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# A Planned Scheduling for Economic Power Sharing in a CHP-based Micro-Grid

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**Abstract:** *The Distributed energy resources (DER) capability can be determined by the planning of CHP-based microgrid, at system loads economically, self-sufficient without any utility's involvement. DERs can be determined by optimal sizes, optimal locations. The loss minimization is obtained by the independent CHP-based DERs types, using Particle Swarm Optimization (PSO) method and loss sensitivity index (LSI). In a microgrid, DERs mainly depends on fuel cost and NO<sub>x</sub> emissions level. So, the main focus is to evaluate the different optimal outputs and their capacity limits. Based on multi-objective optimization method, economical sharing of electrical tracking demand is done among different sizes of micro-turbines and diesel generators.*  
**Keywords:** *Micro-turbine, diesel generator, economic emissions load dispatch, particle swarm optimization, loss sensitivity index, harmonic search algorithm.*

## I. INTRODUCTION

In recent years, the capital cost of new governing generating plant, has been focused on generating station with rapid installation in fossil fuel price with increase in higher efficiency, and electricity market becomes highly aggressive. Today, micro-grid is an important role, on CHP-based DERs with traditional centralized electricity plant.

The new generating plants of supply economic emission load dispatch (EELD) problem required demand plus transmission losses with the minimized cost of production. Because of this, pollution should be minimized due to the public demand, for clean air policies. However, power quality and reliability (PQR) of supply to individual users, micro-grid is become an alternate source for the consumers with low cost of power industry, services and many other places [1] - [5]. Under these circumstances, the environmental of DERs the operation of micro-grid is not only carry out by the units, capability of reducing the fuel cost, but it also capability of satisfying NO<sub>x</sub> emissions level requirements. In a decentralized electricity generation, they some advantage on-site production of heat and provide quality and reliable power to the consumers at economical cost and so, many benefits like, reduction of customer interruption cost (CIC), reduction of emission level, reduction of system loss and waste heat recovery only on CHP related benefit-cost analysis [5] - [7]. It involves maximization of benefit-to-cost ratio (BCR) and generation of electricity and heat can be classified into operation and capital investment cost, maintenance cost and fuel cost.

The present paper is to discuss on NO<sub>x</sub> emission level with penalty factor point of view that can convert a multi-objective function into a single objective optimization problem. They are two CHP-based DERs that are micro-turbines (MT) and diesel generators (DG). MT has lower NO<sub>x</sub> emission level of low combustion temperature whereas DG has higher combustion temperature but results in higher NO<sub>x</sub> emission level. In a distribution network or microgrid there are some recent techniques like soft computing, genetic algorithms, evolutionary programming, DER-CAM, tabu search etc. It developed a unit commitment operation for the fuel consumption of heat and electricity demand for the penalty factor on heat generation and claimed to support the communication infrastructure.

main objective is on CHP-based microgrid is to reduce the fuel cost for an individual customer site. It was developed by Berkeley Laboratory, USA. It discussed on size selection and bus -location of DERs in a 14- bus radial microgrid. The both electric, thermal of economic emissions load dispatch using PSO method, by satisfying the all equality and inequality constraints both for multi-modal as well as uni-modal systems. PSO algorithm is very accuracy and easy concept to implement the efficient and to control parameters, when compared with another algorithm and both results are obtained and implemented in the tabular form.

## II. PROBLEM FORMULATION OF EELD

The present paper is mainly on energy management planning for economic planned scheduling of EELD. So, the formulation of EELD has be,

### A. Bus-Location of DERs

The DERs placement of Newton-Raphson load flow analysis method is given by,

$$\frac{\partial P_L}{\partial P_i} = [J_{L1}] * \left[ \frac{\partial P_L}{\partial \delta_i} \right] \quad (1)$$

Where  $[J_{L1}]$  is an Jacobian sub-matrix of  $[J^T]^{-1}$ , i.e., containing all  $\left[ \frac{\partial \delta_i}{\partial P_i} \right]$  in terms of  $P_i$  is a function of both  $\delta_i$  and  $U_i$

$$P_L = \sum_{i=1}^{N_b} P_i(\delta_i, U_i) \quad (2)$$

### B. Size-Selection of DERs

Objective function of system electric loss minimization ( $P_L$ ) is given by

$$\text{Min} \left( P_L = \sum_{i=1}^N PG_i - P_D \right) \quad (3)$$

Optimization is done on Power quality and reliability constraints is given below.

#### 1) Bus-Voltage Limits:

$$U_{i \min} \leq U_i \leq U_{i \max}$$

#### 2) Limits on Active and Reactive Power Generation on DERs:

$$\begin{aligned} PG_{i \min} &\leq PG_i \leq PG_{i \max} \\ QG_{i \min} &\leq QG_i \leq QG_{i \max} \end{aligned}$$

#### 3) Line Flow Limit: The thermal limits should be below of line and takes internal congestion of microgrid.

$$S_{ij} \leq S_{ij \max}$$

#### 4) Zero Slack Bus Injection: At the planning stage, DER capability should be the internal demand of microgrid and reduces the power drawn from utility to zero.

### C. Economic Emissions Load Dispatch (EELD) – Both Electric and Thermal

Cost function of EELD is given by

$$\text{Minimize} \left( C = W \times f_1 + (1 - W) \times (Pf_\eta) \times f_2 \right) \quad (4)$$

Here, C is the total fuel cost and emission level.  $Pf_\eta$  blends  $NO_x$  emission cost ( $f_2$ ) with the normal cost of fuel ( $f_1$ ). W is the weighting factor and uniformly varies between [0, 1].

#### 1) Power Balance:

$$\sum_{i=1}^N PG_i - P_D - P_L = 0 \quad (5)$$

The quadratic function of the power loss  $P_L$  and their outputs through B-coefficients and its constant terms and as linear terms [8], [20]. of Kron's loss formula, is as to referred.

$$P_L = \sum_{i=1}^N \sum_{j=1}^N PG_i B_{ij} PG_j + \sum_{i=1}^N B_{0i} PG_i + B_{00} \quad (6)$$

Where  $B_{ij}$ ,  $i, j = 1, \dots, N$ , are known as loss-coefficients; and units are  $MW^{-1}$ . It can be rearranged to form a symmetrical square matrix of dimension  $(N \times N)$  and a Units of  $B_{00}$  equal to that of  $P_L$  and it consists of a single element, and units of  $B_{0i}$  are dimensionless and elements of  $B_{0i}$  form  $(1 \times N)$  matrix.

$$\begin{aligned} &B_{11} PG_1^2 + \left( 2 \sum_{i=1}^N B_{1i} PG_i + B_{01} - 1 \right) PG_1 \\ &+ \left( P_D + \sum_{i=2}^N \sum_{j=2}^N PG_i B_{ij} PG_j + \sum_{i=2}^N B_{0i} PG_i - \sum_{i=2}^N PG_i + B_{00} \right) = 0 \end{aligned} \quad (7)$$

Eqn (7) can be simplify as

$$XPG_1^2 + YPG_1 + Z = 0 \quad (8)$$

Where,

$$X = B_{11} \quad (9)$$

$$Y = 2 \sum_{i=2}^N B_{1i} PG_i + B_{01} - 1 \quad (10)$$

$$Z = P_D + \sum_{i=2}^N \sum_{j=2}^N PG_i B_{ij} PG_j + \sum_{i=2}^N B_{0i} PG_i - \sum_{i=2}^N PG_i + B_{00} \quad (11)$$

The real roots of (8) are obtained as

$$PG_1 = \frac{-Y \pm \sqrt{Y^2 - 4XZ}}{2X}, \text{ where } Y^2 - 4XZ \geq 0 \quad (12)$$

- 2) *Constraint of DER Capability Limits:* DER generates the power within the upper limit  $PG_{i\max}$  and lower limit  $PG_{i\min}$ , so expressed as,

$$PG_{i\min} \leq PG_i \leq PG_{i\max} \quad (13)$$

- 3) *Inequality Constraint of Heat Balance:* With the consideration of output heat ( $H_R$ ) of Mt, Dg is directly proportional to electric output

$$H_R = \text{Total heat output} = \sum_{i=1}^N \theta_i PG_i \quad (14)$$

Heat balance inequality constraint as given by,

$$\sum_{i=1}^N \theta_i PG_i \geq H_D \quad (15)$$

heat-to-power ratio of the  $i$ th DER is the  $\theta_i$  which is a proportional to constant and is determined by using heat rate is (16). It can be considered as Unit-wise heat exchanger as,

$$\theta_i = \frac{\text{HeatRate (KJ / kWh)}}{3600} \times \eta_{ith} \times \eta_{ex} \quad (16)$$

#### D. To Find Out the Steps PFN for $NO_x$

- 1) *Cost of the Fuel:* The each DER of the fuel cost can be determined at its maximum output in \$/h is

$$f_{1\max} = \sum_{i=1}^N (a_i + b_i \times PG_{i\max} + c_i PG_{i\max}^2) \quad (17)$$

- 2)  *$NO_x$  Emissions:*  $NO_x$  emission of the  $i$ th DER releases and is determined at its maximum output in g/kWh as

$$f_{2\max} = \sum_{i=1}^N (\alpha_i + \beta_i \times PG_{i\max} + \gamma_i \times PG_{i\max}^2) \quad (18)$$

Fuel cost coefficients ( $a_i, b_i, \text{ and } c_i$ ) can be determined from fuel cost DER outputs whereas Emission coefficients ( $\alpha_i, \beta_i, \text{ and } \gamma_i$ ) for  $NO_x$  emission of the  $i$ th DER are determined by curve fitting technique and are expressed in  $NO_x$  emission level DER outputs.

- 3) *Pfn[i]:* Pfn[i] of the  $i$ th DER is calculated as

$$Pfn[i] = \left( \frac{a_i + b_i \times PG_{i\max} + c_i \times PG_{i\max}^2}{\alpha_i + \beta_i \times PG_{i\max} + \gamma_i \times PG_{i\max}^2} \right) \quad (19)$$

- a) Values of Pfn[i] is set to be arranged in an ascending order.

- b) The each unit of maximum capacity is ( $PG_{i\max}$ ) is added at a time and starts from smallest Pfn[i] unit until



$$\sum PG_{i \max} \geq P_D \quad (20)$$

- c) At this stage, the last unit price penalty factor Pfn[i] is associated for the load demand.
- d) Once the penalty factor Pfn is subjected to the minimized constraints given in (5), (13), and (15).

### III. PSO-BASED ALGORITHM FOR EELD

Particle Swarm Optimization is used for solving the Economic Emission Load Dispatch (EELD) problem.

Let Initialize a population of particles as,  $P_i = [(P_{i1}, P_{i2}, P_{i3}, \dots, P_{iN})]$  be the  $i$ th particle of the population and  $i=1,2,3,\dots,NP$ . 'N' is number of units of generation. The main idea is to minimize the operational fuel cost as discussed in (4). The corresponding PSO algorithm can be determined by the following steps:

- A. The data of emission level coefficients of input system and fuel cost curve coefficients of generators, weighting factor "W", limitations of power generation, coefficients of transmission loss and load demand.
- B. Initialization of population within the d-dimensional search space of velocities and random values are determined. The magnitude of any particle should be maximum velocity Vmax is initialized. The fitness of each particle and assignment of the particle's position to P-best position and fitness to P-best fitness is evaluated. Observe the best particle among the P-best as G-best and store the G-best of fitness value of the particle.
- C. The particle of the position and velocity has to be changed.
- D. For each particle, evaluate the fitness value as per (4), if all decisions variable are within the ranges.
- E. By comparing the fitness evaluation particles with its previous P-best. If the current iteration value is better than the previous P-best, then set the P-best value is equal to the current value and the P-best location is equal to the current location in the d-dimensional search space.
- F. Compare the best current fitness evaluation with the population G-best. If the current value is better than the population G-best, then reset the G-best to the current best position and the fitness value to current fitness value.
- G. Repeat the steps 2-6 until a stopping criterion, such as sufficiently good G-best fitness or a maximum number of iterations/function evaluations is met.
- H. The best compromise solution is that the algorithm can be described the set of solutions are known as Pareto-optimal solutions. In these we have to use fuzzy logic for each objective function is set to Pareto-optimal solutions implemented a fuzzy membership function can be obtained as per eqn.

### IV. IMPLEMENTATION OF PARTICLE SWARM OPTIMIZATION FOR ECONOMIC EMISSION LOAD DISPATCH (EELD)

The main objective of EELD can be obtained minimum cost of generation within the constraints and can be generated by each committed generator, of the amount of real power generation and the components of PSO implementation and can be discussed in detailed.

Particle Swarm Optimization is to solve the economic emissions load dispatch (EELD) problem.

- A. Let  $P_i = [(PG_{i1}, PG_{i2}, \dots, PG_{iN})]$  be the vector designating the  $i$ th particle of the population and  $I = 1,2,3,\dots,NP$ . The real power outputs of the elements of  $P_i$  and N generating units
- B. The objective is to minimize the fuel cost coefficients of generators as mentioned in (1)

$$f_1 = \sum_{i=1}^N F_i(P_i) = \sum_{i=1}^N a_i + b_i P_i + c_i P_i^2 \quad (\$/hr) \quad (21)$$

Where  $F_i(P_i)$  is the generator function of the cost;  $a_i, b_i$  and  $c_i$  are the coefficients of the  $i$ -th generator of the cost function; and  $i$ -th generator of the power output  $P_i$ .

- C. The Emission Level Coefficients of Generators are,

$$f_2 = \sum_{i=1}^N F_{xi}(P_i) = \sum_{i=1}^N \alpha_i + \beta_i P_i + \gamma_i P_i^2 \quad (Kg./hr) \quad (22)$$

Where,  $f_2$  is the system function of the total amount of gases released in (Kg./hr) or Ton/hr  $\alpha_i, \beta_i, \gamma_i$  are coefficients of emission level of generator  $i$ . The above mention equation is to minimize subject of the system equation constraints.

#### D. Real Power Balance Constraint

$$\sum_{i=1}^N P_i - P_D - P_L = 0 \quad (23)$$

E. The total transmission losses  $P_L$  can be determined by using B- loss coefficients and power output unit is given as,

$$P_L = \sum_{i=1}^N \sum_{j=1}^N PG_i B_{ij} PG_j + \sum_{i=1}^N B_{0i} PG_i + B_{00} \quad (24)$$

#### F. Generator Capacity Constraints

If generator's lower limits  $PG_{i\min}$  and upper limits  $PG_{i\max}$ ,

$$PG_{i\min} \leq PG_i \leq PG_{i\max} \quad (25)$$

G. Cost function of EELD of fitness function is given by,

$$\text{Minimize} (C = W \times f_1 + (1 - W) \times (Pf_\eta) \times f_2) \quad (26)$$

H.  $Pfn[i]$ : Pfn[i] of the ith DERs is calculated as,

$$Pfn[i] = \left( \frac{a_i + b \times PG_{i\max} + c_i \times PG_{i\max}^2}{\alpha + \beta_i \times PG_{i\max} + \gamma_i \times PG_{i\max}^2} \right) \quad (27)$$

- I. Initialize of G-best and P-best: The initial particles of the swarm of fitness values can be obtained by the particle of initial pbest value.
- J. The best value among all the Pbest values is identified as G-Best.
- K. If the fitness evaluation value of each individual particle is better than previous P-best, the current value is said to be P-best. If the P-best is better than G-best, then best P-best is said to be G-best and the corresponding value of fitness function can be saved by the particle.
- L. By Comparing the best current fitness evaluation with the population G-best value. If the current iteration value is better than the population G-best, then reset the G-best position of the current value and the fitness value of the particle to current fitness value.
- M. If the iteration of current is equal or greater than to the maximum iteration, then result should keep in an array and should stop, otherwise repeat the steps (2-7).

## V. RESULTS AND DISCUSSION

TABLE I

DERs DATA-FUEL AND EMISSION COEFFICIENTS, OPERATING LIMITS, HEAT RATES

Bus No	1	2	6	11	12
DER Capacity (KW)	500 (Dg)	200 (Dg)	80 (Mt)	100 (Dg)	30 (Mt)
$a_i$	10.193	2.035	0.5768	1.1825	0.338
$b_i$	105.18	60.28	57.783	65.34	89.1476
$c_i$	62.56	44.0	133.0915	44.0	547.619
$\alpha_i$	26.55	14.4296	3.0358	19.38	1.0346
$\beta_i$	16.1836	64.1535	57.3403	176.6946	60.384
$\gamma_i$	7.0508	130.4094	311.5728	821.6573	943.1898
$PG_{i\max}$ (KW)	500	200	80	100	30
$PG_{i\min}$ (KW)	0.00	40.0	16.0	20.0	6.0

Heat Rate (KJ/KWh)	10314	11041	11373	10581	12186
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A. *B-coefficients*

$$B_{ij} = \begin{bmatrix} 0.4355 & -0.1694 & 0.1482 & -0.2684 & -0.0925 \\ -0.1694 & 0.2366 & -0.0247 & -0.0061 & -0.0689 \\ 0.1482 & -0.0247 & 0.1636 & -0.2391 & -0.1046 \\ -0.2684 & -0.0061 & -0.2391 & 0.6517 & 0.1987 \\ -0.0925 & -0.0689 & -0.1046 & 0.1987 & 0.1864 \end{bmatrix}$$

$$B_{0i} = [-0.0326 \ -0.0314 \ 0.0057 \ -0.0018 \ 0.0050]$$

$$B_{00} = [0.0014]$$

B. *No. of Iterations* = 1500

Case.1: To study the planning of CHP-based micro-grid of economic power sharing using PSO method for the load of 169KW of fuel cost is 24.2603\$/hr and the total NOx is 48.6038g/kwh and for the load of 248KW of fuel cost is 52.140\$/hr and total NOx is 96.8993g/kwh by using the eqns 21 & 22 using the MATLAB coding of R2012.

1) *Simulations Result for 169 KW for 5-Unit System* :

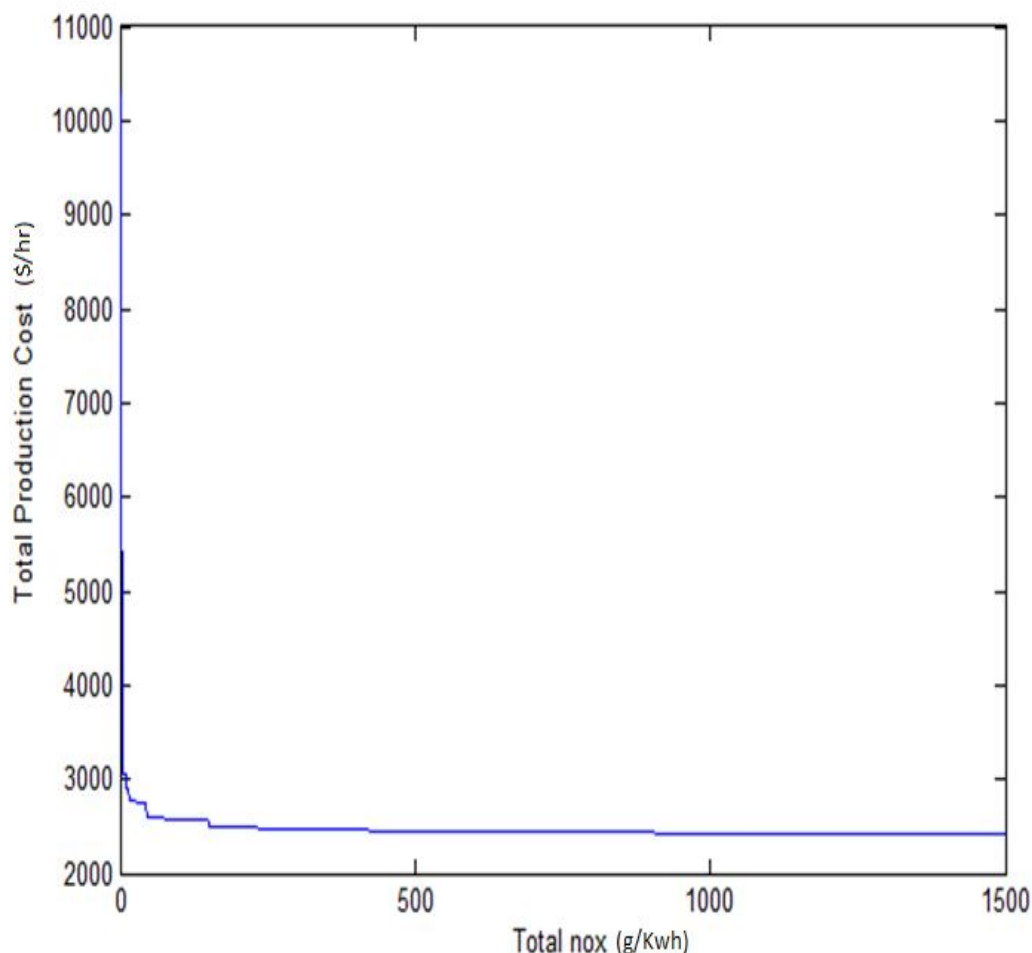


Fig. 1 . Graph between Total NOx and Fuel Cost in \$/hr for load of 169 KW with PSO

## 2) Simulations Result for 248 KW for 5-Unit System

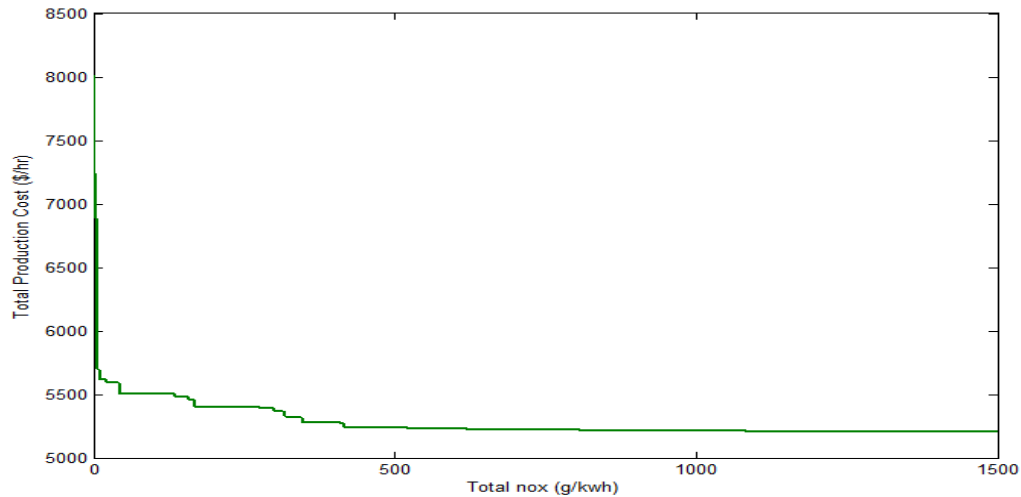


Fig. 2 Graph between Total NOx and Fuel Cost in \$/hr for load of 248 KW with PSO

## C. Discussion

In this paper, the MATLAB coding of Particle Swarm Optimization method is to controlling the particles swarms and generate the best fitness value of personal best and global best solution. Initialize the particle of generating units of each individual particle and get the update best value of the current fitness value of gbest. If the iteration of current is equal or greater than to the maximum iteration, then results should be stop, otherwise repeat the steps.

## VI.COMPARISON BETWEEN (PSO) AND (HSA)

By comparing the PSO and HSA algorithm results of both simulation techniques with each other and only difference is that HSA algorithm is faster than PSO algorithm and HSA algorithm is better than the PSO algorithm because by comparing these two techniques PSO algorithm is to reduce the fuel cost and nitrogen emission level by comparing with the HSA method.

Case 2: To study the comparison of HSA method for the load of 169KW of fuel cost is 25.246\$/hr and the total NOx is 39.6655g/kwh and for the load of 248KW of fuel cost is 54.752\$/hr and total NOx is 74.7885g/kwh by using the above eqns.

## A. Simulations Result for 169 KW for 5-Unit System

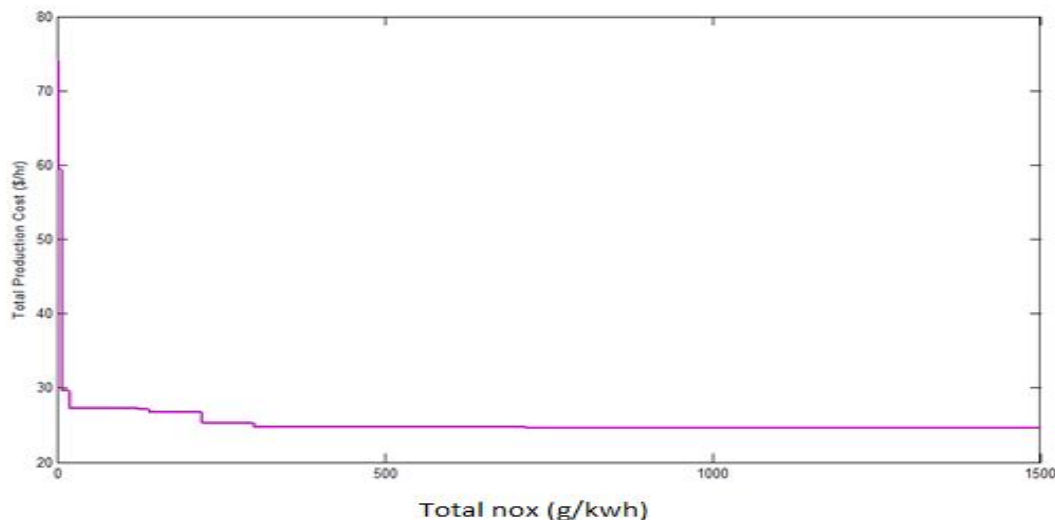


Fig. 3 Graph between Total NOx and Fuel Cost in \$/hr for load of 169 KW with HAS



### B. Simulations Result for 248 KW for 5-Unit System

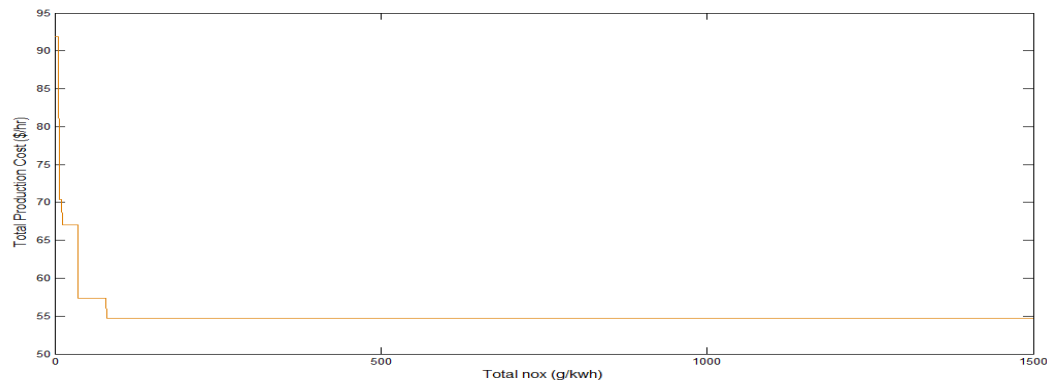


Fig .4 Graph between Total NOx and Fuel Cost in \$/hr for load of 248 KW with HSA

### C. Discussion

In this paper, a PSO and HSA method is implemented, simulated and results were discussed. The active and reactive power generation and bus voltages within capability limits, economically share an electrical tracking demand by comparing these two techniques is to minimize the operational fuel cost and nitrogen oxide emission level is to get the successful results by comparing these two techniques and results are achieved.

TABLE II  
OPTIMAL SCHEDULING OF GENERATORS OF A FIVE-UNIT SYSTEM BY COMPARING PSO METHOD AND HSA METHOD

Method	Load (KW)	DERs output at Buses (KW)					Fuel cost (\$/hr)	NO <sub>x</sub> (g/kwh)	Heat (kwh)
PSO	169	1	2	6	11	12	24.2603	48.6308	160.3
		0.0	70.8	26.5	69.2	6.0			
	248	0.0	107.2	41.7	95.5	10.5	52.140	96.8993	239.8
HSA	169	0.0	73.5	30.5	59.3	8.5	25.246	39.6655	164.2
	248	0.0	132.9	40.3	74.9	6.2	54.752	74.7885	236.2

## VII. CONCLUSION

The main focus of this research study is to develop equality and inequality constraints using CHP-based Micro-grid of Economic Emissions Load Dispatch (EELD). To develop and implement a MATLAB coding for a economic emission load dispatch constraints for reducing the operational fuel cost based on equality and inequality constraints. To develop and implement MATLAB coding to control the power losses of nitric oxide emission level of CHP-based micro-grid. Therefore, in this research, we develop MATLAB coding of PSO and HSA of Distributed Energy Resources (DER) has been analyzed and acceptable simulation results have been obtained. Specially, PSO has to compare with HSA coding and successful results have been obtained.

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