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A Comparative Study of Meta-heuristics Algorithms in evaluation of Economic Load Dispatch Problems in Power Generating Station with Matlab Codes

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Abstract

This paper presents a comparative study of metaheuristics algorithms in evaluation of economic load dispatch problem in power generating station with MATLAB codes. In this paper, the formulation of the ELD problems using mathematical illustrations and MATLAB codes were presented. This consists of the ELD cost model, Model calculations, cost function and parse solution. It also presents the application of some metaheuristics algorithms (solution algorithms) such as ACSA and PSO in solving ELD problem with MATLAB codes. The ELD problem was modeling using Egbin thermal power station, Nigeria as our case study.

Keywords: Economic Load Dispatch (ELD); Ant Colony Search Algorithms (ACSA); Particle Swarm Optimization (PSO); MATLAB codes

Introduction

Economic Load Dispatch (ELD) is the reduction of the total cost of power generation (which includes fuel consumption and operational cost) of power generating plants while meeting the various loads demand and power losses in the power transmission system. The objective is to apportion the total load demand and total loss among the various generating units at the same time satisfying the system constraints with reduced generation costs. With Economic Load Dispatch, it is expected that the power utilities plan and forecast optimal load dispatch. Several considerations are made during energy scheduling, these amongst others are to find out the existing generating units, the distance between load centers and the generating units, identifying the operating limits of each generating units such as the ramp rate limits, maximum and minimum generation level, prohibited zones [1].

Economic Load Dispatch

Economic load Dispatch is to determine the real and reactive power scheduling in power system this is the minimization of the cost function of different generating units. For economic operation of the power system, the total load demand must be optimally shared among all the generating units with an objective to reduce the total generation cost [1]. This is also to find out the power outputs of all generating units in power system so that the total cost of generation of the system is minimized, while meeting the load demand, system equality and inequality constraints. The essential operation constraints are the power balance constraint, that is, the total generated power must be equivalent to the load demands plus the transmission losses on the power system, and the power limit constraints of the generating units [2-6]. The problem of economic operation of a power system is the allocation of the load (MW) among the various units of generating stations in such a way that, the overall cost of generation for the given load demand is minimum. This is an optimization problem which needs to be resolved as quick as possible. For a given load demand, power flow study can be used to calculate active and reactive power generations, line flows and losses. The study also furnishes some control parameters such as the magnitude of voltage and voltage phase differences. The economic load dispatch problem is the results of various power flow studies, where a particular power flow study result is considered more appropriate in terms of cost of generation. The solution to this problem cannot be optimal unless otherwise all system constraints are met. The problem of economic operation of the power system involves two sub-problems, namely, unit commitment (UC) and economic dispatch (ED). While unit commitment (UC) is an off-line problem, economic dispatch (ED) is an area of online concern. The commitment decisions are made many weeks or months in advance. The decision to commit a generating unit to be able to produce electricity means that the power utility is willing to incur fixed costs related to unit startup in order to have that generating units ready and available to generate electricity in real time. Large turbine or nuclear plant generators with large start-up costs cannot run optimally if their output is determined using a single-period analysis (a "period" in the electric power industry usually refers to a length of time of about an hour). Instead, their operation must be scheduled over a longer period of time, usually weeks or months. A power utility would need a forecast of demand weeks in advance before turning on a generator with a long minimum run time [3]. They would need to study the demand forecast over that period of time and decide the lowest-cost mix of generation units that would meet the demand needed. While the procedure of all ocating committed generating units to satisfy customer load demands within a given operational conditions is referred to as "economic dispatch" or "optimal power flow."

Economic Load Dispatch are usually influence by factors such as high operating cost (fuel cost) and transmission losses. The Economic Load Dispatch requires the generation facilities to plan and forecast optimal energy dispatch. Hence the concept is the optimal selection of the generating units in such an economic manner that the total cost of supplying the dynamic requirements of the system is minimized [4].

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Formulation of ELD problem

The ELD problem is an optimization problem that determines the power output of each generating units that will amount to the lowest fuel cost.

Minimize C(x,u) (1)

Subject to:

G(x,u)=0 (2)

H(x,u) ≤ 0 (3)

Where, C=cost function,

x=vector of dependent variables (generating cost)

u=vector of control variables (generator outputs)

G(x,u)=set of non-linear quality constraints (power balance)

H(x,u)=set of inequality constraints (limits in generator outputs).

The objective of the Economic Load Dispatch is to minimize the total operating cost of a power system by adjusting the power output of each of the generators connected to the grid, while satisfying the total load demand plus transmission losses within generator limits.

The generator cost curves are modeled with smooth quadratic (objective) function given by eqn. (4) subject to the equality (power balance) and inequality (generation limits) constraints in eqns. (5) and (7) respectively [6].

Minimize the objective function,

$$F_i P_i = \sum_{i=1}^{n_g} \left(\gamma_i P_i^2 + \beta_i P_i + \alpha_i \right) \quad (4)$$

Subject to power balance equation (equality constraint)

$$\sum_{i=1}^{n_g} P_i = P_D + P_L \quad (5)$$

The system losses can be determined by means of a power flow equation solution which is expressed in krons loss formula in eqn. (6)

$$P_L = \sum_{i=1}^{n_g} \sum_{j=1}^{n_g} P_i B_{ij} P_j + \sum_{i=1}^{n_g} B_{0i} P_i + B_{00} \quad (6)$$

And the (generating limits) inequality constraints,

$$P_{i(min)} \le P_i \le P_{i(max)} \quad (7)$$

Where F_iP_i is the total generation cost, $\alpha_i, \beta_i, \gamma_i$ are cost coefficients, P_D is the load demand, P_i is real power generation of unit i, P_j is real power generation of unit j, P_L is power transmission loss, n_g is number of dispatchable generating plants, $P_{i(min)}$ and $P_{i(max)}$ are the minimum and maximum power generation limits respectively also B_{ij}, B_{oi} and B_{oo} are *B*-coefficient [5].

Operating cost of a thermal plant

In economic scheduling of different generating plants, the total operating cost is minimal in a Thermal Plant [5]. This generally comprises of the input to the thermal power plant which is expressed in Btu/h or Kcal/h and the output in MW.

The input-output curve of a thermal unit is regarded as heat-rate curve and it is usually a graph drawn between fuel input in Btu/h or kcal/h and power output in MW on the x-axis and y-axis, respectively [7-9].

A typical heat-rate curve for a thermal unit is given in Figure 1, while Figure 2 shows the ordinate of heat-rate curve from Btu/h to ₦/h results in the fuel-cost curve.

Hence, the fuel cost of generator *i* can be written as a quadratic function of real power generation as shown in eqn. (8).

$$C_i = \alpha_i + \beta_i P_i + \lambda_i P_i^2 \quad (8)$$

Incremental Fuel-cost curve is obtained by plotting the derivative of the fuel-cost curve versus the real power as shown in Figure 3. It is a measure of how costly it will be to produce the next increment of power. It is drawn by taking the incremental fuel cost in N/MWh as an input on the y-axis and real power in MW as output on the x-axis.

$$\frac{dC_i}{dP_i} = 2\gamma_i P_{ii} + \beta_i \quad (9)$$

The total operating cost includes the fuel cost, the labor cost and maintenance [6].

Research Methodology

Economic Load Dispatch problem was formulated using mathematical illustrations and MATLAB codes.

The ELD problem is formulated as minimizing a scalar objective function through the optimal operation of a vector of controls parameters. This is mathematically illustrated in eqns. (1-3) and diagrammatically represented in Figure 4 [9].

The approach consists of two main components: the controlling device and the controlled device are shown in Figure 4. The ELD problem is one that involves the optimal set of generating units. This minimizes the operating cost (mainly fuel cost). The controlled device is the generating cost model, while the solution algorithm (SA) is the

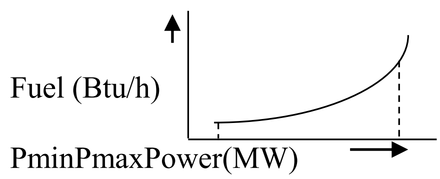

Figure 1: Heat curve of a Thermal Unit.

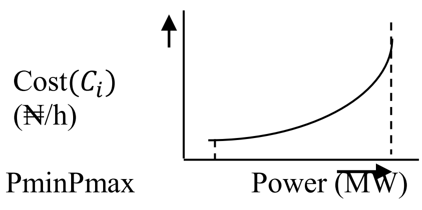

Figure 2: Fuel-cost curve characteristic of a Thermal Unit.

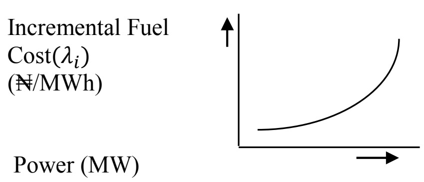

Figure 3: Incremental Fuel-Cost Curve of a Thermal Unit.

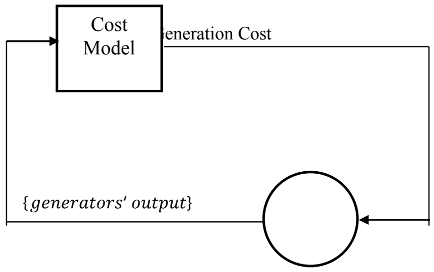

Figure 4: Diagrammatic Representation of Design Approach.

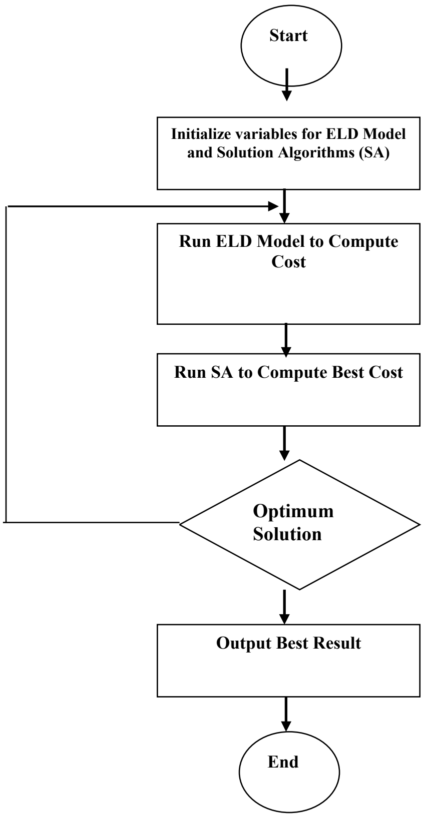

Figure 5: Flow chart of ELD Optimization using Solution Algorithms.

controlling device. A vector of generators output is inputted into the generation cost model, which produces a scalar cost of generating those power outputs. The generation cost is passed on to the solution algorithm to be reduced, an iterative process which continues until either a best cost lesser than acceptable minimum is achieved or number of maximum iterations is reached. Figure 5 show a flow diagram for ELD optimization using Solution Algorithms [9].

Formulation of economic load dispatch problem

The ELD problem is an optimization problem with an aim to find the optimal combination of committed online power generators that will reduce the total operating cost to meet the total system's power demand while satisfying equality (power balance) and inequality (generation limits) constraints. This is usually done over a period of one hour. The constraints in a practical generator include minimum and maximum generation limits, power balance, ramp rate limits and prohibited operating zones.

For a thermal generating station, the unit fuel cost is shown in the quadratic form in Figure 2, and the goal is to minimize the total operating cost as in eqns. (10) and (11), subject to the generating limit constraint of eqn. (14), power balance constraint of eqns. (12), ramp-rate limits constraints of eqn. (15), and prohibited operating zones constraints of eqns. (16-18).

Considering a thermal power station of i^{th} generating units G_1, G_2,……G_i delivering powers P_{g1}, P_{g2},…..,P_{gi} respectively connected to a transmission network as shown in Figure 6. Where P_D is the total power demand and P_L is the total power losses.Each unit has its cost function C_i. The task here is to find the combination of the real power generation for all units such that the total generation cost C_T is minimized [9].

$$\min C_T = \sum_{i=1}^{N} C_i \tag{10}$$

$$= \sum_{i=1}^{N} \alpha_i + \beta_i P_{gi} + \gamma_i P_{gi}^2 \tag{11}$$

Subject to

$$\sum_{i=1}^{N} P_{gi} = P_D + P_L \left(fori = 1,2 \ldots i \right) \tag{12}$$

$$P_L = \sum_{i=1}^{N} P_{gi} B_{ij} P_{gj} \tag{13}$$

Subject to

$$P_{gimin} \le P_{gi} \le P_{gimax} \left(fori = 1,2 \ldots i \right) \tag{14}$$

Where C_T is the total generation cost, Ci is the generation cost of i[th] unit, $\alpha_i, \beta_i, \gamma_i$ are cost coefficients, P_D is the load demand, P_{gi} is real power generation of unit i, P_{gj} is real power generation of unit j, P_L is power transmission loss, N is number of dispatchable generating plants, B_{ij} is B-coefficient, $P_{(i(min))}$ and $P_{(i(max))}$ are the minimum and maximum power generation limits respectively.

Considering also the ramp-rate limits and prohibited zone, eqn. (14) is modified as eqn. (15),

$$\max\left(P_{imin}, P_i^o - DR_i \right) \le P_i \le \min\left(P_{imax}, P_i^o + UR_i \right) \tag{15}$$

Where P_i^o is the previous output, P_i is the present output, DR and UR are the down and up ramp-rate limits

The prohibited zones are described by the following inequality constraints [9].

$$P_{gi}^{min} \le P_{gi} \le P_{gi,1}^{l} \tag{16}$$

$$P_{gi,k-1}^{u} \le P_{gi} \le P_{gi,k}^{l} \tag{17}$$

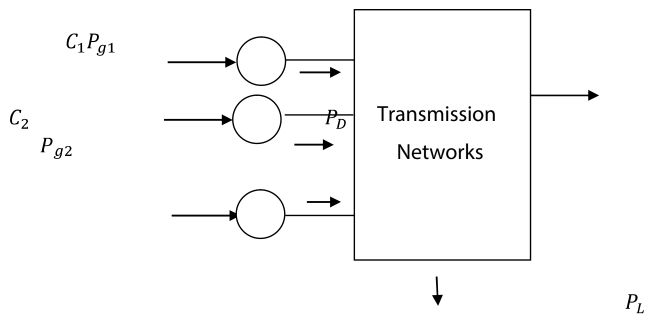

Figure 6: Generating units connected through Transmission Network.

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$$P^{u}_{gi,zoi} \le P_{gi} \le P^{max}_{gi} \quad (18)$$

Where $P^{l}_{gi,k}$ and $P^{u}_{gi,k}$ are lower and upper bounds of the k_{th} prohibited zone of unit *I* respectively, *k* is the index of prohibited zone, *zoi* (Tables 1 and 2).

Using the Matlab codes [7], the ELD was modeled from the concept of ELD problem defined in eqn. (10) through to eqn. (18) above showing the power demand, minimum and maximum generating limits, cost coefficients, ramp-rate limits, prohibited zone and B-coefficient. This is model as a function and called Create Model ( ) as shown Figures 7 and 8.

Applying eqns. (10-18), The Model Calculation for the Economic Load Dispatch problem was formulated and the Load apportioned to various generating units (P_{gi}), Total generated power (PTotal), Total generation cost (CTotal) and Total power losses (PL) were calculated as shown in Figures 9 and 10.

Optimization approach

A main task in the optimization process is constraints handling. The application of the solution algorithm (SA) to solving constrained problems in the ELD involves various techniques of handling constraints, to keep the control variables in feasible region, where all the constraints are satisfied. A technique for handling these constraints constitutes the efficiency within the solution Algorithms to solving this ELD problem [9].

Simulation Approach (Application of Solution Algorithms to Solve ELD)

The modeling and program development of Solution Algorithm and the ELD problem were accomplished by using MATLAB R2008b software. All program were ran on Intel (R) 2.60 GHz CPU, 2 GB RAM, Window 7 Computer and the modeled ELD was used to evaluate the

Gen units	(α) (N/h)	(β) (N/MWh)	(γ) (N/MW² h)	Pmin	Pmax
1	2131.1667	13.1	0.186	55	220
2	2131.1667	13.1	0.186	55	220
3	2131.1667	13.1	0.186	55	220
4	2131.1667	13.1	0.186	55	220
5	2131.1667	13.1	0.186	55	220
6	2131.1667	13.1	0.186	55	220

Table 1: Generator data of Egbin Thermal power station (six generating units) [8].

B-coefficient data					
0.00099	0.00016	-0.0002	-0.0002	-0.0002	0.00015
0.00014	0.00012	-0.0001	-0.0001	-0.0001	0.00012
-0.0001	-0.0001	0.00013	0.00013	0.00012	-0.0001
-0.0001	-0.0001	-0.0001	0.00014	0.00013	-0.0001
-0.0001	-0.0001	0.00013	0.00013	0.00012	-0.0001
0.00015	-0.0001	-0.0001	-0.0001	-0.0001	0.00012

Table 2: Power Losses (B-coefficient) [8].

```
function model=CreateModel()
function model=CreateModel()
model.PD=600;
model.Plants.Pmin=[55 55 55 55 55 55];
model.Plants.Pmax=[220 220 220 220 220 220];
model.Plants.alpha=[2131.1667 2131.1667 2131.1667 2131.1667 2131.1667 2131.1667];
model.Plants.beta=[13.1 13.1 13.1 13.1 13.1 13.1];
model.Plants.gamma=[0.186 0.186 0.186 0.186 0.186 0.186];
   model.Plants.P0=[0 0 0 0 0 0];
model.Plants.UR=[0 0 0 0 0 0];
model.Plants.DR=[0 0 0 0 0 0];
model.Plants.PminActual = max(model.Plants.Pmin,model.Plants.P0-model.Plants.DR);
model.Plants.PmaxActual = min(model.Plants.Pmax,model.Plants.P0+model.Plants.UR);
model.Plants.PZ{1}={[0 0],[0 0]};
model.Plants.PZ{2}={[0 0],[0 0]};
model.Plants.PZ{3}={[0 0],[0 0]};
model.Plants.PZ{4}={[0 0],[0 0]};
model.Plants.PZ{5}={[0 0],[0 0]};
model.Plants.PZ{6}={[0 0],[0 0]};
model.nPlant=numel(model.Plants.alpha);
model.B=[0.0009919  0.0001556 -0.0001651 -0.0001736 -0.0001631 0.0001481
         0.0001417  0.0001209 -0.0001278 -0.0001344 -0.0001263 0.0001155
        -0.0001324 -0.0001169  0.0001256  0.0001321  0.0001238 -0.0001102
        -0.0001408 -0.0001238 -0.0001328  0.0001396  0.0001309 -0.0001169
        -0.0001332 -0.0001170  0.0001254  0.0001319  0.0001237 -0.0001105
0.0001481 -0.0001235 -0.0001290 -0.0001356 -0.0001276 0.0001190];
end
```

Figure 7: Create Model (Model of ELD problem in MatLab codes.

```
function    [z, out]=MyCost(x,model)
P=ParseSolution(x,model);
out=ModelCalculations(P,model);
z=out.z;
end
```

Figure 8: Cost function in ELD problem formulation in MATLAB codes.

```
function out=ModelCalculations(P,model)
alpha=model.Plants.alpha;
beta=model.Plants.beta;
function out=ModelCalculations(P,model)
alpha=model.Plants.alpha;
beta=model.Plants.beta;

gamma=model.Plants.gamma;
        C=alpha+beta.*P+gamma.*P.*P;
CTotal=sum(C);
        B=model.B;
        PL=P*B*P';
PTotal=sum(P);
PD=model.PD;
PowerBalanceViolation=max(1-(PTotal-PL)/PD,0);
q=100;
        z=CTotal*(1+q*PowerBalanceViolation);
Pg=sum(P);
        PLL=Pg-PD;
out.P=P;
out.PTotal=PTotal;
out.C=C;
out.CTotal=CTotal;
out.PLL=PLL;
        out.PL=PL;
out.PowerBalanceViolation=PowerBalanceViolation;
out.z=z;
fprintf('Power Demand          = %f MW\n',PD);
fprintf('Total Generation        = %f MW\n',Pg);
fprintf('Total Losses           = %f MW\n',PLL);
fprintf('Total Cost of Generation   = %f   N/hr\n',CTotal);
```

Figure 9: Model Calculation of the ELD in MatLab codes.

```
function P=ParseSolution(x,model)
PminActual=model.Plants.PminActual;
PmaxActual=model.Plants.PmaxActual;
   P=PminActual+(PmaxActual-PminActual).*x;
   PZ=model.Plants.PZ;
nPlant=model.nPlant;
fori=1:nPlant
for j=1:numel(PZ{i})
if P(i)>PZ{i}{j}(1) && P(i)<PZ{i}{j}(2)
% Correction
if P(i)<(PZ{i}{j}(1)+PZ{i}{j}(2))/2
P(i)=PZ{i}{j}(1);
else
P(i)=PZ{i}{j}(2);
end
end
end
end
disp('Generation of each Units');
disp('  Pg1(MW)  Pg2(MW)  Pg3(MW)  Pg4(MW)  Pg5(MW)   Pg6(MW)');
disp(P);
end
```

Figure 10: Parse solution of the ELD problem in MATLAB codes.

effectiveness and efficiency of these algorithms (ACSA and PSO), the case study involving six generating units (Egbin thermal station) were applied.

The objective was to minimize the total operating cost, while satisfying the system constraints under the allowable limits.

The network data (Generator data & B-coefficient) were obtained [8] which were presented in Tables 1 and 2.

The outputs results of the optimization tools which were evaluated are as follows;

- Loads apportioned to the various generating units
- Total Generated Power
- Total Power Loss
- Total Generation Cost.

Application of solution algorithms in solving ELD problem in MATLAB codes

The Create Model, Cost Function modeled in Figures 7 and 8 are

```
Solving ELD problem using Ant Colony Search Algorithm(ACSA)
clc;
clear;
closeall;
%% Problem Definition
model=CreateModel();                    % Model of the Economic Load Dispatch
CostFunction=@(x) MyCost(x,model);      % Cost Function
nVar=model.nPlant;                      % Number of Decision Variables
VarMin  =0;                             % Decision Variables Lower Bound
VarMax=1;                               % Decision Variables Upper Bound
%% ACO  Parameters
MaxIt=200;            % Maximum Number of Iterations
nAnt=10;              % Number of Ants(Archives Popu          lation Size)
nSample=40;           % Number of New Ants(Sample Size)
q=0.4;                % Intensification Factor (Selection Pressure)
zeta=0.88;               % Deviation     - Distance Ratio
%% Initialization
tic;
% Create Empty Ants Structure
empty_ant.Positio        n=[];
empty_ant.Cost=[];
% Create Ants Matrix
ant=repmat(empty_ant,nAnt,1)
….truncated……..
```

Figure 11: Solving ELD problem using ACSA in MATLAB code [7].

```
Solving ELD problem using PSO
clc;
clear;
close all;
%% Problem Definition
model=CreateModel();
CostFunction=@(x) MyCost(x,model);                  % Cost Function
nVar=model.nPlant;                         % Number of Decision Variables
VarSize=[1 nVar];              % Size of Decision Variables Matrix
VarMin=0;                    % Lower Bound of Variables
VarMax=1;                    % Upper Bound     of Variables
%% PSO Parameters
MaxIt=200;                 % Maximum Number of Iterations
nPop=50;                   % Population Size (Swarm Size)
% w=1;                       % Inertia Weight
% wdamp=0.99;                % Inertia Weight Damping Ratio
% c1=2;                    % Personal Learning Coefficient
% c2=2;                    % Global Learning Coefficient
% Constriction Coefficients
phi1=2.05;
phi2=2.05;
phi=phi1+phi2;
chi=2/(phi - 2+sqrt(phi^2- 4*phi));
w=chi;                     % Inertia Weight
wdamp=1;                   % Inertia Weight Damping Ratio
c1=chi*phi1;               % Perso   nal Learning Coefficient
c2=chi*phi2;               % Global Learning Coefficient
% Velocity Limits
VelMax=0.1*(VarMax-VarMin);
VelMin= - VelMax;
%% Initialization
tic;
empty_particle.Position=[];
empty_particle.Cost=[];
empty_particle.Out=[];
empty_particle.Velocity=[];
empty_particle.Best.Position=[];
empty_particle.Best.Cost=[];
empty_particle.Best.Out=[];
----truncated-------
```

Figure 12: Solving ELD problem using PSO in MATLAB codes [7].

Gen Outputs	ACSA	PSO
G1	84.723	82.348
G2	103.562	103.356
G3	103.894	106.174
G4	108.181	105.734
G5	97.475	97.865
G6	102.176	104.654
Power Demand(MW)	600.000	600.000
Total Power Generated(MW)	600.011	600.130
Total Power Losses	0.011	0,130
Total Generation Cost	31870.672	31891.680

Table 3: Results from simulation using Power Demand of 600MW (comparison between PSO and ACSA).

called into the solution Algorithms as shown in Figures 11 and 12 for ACSA, and PSO, respectively.

Results

Results from simulation using Power Demand of 600 MW (comparison between PSO and ACSA) is shown in Table 3.

Discussion of Results

Table 3 shows that the ACSA has effectively reduced the operating cost by 0.07% as compared with that of PSO.

Conclusion

The ELD problem has been successfully modeled and the Solution Algorithm applied to the modeled ELD problem in power generating station in this paper. Subsequently, results shows that ACSA has effectively minimized the operating cost as compared to that of PSO.

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