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Using of Genetic Algorithms (GAs) to find the optimal power flow

Case study (the 23 bus Serbian system)

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Abstract— **The optimal power flow (OPF) problems have been frequently solved using classical optimization methods and usually considered as the minimization of an objective function. The Genetic algorithms (GA) offer a new and powerful approach to these optimization problems. This task presents an optimization approach for fuel cost and power loss minimization based on genetic algorithm method. To demonstrate optimization power of the presented technique, this method is applied to the 23 bus Serbian system. The results compared with those obtained using OPF method based on mathematical programming approaches by Power System Analysis Toolbox (PSAT).**

Keywords— optimal power flow and genetic algorithm.

I. INTRODUCTION

Power-flow (PF) studies are routinely used in planning, control, and operations of existing electric power systems as well as planning for future expansion. Satisfactory operation of power systems depends upon knowing the effects of adding interconnections, connecting new loads, introducing new generating stations, or constructing new transmission lines before they are installed. Power-flow studies also allow us to determine the best size and the most favorable locations for power capacitors both for improving the power factor and also raising the bus voltages of the electrical network. Power flow studies help us to determine the best location as well as the optimal capacity of proposed generating stations, substations, or new lines.[3]

Power flow studies are performed using digital computer simulations. The treatment of Optimal Power Flow (OPF) will presents. It can be stated that there are many load flow techniques and there is a historical background to the development of these methods. In this task we will study the OPF over power network, which is cost reduction and power loss minimization are the main targets.

This task presents an optimization approach for fuel cost and power loss minimization based on genetic algorithm method. To demonstrate optimization power of the presented technique, this method is applied to the 23 bus Serbian system. The results compared with those obtained using OPF method based on mathematical programming approaches by Power System Analysis Toolbox (PSAT).

II. OPTIMAL POWER FLOW

The optimal power flow (OPF) problem was defined in early 1960, in connection with the economic dispatch of power [3]. Traditionally, the emphasis in performance optimization has been on the cost of generation; however, this problem can become fairly complex when the hourly commitment of units, hourly production of hydroelectric plants, and cogeneration and scheduling of maintenance without violating the needs for adequate reserve capacity are added.

The demand for an OPF tool has been increasing to assess the state and recommended control actions. Today, The thrust for OPF to solve industry problems has faced by many challenges which are before OPF remain to be answered. They can be listed as given below.

1. Because of the consideration of large number of variety of constraints and due to non linearity of mathematical models OPF poses a big challenge for the mathematicians as well as for engineers in obtaining optimum solutions.
2. The deregulated electricity market seeks answer from OPF, to address a variety of different types of market participants, data model requirements and real time processing and selection of appropriate costing for each unbundled service evaluation.
3. To cope up with response time requirements, modeling of externalities (loop flow, environmental and simultaneous transfers), practicality and sensitivity for on line use.
4. How well the future OPF provide local or global control measures to support the impact of critical contingencies, which threaten system voltage and angle stability simulated.
5. Future OPF has to address the gamut of operation and planning environment in providing new generation facilities, unbundled transmission services and other resources allocations.

The OPF problem can be described as the cost of minimization of real power generation in an interconnected

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system where powers and a wide range of inequality constraints are imposed. The standard OPF problem can be written in the following form:

Minimize F(x) (the objective function)

subject to: $g_j(x) = 0$, j = 1, 2, ...,m (equality constraints)

$h_i(x) = 0$, i = 1, 2, ..., n (inequality constraints)

where x is the vector of the control variables, that is those which can be varied by a control center operator (generated active and reactive powers, generation bus voltage magnitudes, transformers taps etc.). The essence of the optimal power flow problem resides in reducing the objective function and simultaneously satisfying the load flow equations (equality constraints) without violating the inequality constraints. This needs to process the network equations with given constraints about an assumed starting point and then increment it with repeating the process until the required tolerance is achieved.

The general OPF problem is posed as minimizing the general objective function F(x,u) while satisfying the constraints g(x, u) = 0 and h(x, u) ≤ 0, where g(x, u) represents nonlinear equality constraints (power flow equations) and h(x,u) is nonlinear inequality constraints on the vectors x and u.

The vector x contains dependent variables like: Bus voltage magnitudes and phase angles, MVAr output of generators designated for bus voltage control, Fixed parameters such as the reference bus angle, Non controlled generator MW and MVAr outputs, Non controlled MW and MVAr loads, Fixed bus voltages, line parameters.

The vector u consists of control variables including: Real and reactive power generation, Phase – shifter angles, Net interchange, Load MW and MVAr (load shedding), Control voltage settings.

The equality and inequality constraints are: Limits on all control variables, Power flow equations, Generation / load balance, Branch flow limits (MW, MVAr, MVA), Bus voltage limits, Active / reactive reserve limits, Generator MVAr limits.

A. *OPF fuel cost minimization*

The OPF problem can be formulated as follows:

Total Generation cost function is expressed as

$$F(P_G) = \sum_{i=1}^{N_G} \left[\alpha_i + \beta_i P_{Gi} + \gamma_i P_{Gi}^2\right] \tag{1}$$

And the network equality constraints are represented by the load flow equations

$$P_i(V,\delta) - P_{Gi} + P_{Di} = 0 \tag{2}$$

$$Q_i(V,\delta) - Q_{Gi} + Q_{Di} = 0 \tag{3}$$

Where

$$P_i(V,\delta) = |V_i| \sum_{i=1}^{N} |V_i||Y_{ij}| \cos(\delta_i - \delta_j - \phi_{ij}) \tag{4}$$

$$Q_i(V,\delta) = |V_i| \sum_{i=1}^{N} |V_i||Y_{ij}| \sin(\delta_i - \delta_j - \phi_{ij}) \tag{5}$$

And the load balance equation

$$\sum_{i=1}^{N_G}(P_{Gi}) - \sum_{i=1}^{N_D}(P_{Di}) - P_l = 0 \tag{6}$$

The Inequality constraints representing the limits on all variables, line flow constraints,

$$\begin{aligned} &V_{i\min} \le V_i \le V_{i\max}, i = 1,....., N. \\ &P_{G_i\min} \le P_{G_i} \le P_{G_i\max}, i = 1,....., N_G \\ &Q_{G_i\min} \le Q_{G_i} \le Q_{G_i\max}, i = 1,.... N_{Gq} \end{aligned} \tag{7}$$

B. *OPF Active power loss minimization*

The objective functions to be minimized are given by the sum of line losses

$$P_L = \sum_{K=1}^{N_l} P_{l_k} \tag{8}$$

Individual line losses P_{l_k} can be expressed in terms of voltages and phase angles as:

$$P_{l_K} = g_K\left[V_i^2 + V_j^2 - 2V_iV_j\cos(\delta_i - \delta_j)\right] \tag{9}$$

The objective function can now be written as:

$$Min.P_L = \sum_{i=1}^{N_l} g_K\left[V_i^2 + V_j^2 - 2V_iV_j\cos(\delta_i - \delta_j)\right] \tag{10}$$

This is a quadratic form and is suitable for implementation. The constraints are equivalent to those specified in Section 3.1 for cost minimization, with voltage and phase angle expressed in rectangular form [3].

III. GENATIC ALGHORITHM IN OPF

The genetic algorithms are part of the evolutionary algorithms family, which are computational models, inspired in the Nature. Genetic algorithms are powerful stochastic search algorithms based on the mechanism of natural selection and natural genetics. GAs works with a population of binary string, searching many peaks in parallel. By employing genetic operators, they exchange information between the peaks, hence reducing the possibility of ending at a local optimum. GAs are more flexible than most search methods because they require only information concerning the quality of the solution produced by each parameter set (objective function values) and not like many optimization methods which require derivative information, or worse yet, complete knowledge of the problem structure and parameters [6].

It is observed that, Genetic Algorithm (GA) method differs from other optimization methods in four ways:

- GAs work with a coding of the parameter set, not the parameters themselves. Therefore GAs can easily handle the integer or discrete variables.
- GAs search within a population of points, not a single point. Therefore GAs can provide a globally optimal solution.
- GAs use only objective function information, not derivatives or other auxiliary knowledge. Therefore GAs can deal with non-smooth, non-continuous and non-differentiable functions which are actually exist in a practical optimization problem.
- GAs use probabilistic transition rules, not deterministic rules.

A. GA steps in OPF

A simple Genetic Algorithm is an iterative procedure, which maintains a constant size population P of candidate solutions. During each iteration step (generation) three genetic operators (reproduction, crossover, and mutation) are performing to generate new populations (offspring), and the chromosomes of the new populations are evaluated via the value of the fitness which is related to cost function. Based on these genetic operators and the evaluations, the better new populations of candidate solution are formed. With the above description, a simple genetic algorithm is given as follow[6]:

1. Generate randomly a population of binary string.
2. Calculate the fitness for each string in the population.
3. Create offspring strings through reproduction, crossover and mutation operation.
4. Evaluate the new strings and calculate the fitness for each string (chromosome).
5. If the search goal is achieved, or an allowable generation is attained, return the best chromosome as the solution; otherwise go to step 3.

B. Chromosome coding and decoding

Each chromosome represents a potential solution for the problem and must be expressed in binary form in the integer interval. We could simply code X in binary base. If we have a set of binary variables, a bit will represent each variable. For a multivariable problem, each variable has to be coded in the chromosome[3].

The first step of any genetic algorithm is to create an initial population of GA by randomly generating a set of feasible solutions. A binary string of length L is associated to each member (individual) of the population. The string is usually known as a chromosome and represents a solution of the problem. A sampling of this initial population creates an intermediate population. Thus some operators (reproduction, crossover and mutation) are applied to an intermediate population in order to obtain a new one, this process is called Genetic Operation. The process, that starts from the present population and leads to the new population, is called a generation process.

C. Genetic Operation-Crossover

Crossover is the primary genetic operator, which promotes the exploration of new regions in the search space. For a pair of parents selected from the population the recombination operation divides two strings of bits into segments by setting a crossover point at random locus, i.e. Single Point Crossover. The segments of bits from the parents behind the crossover point are exchanged with each other to generate their off-spring. The mixture is performed by choosing a point of the strings randomly and switching the left segments of this point. The new strings belong to the next generation of possible solutions. The strings to be crossed are selected according to their scores using the roulette wheel. Thus, the strings with larger scores have more chances to be mixed with other strings because all the copies in the roulette have the same probability to be selected[6].

D. Genetic Operation-Mutation

Mutation is a secondary operator; it prevents the premature stopping of the algorithm in a local solution. This operator is defined by a random bit value change in a chosen string with a low probability. The mutation adds a random search character to the genetic algorithm.

E. Genetic Operation-Reproduction

Reproduction is simply an operator where by an old chromosome is copied into a Mating pool according to its fitness value. Highly fit chromosomes (closer distances to the optimal solution mean highly fit) receive higher number of copies in the next generation. Copying chromosomes according to their fitness means that the chromosomes with a higher fitness value have higher probability of contributing one or more offspring in the next generation.

F. Evaluation-Candidate solutions fitness

In the evaluation, suitability of each of the solutions from the initial set as the solution of the optimization problem is determined. For this function called “fitness function” is defined. This is used as a deterministic tool to evaluate the fitness of each chromosome. The optimization problem may be minimization or maximization type. In the case of maximization type, the fitness function can be a function of variables that bear direct proportionality relationship with the objective function. For minimization type problems, fitness function can be function of variables that bear inverse proportionality relationship with the objective function or can be reciprocal of a function of variables with direct proportionality relationship with the objective function. In either case, fitness function is so selected that the most fit solution is the nearest to the global optimum point.

A standard GA procedure for solving the optimal power flow problem is summarized in the diagram of the Figure 1.[4].

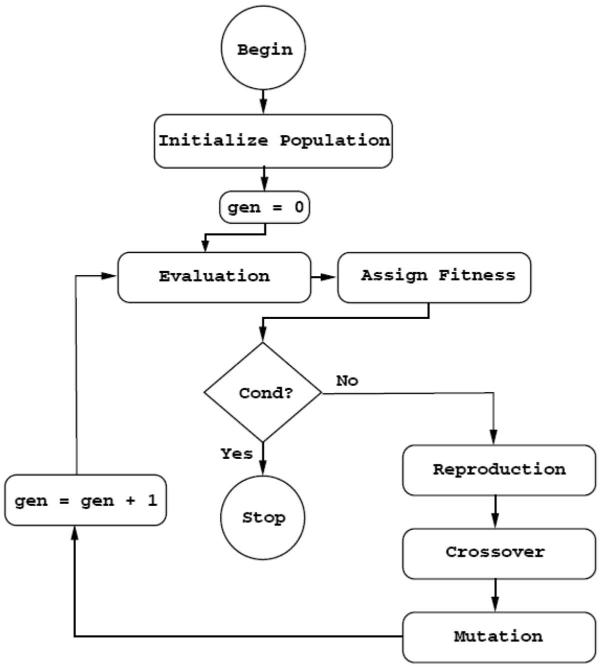

Fig. 1. A Simple flow chart of the GAOPF

IV. CALCULATIONS AND RESULTS

In this work, the Serbian electrical network for 23-bus system is considered to investigate effectiveness of the proposed GA method. The applied Serbian electrical network is represented in Fig. 2. The network has 6 generators, 25 lines, 7 transformers and 23 loads. Upper and lower active power generating limits, reactive power limits, unit cost coefficients, lower and upper limits of voltage magnitude for generator buses and all the system's data are in a file attached to the main program. The proposed GA approach is developed by the use of MATLAB R2009a.

It's required to performing a load flow solution in order to make fine adjustments on the optimum values obtained from the GAOPF procedure. This requires a fast load flow program with best convergence properties. In this case, the used program solves the power flow problem by Newton-Raphson method.

The solution of Optimal Power Flow (OPF) is presented with two different objective functions. OPF solution is carried out considering fuel cost minimization and active power loss minimization as objective. For the study the number of generations was set to 10 and 100 for 3 times and set to 1000 for 10 times.

A. *Number of generations = 10*

TABLE 1. THE FUEL COST

	1	2	3
Fuel cost ($/h)	27560.47	28122.91	27544.6

TABLE 2. THE POWER LOSS

	1	2	3
Power loss (MW)	21.95676	23.52261	20.83314

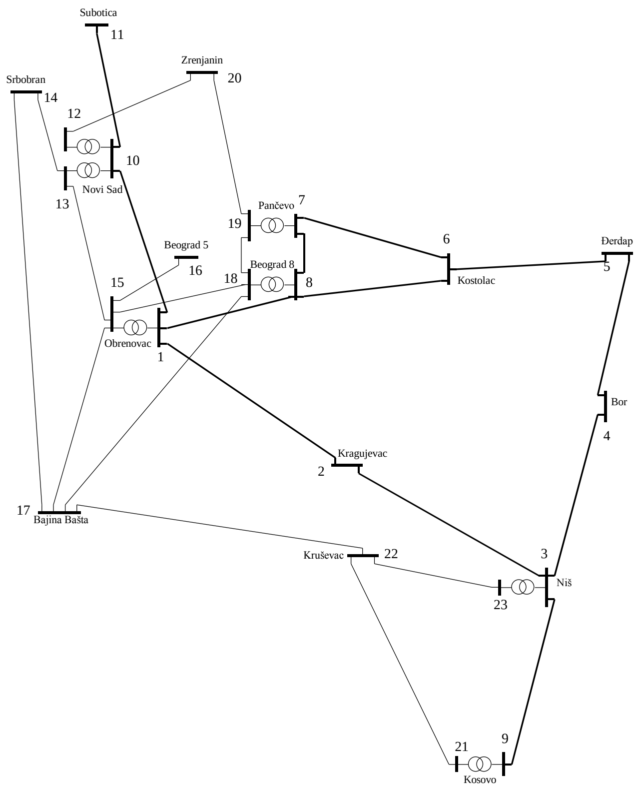

Fig. 2. The 23-bus electrical net work.

B. *Number of generations = 100*

TABLE 3. THE FUEL COST

	1	2	3
Fuel cost ($/h)	27164.09	27155.51	27175.1

TABLE 4. THE POWER LOSS

	1	2	3
Power loss (MW)	19.48315	19.36902	18.87203

C. *Number of generations = 1000*

The OPF solutions are computed in time about 10 minutes for each objective (10 minutes for number of generation =1000. The time for number of generation =10 and 100 is more less) . The optimal active and reactive power dispatches and cost for the OPF solutions are shown in Table 5.

The Table 6 shows that all voltage magnitudes, active and reactive power generation levels are inside limits. However, it must be pointed out that "power generated from the generators

5 and 6 are set to their upper limits because of the cost of power generation from them are the minimum".

TABLE 5. THE FUEL COST AND POWER LOSSES

	Fuel cost ($/h)
1	27107.05
2	27116.41
3	27105.61
4	27107.05
5	27103.91
6	27105.93
7	27160.38
8	27110.67
9	27153.99
10	27125.98

	Power loss (MW)
1	17.95105
2	18.64364
3	18.18499
4	17.95836
5	17.95836
6	17.95836
7	18.07519
8	18.22273
9	18.54615
10	20.46737

TABLE 6. THE OPF SOLUTION DISPATCHE FOR FUEL COST

Objective function: Fuel cost ($/h)

Objective function value

OF1= 27103.91

Bus	Pgen	Qgen	Vmag
1	945.0872	313.7904	1.091789
2	0	0	1.099526
3	0	0	1.095066
4	0	0	1.089593
5	500	-113.051	1.08651
6	500	229.4972	1.093157
7	0	0	1.080247
8	0	0	1.079364
9	0	0	1.088518
10	0	0	1.072424
11	0	0	1.0643
12	0	0	1.054697
13	0	0	1.045581
14	0	0	1.024432
15	942.131	152.6239	1.069501
16	0	0	1.058788
17	702.0528	137.8818	1.071065
18	0	0	1.044325
19	0	0	1.050746
20	0	0	1.040348
21	703.6168	122.4747	1.080841
22	0	0	1.052106
23	0	0	1.080354

TABLE 7. THE OPF SOLUTIONS DISPATCHE FOR POWER LOSSES

Objective function: Power loss (MW)

Objective function value

OF2= 17.95105

Bus	Pgen	Qgen	Vmag
1	1481.076	278.0965	1.093744
2	0	0	1.099375
3	0	0	1.092246
4	0	0	1.088986
5	306.4516	-108.326	1.087292
6	497.263	259.4734	1.098436
7	0	0	1.084473
8	0	0	1.083052
9	0	0	1.081137
10	0	0	1.074444
11	0	0	1.066353
12	0	0	1.057519
13	0	0	1.049127
14	0	0	1.027858
15	708.3089	181.5165	1.073216
16	0	0	1.062546
17	626.9795	137.5158	1.07087
18	0	0	1.04847
19	0	0	1.054809
20	0	0	1.04379
21	670.7722	100.0991	1.071065
22	0	0	1.047579
23	0	0	1.076954

V. COMPARISON

The optimal generation cost obtained by the GA is compared to that obtained using different OPF method named Power System Analysis Toolbox (PSAT). The (PSAT) is a Matlab toolbox for electric power system analysis and simulation. All operations can be assessed by means of graphical user interfaces (GUIs) and a Simulink-based library provides an user-friendly tool for network design [7]. The obtained generation cost compares well and is slightly higher (as seen in table 8). So, The results demonstrate that "the GA method shows great promise".

TABLE 8. THE OPF RESULTS FROM GA AND (PSAT)

Fuel cost ($/h)	
GA	PSAT
27103.91	27102.8624

TABLE 9. GENERATED POWER AND VOLTAGE FOR GENERATOR BUSES

Generated Power and Voltage for generator buses				
Bus Number	$P_{Generation}$ (MW)		$V_{magnitude}$ (pu)	
	GA	PSAT	GA	PSAT
1	945.0872	943.5406	1.091789	1.0914
5	500	500	1.08651	1.0945
6	500	500	1.093157	1.0993
15	942.131	938.7293	1.069501	1.0781
17	702.0528	705.1336	1.071065	1.0818
21	703.6168	705.4102	1.080841	1.0767

VI. CONCLUSION

The drawbacks of conventional methods usually getting stuck at a local optimal. These methods are based on assumption of continuity and differentiability of objective function which is not actually allowed in a practical system. However, modern methods are getting more attention in solving optimization problems.

It is observed that Genetic Algorithm (GA) is an appropriate method to eliminate the above drawbacks and solve those problems. In additional, GA has feature where it searches many peaks in parallel and hence reducing the possibility of local minimum trapping. Another advantage represented in it works with a coding of parameters instead of the parameters themselves. The coding of parameter will help the genetic operator to evolve the current state into the next state with minimum computations.

GA Optimal Power Flow program (MATLAB program) has been a applied to electrical network with 23-bus system. It's recommended to indicate that in large number of generation, the GA accomplished in a more time. The results show that GA can give a very good optimal solutions when it is compared with another method.

On the other hand, GAs provides solutions to the OPF problem which is not guaranteed to be optimum. Also, the execution time and the quality of the solution, deteriorate with the increase of the number of generation and chromosome length.

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