Optimal Generation Schedule for Yangon Distribution Network Using Genetic Algorithm

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Abstract: In a practical power system, the power plants are not located at the same distance from the centre of loads and their fuel costs are different. In an interconnected power system, the main objective is to provide a reliable power scheduling of each power plant in such a way as to minimize the operating cost and transmission loss. In order to achieve this, power system needs to optimally analyze, monitor and control at every moment. These main tasks are Economic Dispatch ED and Optimal Power Flow OPF generally modeled as large scale optimization problems. ED is the scheduling of generators to minimize total operating cost of generator units subjected to equality constraint of power balance within the minimum and maximum operating limits of the generating units. OPF is to generate the final real power and reactive power flow based upon the optimized generator scheduling. The Genetic Algorithm GA method has been used to solve the two important power system optimization problems such as ED and OPF. The results of ED and OPF were compared in same proposed area which is Yangon Division. This paper presents that 23.11% and 21.76% can be saved for the total generation cost with GAOPF and GAED and also total real power loss can be reduced to 0.71% in GAOPF solution compared with current situation of operation system for Yangon distribution network.

Key Words: Economic Dispatch, Optimal Power Flow, Genetic Algorithm method, minimum operation cost, minimum loss.

1. INTRODUCTION:

Power system optimization involving power generation and delivery can be subdivided into two parts; one is dealing with minimum cost of power production called Economic Dispatch ED and the other dealing with minimum loss delivery of generated power to the loads [1].

For any specified load condition, Economic Dispatch ED determines the power output of each generating unit within the plant which will minimize the overall cost of fuel needed to serve the system load. The cost curve of thermal unit is generally modelled as a smooth curve. Thus, Economic Dispatch ED focuses upon coordinating the production cost at all power plants operating on the system. Economic dispatch ED is an important optimization problem which aims at scheduling the committed thermal generating units to meet the load demand for minimum operating cost while satisfying the equality and inequality constraints. The minimum loss problem can assume many forms depending on how control of the power flow in the system is calculated. Optimal Power Flow OPF problem is a special tool to obtain the optimal state of the control variables by minimizing the certain objective function. Optimal Power flow OPF is also important for determination of electricity prices and congestion management. Optimal Power Flow OPF optimizes a power system operating objective function, while satisfying a set of system constraints [3]. Power system optimization problems have complex and non-linear characteristics with several equality and inequality constraints. There are two ways namely traditional and evolutionary methods by which the problems are solved. The traditional optimization methods are linear programming, quadratic programming, Newton's method and interior point method. Similarly, evolutionary optimization methods are classified as genetic algorithm GA, evolutionary programming EP, particle swarm optimization PSO, differential evolution DE and harmony search algorithm HSA.

Genetic algorithm GA is one of the most popular paradigms of evolutionary computation. Genetic algorithm GA method offers a new and powerful approach to these optimization problems made possible by the increasing availability of high performance computers at relatively low costs. It has the superior global searching capability in a complex searching surface using little information of searching space, such as derivative, continuity thus providing potential tool for real Economic Dispatch ED problem. Genetic Algorithm of Optimal Power Flow GAOPF problem is solved based on the use of a Newton method load flow. The method is not sensitive to the starting points and capable to determining the global optimum solution to the OPF for range of constraints and objective functions [2]. In this paper, Genetic algorithm GA method is applied to achieve the best result of both Economic Dispatch ED and Optimal Power Flow OPF problems in Yangon Distribution Network.

2. PROBLEM STATEMENT:

Electric power systems are among the most complex industrial systems of today's civilization that play a central role in the functioning of modern societies. In order to perform this role, production and delivery of electric power must be achieved reliably and cost-effectively. There are two major power generating types to distribute in Yangon network. They are hydroelectric generating system and thermal (coal, oil or natural gas) power generating system. The main fuel used in thermal stations is natural gas which is obtained from inland as well as offshore. As hydro plants have essentially no variable operating costs, fundamental to the economic operation problem is the set of input-output characteristics of a thermal power generation unit. Single line diagram for Yangon distribution system is shown in figure 1. Generating stations are located in Ywama, Hlawgar, Ahlone and Tharketa. All generating stations operate both simple and combined cycle units. In addition, Hlawga, Hlaingtharyar and Thanlyin obtain the hydro power from the grid connected system. In the process of transmitting the generated power, an estimated 2.76% of the total energy produced is lost and optimal generation cost cannot be obtained due to absence of optimal generation schedule in Yangon Distribution Network.

In current condition in YESC, the total operating cost and transmission loss are 59256.32$/hr and 26.82 MW which are very high compared to achieve optimum result. The economic viability of power systems, especially in a competitive energy market, demands an optimum mix of all of the parameters that influence power generation and transmission. An approach to achieving this optimum is to include the transmission losses as one of the objectives in the Optimal Power Flow OPF problem.

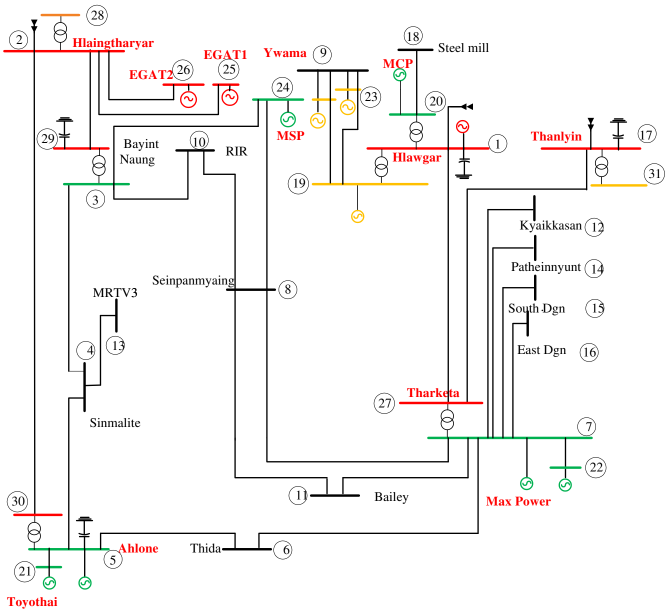

Fig.1Single line diagram for Yangon Distribution Network

Thus, the optimal dispatch problem becomes a multi objective optimization in which the fuel cost and the transmission losses are minimized [2]. This is achieved by aggregating the objective functions into a single function. The economic dispatch ED problem is one of the most important operational functions of energy management system. The purpose of the ED is to find the optimum generation among the existing units, such that the total generation cost is minimized while simultaneously satisfying the power balance equations and various other constraints in the system [4].

A. Problem Formulation of Economic Dispatch

The ED problem may be expressed by minimizing the fuel cost of generator units under constraints. Depending on load variations, the output of generators has to be changed [5]. The ED problem can be expressed as:

$$min \sum_{i=1}^{NG} F_i(P_{Gi}) \quad (1)$$

$$F_i(P_{Gi}) = a_i + b_i P_{Gi} + c_i P_{Gi}^2 \quad (2)$$

Where ai, bi and ci are the cost coefficients of the generator and PGi is the real power output of the i-th generator (MW). Fi (PGi) is the operating cost of unit ($/h).Subjects to the following constraints.

$$P_{Gi}^{min} \leq P_{Gi} \leq P_{Gi}^{max} \quad \text{for } i=1\ldots\ldots\ldots NG$$

$$\sum_{i=1}^{NG} P_{Gi} - P_D - P_L = 0 \quad (3)$$

$$P_L = \sum_{i=1}^{ng} \sum_{j=1}^{ng} P_i B_{ij} P_j + \sum_{i=1}^{ng} B_{0i} P_i + B_{00} \quad (4)$$

where,

P_D= Total demand (MW)

P_L= Transmission loss(MW)

P_{Gi}^{min} =Minimum generation of the i-th Generator

P_{Gi}^{max} =Minimum generation of the i-th Generator

B=Coefficient of Transmission Losses

B. Problem Formulation of Optimal Power Flow

Optimal Power Flow OPF provides the optimal settings of the control variables for a given load by minimizing a selected objective function such as the cost of active power generation or losses. Again, OPF have to formulate according to the system constraints [3]. In general, OPF is formulated as a constrained optimization problem as follow:

Minimize f (u: x) (5)

Subject to g (u, x) = 0 (6)

h (u, x) ≤ 0 (7)

where

- u : vector of control variables.
- x : vector of state variables.
- f (u,x) : Objective function.
- g (u,x) : set of equality constraints.
- h (u,x) : set of inequality constraints.

The objective function is simply a summation of individual polynomial cost function of real and reactive power injections, respectively, for each generator:

$$\min_{\theta, V_m, P_g, Q_g} \sum_{i=1}^{n_g} f_P^i (P_g^i) + \sum_{i=1}^{n_g} f_Q^i (Q_g^i) \quad (8)$$

The equality constraints are the basic load flow equations. For each bus in a power system, there are two equations for equality constraints:

Real power balance equation

$$P_{Gi} - P_{Di} - P_i(V, \delta, t) = 0 \quad (9)$$

Reactive power balance equation

$$Q_{Gi} - Q_{Di} - Q_i(V, \delta, t) = 0 \quad (10)$$

The variable limits include an equality constraint on any reference bus angle and upper and lower limits on all bus voltage magnitudes and real and reactive generator injections:

$$\theta_{lowi}^{ref} \le \theta_i \le \theta_{highi}^{ref}, \quad i = 1, ..., n_g$$

$$v_m^{i,min} \le v_m^i \le v_m^{i,max}, \quad i = 1, ..., n_b$$

$$P_g^{i,min} \le P_g^i \le P_g^{i,max}, \quad i = 1, ..., n_g$$

$$Q_g^{i,min} \le Q_g^i \le Q_g^{i,max}, \quad i = 1, ..., n_g$$

3. GENETIC ALGORITHM GA METHOD:

Genetic algorithm is one of the most developed paradigms in evolutionary computation. It basically implements the theory of evolution as an algorithm [6]. The method of selecting or picking parents and method of inserting offspring back into population taken together is called model of evolution. GAs is 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). GAs are simple and practical algorithm and easy to be implemented in power system [7].

GA may be binary coded or real coded depending upon the representation of problem variable.GA start with random generation of initial population and then the selection, crossover and mutation operations are carried out until best population is found [8]. In other words, assuming an initial random population produced and evaluated, genetic evolution takes place by means of three basic genetic operators.

1. Parent selection: The selection of parents to produce successive generations plays an important role in the GA. This allows the fitter individuals to be selected more often to reproduce.

2. Crossover: Crossover is an important operator of the GA. The main objective of crossover is to reorganize the information of two different individuals and produce a new one. It is a structured, yet randomized mechanism of exchanging formation between strings. It promotes the exploration of new regions in search space.
3. Mutation: Mutation consists of protecting the process of reproduction and crossover effectively without much loss of the potentially useful genetic material. Mutation is by itself a random walk through the string space and provides for occasional disturbances in the crossover operation by inserting one or more genetic elements during reproduction. This operation ensures diversity in the genetic strings over long period of time and prevents stagnation in the evolution of optimal individuals [9].

A. GA Applied to Economic Dispatch ED

The detailed Algorithm for solving the classical Economic Dispatch ED problem using unit output based Binary Coded Genetic Algorithm method is given below [8].

1. Read data, namely cost coefficients, a_i,b_i,c_i, no.of iterations, length of string, population size, probability of crossover and mutations, power demand and $\mathbf{P^{min}}$ and $\mathbf{P^{max}}$.
2. Create the initial population randomly in the binary form.
3. Decode the string or obtain the decimal integer from the binary string using Eq.(11).

$$y_i = \sum_{j=0}^{L-1} 2^j b_{ij} \qquad (11)$$

Where b is the binary bit and L is the length of chromosome.

4. Calculate the power generated from the decoded population by using Eq.(12).

$$P_i^j = P_i^{min} + \frac{P_i^{max} + P_i^{min}}{2^L - 1} y_i^j$$

(i=1,2……NG; j=1,2……L) (12)

Where L is the number of strings and $\mathbf{y_i^j}$ is the binary coded value of the i^{th} substring.

5. Check $\mathbf{P_i^j}$,
If $\mathbf{P_i^j} > \mathbf{P_i^{max}}$,then set $\mathbf{P_i^j} = \mathbf{P_i^{max}}$
If $\mathbf{P_i^j} < \mathbf{P_i^{max}}$,then set $\mathbf{P_i^j} = \mathbf{P_i^{min}}$
6. Calculate the transmission loss by using Eq.(4)
7. Find the fitness or cost function by using Eq.(2).
8. Find population with maximum fitness and average fitness of the population.
9. Perform the reproduction process.
10. Perform the crossover process.
11. Perform mutation by randomly selecting the mutation points from the total number of bits in the population matrix.
12. Update the population.
13. If the number of iteration reaches the maximum, then go to step 14. Otherwise, go to step 7.
14. The fitness that generates the minimum total generation cost is the solution of the problem [10].

B. GA Applied to Optimal Power Flow 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:

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 [12].

To minimize F(x) is equivalent to getting a maximum fitness value in the searching process. A chromosome that has lower cost function should be assigned a larger fitness value. The objective of OPF has to be changed to the maximization of fitness to be used in the simulated roulette wheel as follows:

$$\text{Fitness}_i = \begin{cases} f_{max} - f_i \; ; \text{ if } f_{max} \le f_i \; ; i=1,ng \\ 0; \quad \text{otherwise} \end{cases} \qquad (13)$$

Then the GA tries to generate better offspring to improve the fitness. Using the above components, a standard GA procedure for solving the optimal power flow problem is summarized in the diagram of the Figure 2. After the search goal is achieved, or an allowable generation is attained by the genetic algorithm. It's required to performing a load flow solution in order to make fine adjustments on the optimum values obtained from the GAOPF procedure. The developed load flow process is based upon the full Newton-Raphson algorithm using the optimal multiplier technique [11].

4. SIMULATION RESULTS OF GAED AND GAOPF:

A. Simulation Results of GAED

According to collected data from Yangon Electricity Supply Corporation YESC, the loss coefficients, fuel cost and maximum and minimum power limits are required for calculation of GAED. The power demand is considered to be **952.5MW**. The fuel cost equations are evaluated with "polyfit(x,y,n)" function in MATLAB. The fuel consumptions values are assigned as "x" and output power values are assigned as "y". The required order for cost equations is taken as "n". After applying the required values in "polyfit(x,y,n)" function, cost equations of YESC network are achieved. And then, loss coefficient matrix is calculated with equation 4.
Generator Characteristics of 14- units of YESC Network

$F1 = 30.69P_G - 20.47(\$/hr)$ $200 \le P \le 230(MW)$
$F2 = 30.69P_G - 20.47(\$/hr)$ $100 \le P \le 110(MW)$
$F3 = 2P_G^2 - 293.5P_G + 16792.5(\$/hr)$ $20 \le P \le 154.2(MW)$
$F4 = 2.2P_G^2 - 216.49P_G + 8300\ (\$/hr)$ $20 \le P \le 92(MW)$
$F5 = 0.69\ P_G^2 + 11.26P_G + 1392.03(\$/hr)$ $20 \le P \le 36.9(MW)$
$F6 = 30.69P_G - 20.47(\$/hr)$ $100 \le P \le 110(MW)$
$F7 = 2P_G^2 - 308.5P_G + 17013\ (\$/hr)$ $20 \le P \le 154.2(MW)$
$F8 = 5.75P_G^2 - 148.74P_G + 1755.8(\$/hr)$ $15 \le P \le 26.7(MW)$
$F9 = 0.19\ P_G^2 - 29.321P_G + 5056.5(\$/hr)$ $20 \le P \le 125.6(MW)$
$F10 = 1.57P_G^2 - 121.59P_G + 3923.2(\$/hr)$ $20 \le P \le 53.6(MW)$
$F11 = 10.5\ P_G^2 - 420.5P_G + 5467.5\ (\$/hr)$ $5 \le P \le 33.4(MW)$
$F12 = 9P_G^2 - 787.5P_G + 19664(\$/hr)$ $20 \le P \le 52(MW)$
$F13 = 2.5P_G^2 - 426P_G + 24502(\$/hr)$ $20 \le P \le 120(MW)$
$F14 = 1.668P_G^2 - 17.68P_G + 938.48(\$/hr)$ $5 \le P \le 120(MW)$
Loss Coefficient matrix

```
B =

    0.0109   -0.0076   -0.0145    0.0115    0.0070    0.0025    0.0201   -0.0063   -0.0043    0.0033    0.0052   -0.0107   -0.0028   -0.0028
   -0.0076    0.0118    0.0173   -0.0101   -0.0056   -0.0052   -0.0121    0.0014    0.0069   -0.0042   -0.0047    0.0111    0.0063    0.0063
   -0.0145    0.0173    0.0642   -0.0275   -0.0067   -0.0055   -0.0342    0.0202    0.0082   -0.0037   -0.0028    0.0225   -0.0006   -0.0006
    0.0115   -0.0101   -0.0275    0.0353    0.0051    0.0036    0.0274   -0.0165   -0.0032    0.0042    0.0021   -0.0188    0.0009    0.0009
    0.0070   -0.0056   -0.0067    0.0051    0.0075    0.0024    0.0086    0.0028   -0.0043    0.0033    0.0071   -0.0059   -0.0042   -0.0042
    0.0025   -0.0052   -0.0055    0.0036    0.0024    0.0148    0.0022    0.0023   -0.0041    0.0034    0.0025   -0.0050   -0.0043   -0.0043
    0.0201   -0.0121   -0.0341    0.0274    0.0086    0.0022    0.0488   -0.0305   -0.0037    0.0029    0.0030   -0.0227    0.0014    0.0014
   -0.0063    0.0014    0.0202   -0.0165    0.0028    0.0023   -0.0305    0.0336   -0.0041    0.0031    0.0074    0.0110   -0.0087   -0.0087
   -0.0043    0.0069    0.0082   -0.0032   -0.0043   -0.0041   -0.0037   -0.0041    0.0082   -0.0034   -0.0044    0.0043    0.0065    0.0065
    0.0033   -0.0042   -0.0037    0.0042    0.0033    0.0034    0.0029    0.0031   -0.0034    0.0042    0.0033   -0.0037   -0.0038   -0.0038
    0.0052   -0.0047   -0.0028    0.0021    0.0071    0.0025    0.0030    0.0074   -0.0044    0.0033    0.0076   -0.0035   -0.0050   -0.0050
   -0.0107    0.0111    0.0225   -0.0188   -0.0059   -0.0050   -0.0227    0.0110    0.0043   -0.0037   -0.0035    0.0270    0.0018    0.0018
   -0.0028    0.0063   -0.0006    0.0009   -0.0042   -0.0043    0.0014   -0.0087    0.0065   -0.0038   -0.0050    0.0018    0.0104    0.0091
   -0.0028    0.0063   -0.0006    0.0009   -0.0042   -0.0043    0.0014   -0.0087    0.0065   -0.0038   -0.0050    0.0018    0.0091    0.0104


B0 =

  1.0e-012 *

    0.1853   -0.1306   -0.6032    0.4087    0.0503    0.0093    0.5491   -0.4352    0.0007    0.0032   -0.0288   -0.2826    0.0909    0.0908


B00 =

  1.6023e-014
```

In this case, the objective was to minimize the total fuel cost. And it can be easily seen from the given figure 2. After applying ED with GA the total fuel cost is 46363.7742 \$/hr according to best fitness value, transmission loss is 11.9635MW and running time is 9.258794sec. When the number of Generation increases, the curve is approaching to a minimum fitness value i.e. fuel cost. Moreover, the value of decision variable as current best individual for last Generation or iteration is found in figure 2.

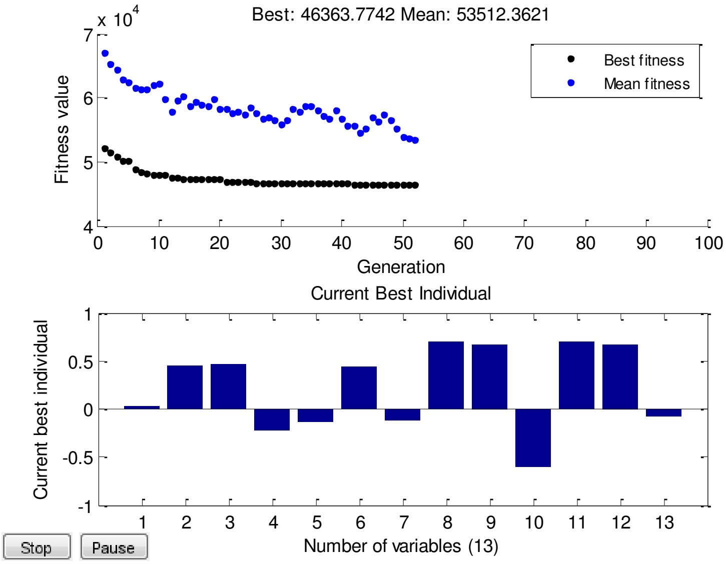

Fig.2 Program simulation results of GAED

B. Simulation Results of GAOPF

In Yangon Distribution Network, there are fourteen generator buses in this system. The generation power is largest at Bus 1 and thus it is taken as slack bus. The other generator buses are taken as voltage control buses and remaining buses are load buses. The number of total buses is 31 and number of interconnected lines has 34connections. The single line diagram has been described in figure 1. The powers are also regarded as per unit values based on 100 MVA.

TABLE I OPF GENERATOR INPUT DATA FOR YANGON DISTRIBUTION SYSTEM

Bus	P_g	Q_g	Q_{max}	Q_{min}	P_{max}	P_{min}
1	205.9058	154.43	180	-180	230	100
2	100.3445	75.26	90	-90	110	100
5	80.5084	60.38	115.65	-115.65	154.2	0
7	53.8576	40.39	69	-69	92	0
9	23.6829	17.76	27.67	-27.67	36.9	0
17	101.2729	75.95	82.5	-82.5	110	100
19	79.3675	59.53	115.65	-115.65	154.2	0
20	16.4244	12.32	20.025	-20.025	26.7	0
21	93.7199	70.29	94.2	-94.2	125.6	0
22	42.7177	32.04	40.2	-40.2	53.6	0
23	22.1019	16.58	25.05	-25.05	33.4	0
24	42.6081	31.96	39	-39	52	0
25	87.8652	65.90	90	-90	120	0
26	14.0867	10.57	90	-90	120	0

The generator data for Yangon Distribution system is shown in Table I. The real power input of OPF is also assigned by ED scheduling result for each generation. The maximum reactive powers and real powers are taken 20% added to real and reactive power generation as shown in this table. They are power generation constraints of OPF. The status is set as 1 for all generators. This means that all generators are operating. The cost equations are same ED input Generator Characteristics of 14- units of YESC Network. The simulation result of GAOPF is shown in figure 3. This figure shows the GA population for best and means fitness value of the fitness function. Current best individual is found the value of all 14 decision variable after the final Generation. The total generation cost is obtained as 45564.8543 $/hr and the total generation is 959.667MW and total loss is 7.1659MW. Total transmission efficiency is 0.75 % in Genetic Algorithm result of OPF.

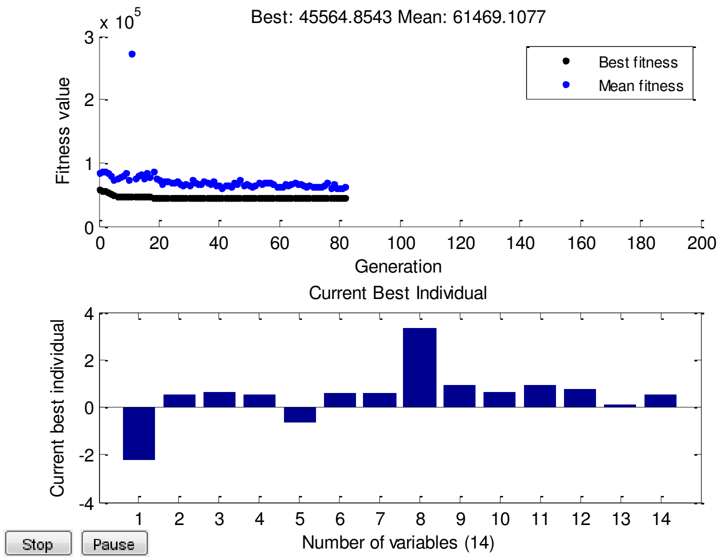

Fig.3 Program simulation results of GAOPF

5. PERFORMANCE COMPARISON OF SIMULATION RESULTS:

In this paper, power system optimization problem for YESC network of power demand 952.5MW is executed with genetic algorithm method. Economic Dispatch ED and Optimal Power Flow OPF are two important considerations in this case. The main objectives are to reduce total generation cost and high transmission losses. For comparison, the iteration for each method is carried out for 20 counts. The resulting main parameters are tabulated in Table II.

TABLE II RESULT COMPARISON OF GAED AND GAOPF

No	Output Results	Generation Scheduled with GAED	Generation Scheduled with GAOPF
1	Pg1(MW)	205.9058	175.8658
2	Pg2(MW)	100.3445	77.8372
3	Pg5(MW)	80.5084	77.1072
4	Pg7(MW)	53.8576	59.1130
5	Pg9(MW)	23.6829	18.6926
6	Pg17(MW)	101.2729	93.5455
7	Pg19(MW)	79.3675	91.5775
8	Pg20(MW)	16.4244	16.1753
9	Pg21(MW)	93.7199	125.6
10	Pg22(MW)	42.7177	50.1645
11	Pg23(MW)	22.1019	21.7546
12	Pg24(MW)	42.6081	47.1451
13	Pg25(MW)	87.8652	88.4726
14	Pg26(MW)	14.0867	16.6251
15	Total Cost($/hr)	46364	45565
16	Total Loss(MW)	11.9635	7.1659

According to evaluation of ED and OPF corresponding equations in the genetic algorithm of the optimization toolbox, total generation cost and total losses obtained by GAOPF is better than GAED. The generation scheduling of each unit is nearly equal in both cases. The result of transmission losses obtained by GAOPF is obviously less than GAED. However, the main objective of ED is only to minimize the total generation cost and difference of total cost result between GAED and GAOPF is not high. For the total generation cost, 23.11% can be saved with GAOPF and 21.76 % saved with GAED compared to current condition in YESC. Total transmission efficiency can be reduced from 2.76% existing value in YESC to 0.75 % in GAOPF calculation which is satisfied for optimal generation schedule of YESC Network.

6. CONCLUSION:

In this paper, Economic Dispatch ED and Optimal Power Flow OPF using with Genetic Algorithm GA methods are employed to obtain the optimum solution of YESC network. The total generation cost and power losses are taken as the main parameters to compare. Total generation cost is nearly equal in both cases. It was shown that the GAOPF performed better as compared to GAED for the total losses as Economic dispatch only contains a single constraint which held the total generation to equal the total load plus losses. Optimal load dispatch requires that the optimization calculation also balance the entire power flow-at the same time. Here it can be observed that GAOPF can reduce obviously the total losses and minimize the power generation, after scheduling the generation units with Economic Dispatch.This study help to achieve the optimum result of generation schedule for Yangon Distribution Network.

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