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# Computational Intelligence Based Technique for Fuel Cost Minimization in Small and Bulk Power

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## ABSTRACT

Fuel is one of the important sources in the electricity generation. However, due the fluctuation of the crude oil; the cost of generation of electricity will be much affected. Thus, a pre-offline study could be one of the acceptable efforts for the power system planner to conduct such measure in the avoidance of undesired event. This will require an optimization process to ensure the optimal parameters are identified to achieve their pre-determined objective. This paper presents the application of evolutionary programming (EP) algorithm for fuel cost minimization. The EP technique has been tested on IEEE30-Reliability Test System (RTS) and IEEE 118- Reliability Test System (RTS) under several scenarios. The simulated scenarios are (i) base case, (ii) stressed condition (iii) line outage condition and (iv) generator outage condition. With the forecasted four scenarios, a power system operator or planner will have initial information of the system status during the offline studies. Results obtained from the study would be beneficial to the system utility for any remedial action for power operation.

**Key words:** Evolutionary programming, economic load dispatch, optimization.

## 1. INTRODUCTION

The increasing demand in a power system has led the system to experience undesirable operation of the grid system. Thus, this phenomenon may cause insecure and unsmooth power delivery to the consumer. To alleviate the demand response and total generation capacity, power system planners and operators need to perform appropriate studies on their system to ensure economic operation of the system. Thus, optimization technique is one of the options to alleviate this condition.

Economic dispatch (ED) is a process to determine the optimum output of power generated to meet the demand while fulfilling the equality and inequality constraints and producing the lowest possible cost. The main constraints are the power balance, power generation capacity and ramp rate [1]–[3]. ED formulation is presented in a quadratic function which is continuous and smooth. Traditional mathematical optimization techniques are simply employed to solve the cost function, such as linear programming [4], Lagrangian relaxation [5],quadratic programming [6], and Newton-Raphson[7]. The work conducted in[8] has discovered that these traditional techniques produced some drawbacks which are stuck in a local optimum, sensitivity of starting points and relevancy issue to some types of a cost function.

Despite of traditional optimization, many researchers have been interested to integrate meta-heuristic techniques, due to the their high performance and simplicity[1], which are well explored by [9]–[13] using PSO, chaotic bat[14], genetic algorithm GA[15], evolutionary programming[16] modified crow[17], exchange market algorithm [18],[19], improved harmony search [20], moth-flame [21], simulated annealing[22] and social spider [23]. These algorithms are inspired by the natural phenomenon or social behavior of creatures.

However, a hybrid method also rapidly discovered by many researchers, by combining two or more algorithms. As an example, ACO-ABC-HS [24], algae-simplex search method[25], firefly-bat[26], MPSO-GA [27], DE-PSO[28], PSO-AFSA[29], SSO-PSO [30] and so on. All of those implemented techniques are capable to provide good results compared to single techniques.

In this paper, Evolutionary Programming (EP) has been successfully applied to solve single objectives in ED problems. Darwinian model has been inspired to create the EP algorithm and this technique is categorized as a stochastic search method. This is a preliminary study which is initially aimed to investigate the performance of EP as artificial intelligence-based optimization technique in solving the ED problem. Validation on two reliability test systems revealed that EP has managed to produce promising results. For future development, the integration between EP with other technique is hope to help achieve much better results and robust.

## 2. ED PROBLEM FORMULATION

Optimization in economic load dispatch involves minimization of the total fuel cost and simultaneously considering various constraints such as power balance and generation unit limits.

### 2.1 Objective Function

The operating cost function is formulated in quadratic, represented as

$$F(P_G) = \sum_{i=1}^{N} a_i + b_i P_{Gi} + C_i P_{Gi}^2 \tag{1}$$

Where *ai, bi, ci*are the cost coefficients of the $i^{th}$ generator, which are constants.

### 2.2 Optimization Constraints

Active power balance criterion and power generating capacity are the equality and inequality constraints in economic load dispatch. The equations are given by the following

$$\sum_{i=1}^{N} P_{Gi} = P_D + P_L \tag{2}$$

Where $P_D$ is total real power demand and $P_L$ is total real power loss.

$$P_{Gi}^{min} \le P_{Gi} \le P_{Gi}^{max} \tag{3}$$

Where ${P_{Gi}}^{max}$ and ${P_{Gi}}^{min}$ are the maximum and minimum real power at generation unit, $i^{th}$ respectively. The real power limitation must be considered for completing a stable operation.

## 3. PROCEDURE EVOLUTIONARYPROGRAMMING

This section describes the procedures of EP, starting from initialization until the convergence test. The steps are as follows;

Step 1- Initialization: This process generates random numbers to represent the variables that control the objective function. In this case, the generated power on each generator in the system.

Step 2- Calculation of fitness 1: Calculation of fitness is conducted which plays the main role of the optimization process. Apparently, the fitness values are the parameters which need to be optimized; and the equation could be a single mathematical equation or a set of sub-program or subroutine.

Step 3- Mutation: It is a process to generate offsprings or children. This is executed by using the Gaussian Mutation Technique based on equation (4); -

$$X_{i+m,j} = X_{i,j} + N\left(0, \beta\left(X_{jmax} - X_{jmin}\right)\left(\frac{f_i}{f_{max}}\right)\right) \tag{4}$$

where $X_{i,j}$are the parents, $\beta$ is search step, $X_{jmax}$is maximum parents, $X_{jmin}$ is minimum parents, $f_i$is the $i^{th}$ fitnessand$f_{max}$ is the maximum fitness. In this paper, $N=20$, which is number of candidates and $b=0.005$.

Step 4- Calculation of fitness 2: repetition as fitness 1 calculation but using the output value from the mutation process (offsprings).

Step 5- Combination: to combine offsprings and parent.

Step 6- Selection: to find the survivors or the best value.

Step 7- Convergence test: to determine the stopping criteria by defining the minimum and maximum fitness.

To examine the effectiveness of this EP algorithm, it has been tested according to all these scenario cases tabulated in Table 1.

Figure 1 illustrates the conceptual model to show the integration of EP and utility data for fuel cost minimization for the study. The power system network will work with a random number of power generators that generated using MATLAB code. Then the processed complete system data is fed to EP optimizer to be trained until it converged to the satisfied value. After that, the satisfied value will be accepted again by the power system network to be sent to the power system control center where the power system operators or planners are there to be updated with the load demand and power generated.

**Table 1:** Several Scenarios for Solving ED Problem

| Scenario No | Description |
|---|---|
| Scenario 1 | Base case: The system is operating in a normal condition. |
| Scenario 2 | Stressed condition: Increment of real and reactive power load ($P_d$and $Q_d$) with a factor value, *k*. |
| Scenario 3 | Line outage: Randomly disconnected one of the line data. |
| Scenario 4 | Generator outage: Randomly disconnected one of the generators. |

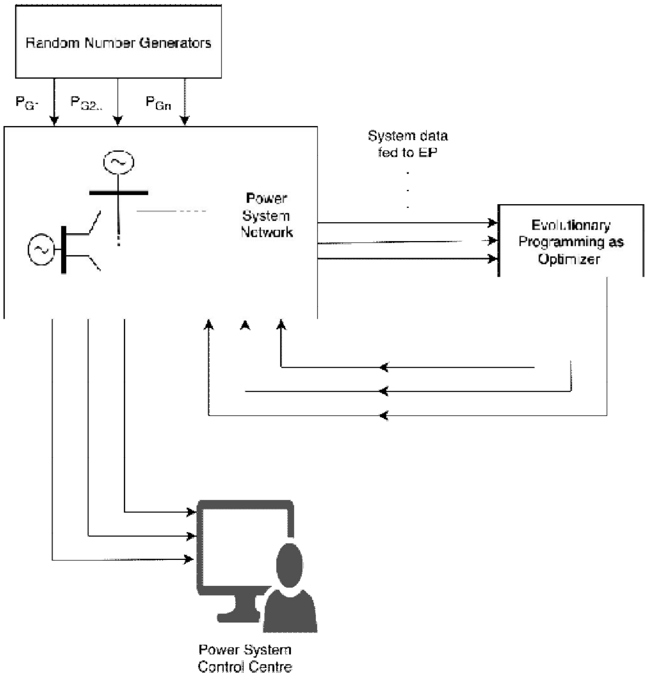

**Figure 1:** Conceptual model to show the integration of EP and utility data for fuel cost minimization

## 4. RESULTS AND DISCUSSION

This section explains the results and discussion of fuel cost minimization which has been validated on two reliability test systems, 30-Reliability Test System (RTS)and IEEE 118-Reliability Test System (RTS).

The bus system that consists of 5 generators and 41 lines is used to validate the EP algorithm. The characteristics of 30 bus system are presented in Table 2[31].

**Table 2:**Cost coefficient of generation units for IEEE 30-Bus RTS

| No | a | b | c | $P_{Gmin}$ (MW) | $P_{Gmax}$ (MW) |
|---|---|---|---|---|---|
| $P_{G1}$ | 10 | 200 | 100 | 5 | 150 |
| $P_{G2}$ | 10 | 150 | 120 | 5 | 150 |
| $P_{G3}$ | 20 | 180 | 40 | 5 | 150 |
| $P_{G4}$ | 10 | 100 | 60 | 5 | 150 |
| $P_{G5}$ | 20 | 180 | 40 | 5 | 150 |
| $P_{G6}$ | 10 | 150 | 100 | 5 | 150 |

The system data for the IEEE 118-Bus RTS involves 14 generators and 177 lines are tabulated in Table 3. The cost coefficients are also extracted from [31] with some changes in $P_{Gmax}$ value.

**Table 3:**Cost coefficient of generation units for IEEE 118-Bus RTS

| No | a | b | c | $P_{Gmin}$ (MW) | $P_{Gmax}$ (MW) |
|---|---|---|---|---|---|
| $P_{G69}$ | 150 | 189 | 0.5 | 50 | 150 |
| $P_{G1}$ | 115 | 200 | 0.55 | 50 | 150 |
| $P_{G4}$ | 40 | 350 | 0.6 | 50 | 150 |
| $P_{G6}$ | 122 | 315 | 0.5 | 50 | 150 |
| $P_{G8}$ | 125 | 305 | 0.5 | 50 | 150 |
| $P_{G10}$ | 70 | 275 | 0.7 | 50 | 150 |
| $P_{G12}$ | 70 | 345 | 0.7 | 50 | 150 |
| $P_{G15}$ | 70 | 345 | 0.7 | 50 | 150 |
| $P_{G18}$ | 130 | 245 | 0.5 | 50 | 150 |
| $P_{G19}$ | 130 | 245 | 0.5 | 50 | 150 |
| $P_{G24}$ | 135 | 235 | 0.55 | 50 | 150 |
| $P_{G25}$ | 200 | 130 | 0.45 | 50 | 150 |
| $P_{G26}$ | 70 | 345 | 0.70 | 50 | 150 |
| $P_{G27}$ | 45 | 389 | 0.60 | 50 | 150 |

**Table 4:** Result for base case scenario for IEEE 30 RTS and IEEE 118-Bus RTS

| RTS | Total fuel cost without EP ($/h) | Total cost with EP ($/h) |
|---|---|---|
| 30 Bus | 7.0623e+06 | 1.3351e+06 |
| 118 Bus | 7.9371e+05 | 5.5826e+05 |

The presented result in Table 4 indicates that the total fuel cost for both systems have been significantly reduced when EP optimization is applied. It is proven that the EP algorithm is capable to minimize the fuel cost in power dispatch. For the IEEE 30-Bus RTS, the cost has been minimized to 1.3351e+06 $/h from 7.0623e+06 $/h, while for the IEEE 118-Bus RTS, it was reduced from 7.9371e+05 $/h decreased to 5.5826e+05 $/h.

**Table 5:** Result for scenario 2 when $P_d$ is increased for IEEE 30-Bus RTS

| Load multiplication factor, *k* | Total cost without EP ($/h) | Total cost with EP($/h) |
|---|---|---|
| 1.0 | 7.0623e+06 | 1.5839e+06 |
| 1.5 | 1.8820e+07 | 2.4013e+06 |
| 2.0 | 3.8655e+07 | 3.8137e+06 |
| 2.5 | 6.9689e+07 | 7.2691e+06 |
| 3.0 | 1.1961e+08 | 1.6365e+07 |

**Table 6:** Result for scenario 2 when $P_d$is increased for IEEE 118 RTS

| Load multiplication factor, *k* | Total cost without EP($/h) | Total cost with EP($/h) |
|---|---|---|
| 1.0 | 7.9371e+05 | 5.5826e+05 |
| 1.5 | 6.4690e+06 | 3.4235e+06 |

Table 5tabulates the result for $P_d$ increment for IEEE 30-BusRTS, while Table 6 shows the result for $P_d$ increment in IEEE 118-BusRTS. All the results yield to a low total fuel cost with the implementation of EP optimization. For the IEEE 30-BusRTS, the costliest occurs when the $P_d$is multiplied with a factor of 3. The cost is 1.1961e+08 $/h and has been cut to 1.6365e+07 $/h using the EP optimization. On the other hand, for the IEEE 118-BusRTS, the maximum cost is experienced when the load multiplication is 1.5, producing 6.4690e+06 $/h and has successfully been minimized to 3.4235e+06.

The load multiplication factor for the IEEE 118-BusRTS must be stopped at 1.5 since the system network had reached the maximum limit for the power loading, which can affect the stability of the system.

**Table 7:** Result for scenario 2 when $Q_d$is increased in IEEE 30-Bus RTS

| Load multiplication factor, *k* | Total cost without EP($/h) | Total cost with EP ($/h) |
|---|---|---|
| 1.0 | 7.0697e+06 | 1.3352e+06 |
| 1.5 | 7.1007e+06 | 1.3354e+06 |
| 2.0 | 7.1754e+06 | 1.3359e+06 |
| 2.5 | 7.2500e+06 | 1.3382e+06 |
| 3.0 | 7.3241e+06 | 1.3424e+06 |

**Table 8:** Result for scenario 2 when $Q_d$ is increased in IEEE 118-Bus RTS

| Load multiplication factor, k | Total cost without EP($/h) | Total cost with EP ($/h) |
|---|---|---|
| 1.0 | 7.9371e+05 | 5.5826e+05 |
| 1.5 | 7.9872e+05 | 5.6013e+05 |
| 2.0 | 8.0788e+05 | 5.6318e+05 |
| 2.5 | 8.1439e+05 | 5.6580e+05 |
| 3.0 | 8.2412e+05 | 5.6951e+05 |

Table 7 and Table 8 present the results for scenario 2 when $Q_d$ is increased for both systems. By increasing the reactive power, it affects the fuel cost since $Q_d$ is the main controller of the voltage level in the power system.

Anyhow, with EP optimization, both systems exhibit low total fuel costsas compared to the value without the optimization process. The greatest cost is recorded when the reactive power is multiplied with a factor of 3. In the IEEE 30-Bus RTS, the cost has been minimized from 7.3241e+06 $/h to 1.3424e+06 $/h and for the IEEE 118-Bus RTS, EP managed to reduce from 8.2412e+05 $/h to 5.6951e+05 $/h.

Table 9 and Table 10 show the results when contingency due to line outage was randomly disconnected from the systems. Any changes to the line data will affect the power delivery. For the IEEE 30-Bus RTS, the removal of line connecting buses 2 and 5 has produced the highest cost worth 7.8542e+06 $/h. With EP optimization process, it has been reduced to 2.8400e+04 $/h. On the other hand, for the IEEE 118-Bus RTS, the contingency due to line outage connecting buses 100 and 103 has resulted to the highest total fuel cost worth 8.0766e+05 $/h. The value has been successfully reduced to 5.6324e+05 $/h with the EP optimization process.

**Table 9:** Result for scenario 3, line outage for IEEE 30-Bus RTS

| Line | Total cost without EP($/h) | Total cost with EP($/h) |
|---|---|---|
| 29-30 | 7.0697e+06 | 7.8855 e+05 |
| 4-12 | 7.2050e+06 | 2.8456 e+04 |
| 2-5 | 7.8542e+06 | 2.8400 e+04 |
| 23-24 | 7.0631e+06 | 3.3889 e+04 |
| 28-27 | 7.1839e+06 | 3.1561 e+04 |

**Table 10:** Result for scenario 3, line outage for IEEE 118-Bus RTS

| Line | Total cost without EP($/h) | Total fuel cost ($/h) |
|---|---|---|
| 3-5 | 7.9671e+05 | 5.5822e+05 |
| 12-14 | 7.9397e+05 | 5.5823e+05 |
| 40-42 | 7.9369e+05 | 5.5826e+05 |
| 90-91 | 7.9370e+05 | 5.5825e+05 |
| 100-103 | 8.0766e+05 | 5.6324e+05 |

**Table 11:** Result for scenario 4, generator outage for IEEE 30-Bus RTS

| Generator Bus | Total cost without EP ($/h) | Total cost with EP ($/h) |
|---|---|---|
| 2 | 7.1409e+06 | 1.2106e+06 |
| 5 | 7.0623e+06 | 1.7855e+06 |
| 8 | 7.1335e+06 | 1.4924e+06 |
| 11 | 7.1335e+06 | 1.6058e+06 |
| 13 | 7.1335e+06 | 1.5838e+06 |

**Table 12:** Result for scenario 4, generator outage for IEEE 118-Bus RTS

| Generator Bus | Total cost without EP ($/h) | Total cost with EP ($/h) |
|---|---|---|
| 4 | 7.9367e+05 | 5.3664e+05 |
| 15 | 7.9364e+05 | 5.3803e+05 |
| 19 | 7.9358e+05 | 5.4627e+05 |
| 25 | 7.4313e+05 | 5.7097e+05 |
| 27 | 7.9367e+05 | 5.4131e+05 |

Table 11 and Table 12tabulate the results for generator outage contingency experienced in both systems. Generator outage contingency is emulated by setting one generator to be turned off. The most expensive total fuel cost in the IEEE 30-Bus RTS, is experienced when generator 2 is disconnected from the system. The cost has been minimized to 1.2106e+06 $/h from 7.1409e+06 $/h. For the IEEE 118-BusRTS, the generator outages for buses 4 and 27 give the highest cost, worth 7.9367e+05 $/h. With EP optimization process the total fuel cost has been decreased to 5.3664e+05 $/h and 5.4131e+05 $/h respectively.

## 5. CONCLUSION

This paper has presented computational intelligence-based technique for fuel cost minimization in small and bulk power. In this study, Evolutionary Programming has been applied in solving total fuel costs problems involving small and bulk power systems. Results obtained from the study revealed that, all the 4 cases have experienced successful total fuel cost reduction with the EP implementation. This can facilitate the power system operators and planners towards economic operation in the respective utility.

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