capacitor cost /KVAr =3 $.

Table 1: Results of the Heuristic-GA & other Evolutionary algorithms : Planning Problem

Test System	**Heuristic– GA**	**GA**	**PSO**	**DE**
IEEE 14 Bus	Optimum Solution	Optimum Solution	Optimum Solution	Optimum Solution
	Cost in $:- 6.9474×106	Cost in $:- 6.9493×106	Cost in $:- 6.9477×106	Cost in $:- 6.9470×106
	Variable Values:- Generator:- 0.3134 0.2499 0.2117 0.0748 tap position:- 0.9531 0.95 0.95 Shunt values:- 0.006 (7) 0.012 (10) 0.072 (13) 0.048 (14)	Variable Values:- Generator:- 0.3221 0.2532 0.1650 0.1161 tap position:- 0.95 0.95 0.95 Shunt values:- 0.0461 (14) 0.0632 (13) 0.0203 (12)	Variable Values:- Generator:- 0.3082 0.2487 0.24 0.1014 tap position;_ 0.95 0.95 0.95 Shunt values:- 0.0476 (14) 0.0519 (13) 0 (12)	Variable Values:- Generator:- 0.3135 0.2499 0.2318 0.0907 tap position:- 0.95 0.95 0.95 Shunt values:- 0.0477 (14) 0.0513 (13) 0.0141 (12)
IEEE 30 Bus	Optimum Solution	Optimum Solution	Optimum Solution	Optimum Solution
	Cost in $:- 3.5858×106	Cost in $:- 3.5899×106	Cost in $:- 3.6029×106	Cost in $:- 3.5877×106
	Variable Values:- Generator:- 0.1574 0.2391 0.2259 0.6457 0.2543 tap position:- 0.9 0.9 0.9 0.9 Shunt values:- 0.036 (21) 0.036 (26) 0.048 30)	Variable Values:- Generator:- 0.1371 0.2603 0.2575 0.0887 0.2061 tap position:- 0.9084 0.9007 0.9101 0.9001 Shunt values:- 0.0136 (29) 0.0394 (20) 0.0232 (30) 0.0245 (14)	Variable Values:- Generator:- 0.1818 0.2721 0.3466 0.1 0.2639 tap position;_ 0.9 0.9104 0.9090 0.9 Shunt values:- 0.0204 (29) 0.0636 (20) 0.0169 (30) 0 (14)	Variable Values:- Generator:- 0.1572 0.2523 0.2495 0.432 0.2366 tap position:- 0.9 0.9 0.9 0.9 Shunt values:- 0.0140 (29) 0.0455 (20) 0.0307 (30) 0.0169 (14)

Note: Numbers within the parenthesis indicate the buses or branches where the devices are connected

Table 2: Results of the Heuristic- PSO & other Evolutionary algorithms : Planning Problem

Test System	Heuristic – PSO	GA	PSO	DE
IEEE 14 Bus	Optimum Solution	Optimum Solution	Optimum Solution	Optimum Solution
	Cost in $:- 6.9459×106	Cost in $:- 6.9493×106	Cost in $:- 6.9477×106	Cost in $:- 6.9470×106
	Variable Values:- Generator:- 0.3013 0.2485 0.240 0.0483 tap position:- 0.95 0.95 0.95 Shunt values:- 0.006 (7) 0.03 (10) 0.072 (13) 0.048 (14)	Variable Values:- Generator:- 0.3221 0.2532 0.1650 0.1161 tap position:- 0.95 0.95 0.95 Shunt values:- 0.0461 (14) 0.0632 (13) 0.0203 (12)	Variable Values:- Generator:- 0.3082 0.2487 0.24 0.1014 tap position;_ 0.95 0.95 0.95 Shunt values:- 0.0476 (14) 0.0519 (13) 0 (12)	Variable Values:- Generator:- 0.3135 0.2499 0.2318 0.0907 tap position:- 0.95 0.95 0.95 Shunt values:- 0.0477 (14) 0.0513 (13) 0 (12)
IEEE 30 Bus	Optimum Solution	Optimum Solution	Optimum Solution	Optimum Solution
	Cost in $:- 3.5853×106	Cost in $:- 3.5899×106	Cost in $:- 3.6029×106	Cost in $:- 3.5877×106
	Variable Values:- Generator:- 0.1495 0.2546 0.488 0.0498 0.2507 tap position:- 0.9 0.9 0.9 0.9 Shunt values:- 0.036 (21) 0.036 (26) 0.048 30)	Variable Values:- Generator:- 0.1371 0.2603 0.2575 0.0887 0.2061 tap position:- 0.9084 0.9007 0.9101 0.9001 Shunt values:- 0.0136 (29) 0.0394 (20) 0.0232 (30) 0.0245 (14)	Variable Values:- Generator:- 0.1818 0.2721 0.3466 0.1 0.2639 tap position;_ 0.9 0.9104 0.9090 0.9 Shunt values:- 0.0204 (29) 0.0636 (20) 0.0169 (30) 0 (14)	Variable Values:- Generator:- 0.1572 0.2523 0.2495 0.432 0.2366 tap position:- 0.9 0.9 0.9 0.9 Shunt values:- 0.0140 (29) 0.0455 (20) 0.0307 (30) 0.0169 (14)

4. CONCLUSION

Heuristic based GA technique results system cost considerably less than generated by Simple GA, slightly lower than PSO and very close to system cost as produced by DE technique in case of IEEE 14 bus. In case of IEEE 30 bus heuristic based GA technique found to be the best in comparison to the other techniques. Similarly the heuristic– PSO technique found to be the best in resulting system cost in comparison with GA, PSO and DE technique both for IEEE 14 and IEEE 30 bus test system. If heuristic DE technique is compared with GA, PSO and DE methods for reactive power planning it out smarts all other techniques both for IEEE 14 and IEEE 30 bus. So, it is observed that if heuristic approach is used for shunt capacitor placement purpose and then evolutionary programming is continued for solving reactive power planning problem, then considerable improvement is noticed in all cases (i.e. with GA, PSO and DE). So among heuristic - GA, heuristic – PSO, heuristic – DE techniques, heuristic – DE and heuristic – PSO both worked extremely well for reactive power optimization. Heuristic – GA also worked very well closely following the above two methods on the basis of results. So this approach could be a new method for solving reactive power optimization problem. This approach is used for finding the solution of the reactive power problem by using variable decomposition technique in the sense that some of the power system control variable is treated as planning variable and the rest of the variables those does not incorporate cost in the objective function are treated as dispatch variables.

Table 3: Results of the Heuristic- DE & other Evolutionary algorithms: Planning Problem

Test System	Heuristic – DE	GA	PSO	DE
IEEE 14 Bus	Optimum Solution	Optimum Solution	Optimum Solution	Optimum Solution
	Cost in $:- 6.9441×106	Cost in $:- 6.9493×106	Cost in $:- 6.9477×106	Cost in $:- 6.9470×106
	Variable Values:- Generator:- 0.3109 0.2514 0.2259 0.0421 tap position:- 0.9568 0.95 0.95 Shunt values:- 0.006 (7) 0.03 (10) 0.072 (13) 0.048 (14)	Variable Values:- Generator:- 0.3221 0.2532 0.1650 0.1161 tap position:- 0.95 0.95 0.95 Shunt values:- 0.0461 (14) 0.0632 (13) 0.0203 (12)	Variable Values:- Generator:- 0.3082 0.2487 0.24 0.1014 tap position;_ 0.95 0.95 0.95 Shunt values:- 0.0476 (14) 0.0519 (13) 0 (12)	Variable Values:- Generator:- 0.3135 0.2499 0.2318 0.0907 tap position:- 0.95 0.95 0.95 Shunt values:- 0.0477 (14) 0.0513 (13) 0.0141 (12)
IEEE 30 Bus	Optimum Solution	Optimum Solution	Optimum Solution	Optimum Solution
	Cost in $:- 3.5852×106	Cost in $:- 3.5899×106	Cost in $:- 3.6029×106	Cost in $:- 3.5877×106
	Variable Values:- Generator:- 0.1513 0.2561 0.22629 0.0382 0.2514 tap position:- 0.9 0.9 0.9 0.9 Shunt values:- 0.036 (21) 0.036 (26) 0.048 30)	Variable Values:- Generator:- 0.1371 0.2603 0.2575 0.0887 0.2061 tap position:- 0.9084 0.9007 0.9101 0.9001 Shunt values:- 0.0136 (29) 0.0394 (20) 0.0232 (30) 0.0245 (14)	Variable Values:- Generator:- 0.1818 0.2721 0.3466 0.1 0.2639 tap position;_ 0.9 0.9104 0.9090 0.9 Shunt values:- 0.0204 (29) 0.0636 (20) 0.0169 (30) 0 (14)	Variable Values:- Generator:- 0.1572 0.2523 0.2495 0.432 0.2366 tap position:- 0.9 0.9 0.9 0.9 Shunt values:- 0.0140 (29) 0.0455 (20) 0.0307 (30) 0.0169 (14)

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