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Emission Constrained Economic Dispatch with PV Energy Penetration

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Abstract—Power system planners are forced to consider the alarming rate of environmental pollution and rapiddepletion of fossil fuels andutilize renewable energy resources to mitigate the environmental effects of thermal power stations. Combined Economic Emission Dispatch(CEED)offers an effectivesolution to reducefossil fuel emissions as well ascost.Since 1985, CEED is considered to be a common optimization strategy. Literature contains lot of optimization methods for the strategy.In the recent times, using PV energy has proved to be a feasible and dependable alternative for electricity generation systems based on fossil fuels. In the developing countries, the dependency on fossil fuels has been seen as inevitable. At present,the use of renewable energy sources is rapidly increasing in inconventional power generation systems.

The present paper puts forwardan approach of combining PVenergy-based grid integrated PV system with fossil fuel based thermal power plant using evolutionary programmingbased optimization technique.Among the various optimization techniques, the Particle Swarm Optimization (PSO) is considered to be the most suitable technique for the problem is explained in detailed manner.The proposed method is to combine CEED with the PV energy and thereby reduces the use of conventional energy resources.It also permits an effective utilizationof abundantlyavailable PV energy.It is tested on standard IEEE 30 bus system with the real time ratings of proposed PV plant situated in Tamilnadu.

Index of terms—Fossil fuel depletion, fuel economy,PV insolation,economic dispatch, emission dispatch, grid integrated PVphotovoltaic systems, Particle Swarm optimization.

I. INTRODUCTION

Combined Economic Emission Dispatch (CEED) is a proven method to effectively reduce greenhouse emissions as laid down by the IPCC (Inter Governmental Panel on Climate Changes). The Paris Summit on Climatic Changes held recently considerably lowered the ceiling of carbon dioxide emissions. The present paper suggests methodswherein
renewable energy sources are used with fossil fuels through CEED.

Planningfor effective power generation carries tremendous significance for electrical utility.Looking from the perspective of environmental conservation, pollution caused by emissions from fossil fuel-basedpower generation plants adversely affect life forms on earth in one way or the other.

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So, the present times demand a reliable, economic and eco-friendly electrical generation methods[1].Efficient planning of power generation in thermal power plants includesproper allocation of power generation in order to optimize fuel costs and emissions considering power constraints [2]. Increasing energy prices, environmental concerns and fast depletion of the known fuel resources have significantly enhanced the scope of renewable energy resources. The CEED problem is mathematically defined as multiple objective optimization approaches to examine the effective usage of thermal and conventional resources to sustain the load balancing in power stations [3]. Combining renewable and non-renewable energy sources helps in bringing down greenhouse emissions considerably. A major hurdle in this integration is the uncertainty associated with the availability of renewable power sources. Until now, PSO algorithm is usedsolely to minimise fuel costs and emission levels [4].A research done earlier on CEED with power flow constraintsuses various evolutionary programming techniquesand compares their performance[5]. Until now, the option of utilising PV energy for minimizing fossil fuel cost alone is considered but that of emissions has not been considered [6].By integrating renewable energy sources like wind, PV, etc. into the conventional power plants, the expenditure on fuel costs can be reducedsignificantly [7]. Various non-conventional energy sourceshave been used to reduce the use of fossil fuelsconsidering valve point loading. However, PV energy has not been accounted for in CEED related problem. [7].Real time modelscould achieve best possible solution when the CEED issue is considered along with valve point loading. However, the reduction of expenses related to fuel comes with other augmented losses [7].Literature review clearly reveals the need for an efficient optimization algorithm to solve the CEED problem.Kennedy and Eberhart came up with an algorithm based on PSOwhich is based on the behaviour offish schools and bird swarms.When this Swarm model is differently configured,it can offeralmost perfectand easy to apply solution with quickerconvergence [8-13].Considering all the above factors, the authors of the present paper arrived at a decision to consider the classical model of PSO algorithm to solve the problem dealt with in this research work.

II. METHODOLOGY

The objective of CEED problem is to planthe generating unit outputs aimed atdesiredload demand at minimum operating cost and emission value is met while fulfilling the constraints of all the generating units. This problem of CEED can be stated as:

$$\min Q = \sum_{i=1}^{n} (Eco_i(G_i) + Emi_i(G_i)) \quad (1)$$

Where Q: objective function
$Eco_i(G_i)$: Economic fuel cost
$Emi_i(G_i)$: ithunit Emissions of
Equality Constraint

$\sum_{i=1}^{n} G_i - G_L - G_d = 0$ (2)
Where G_i : i[th] unitPower generation
G_L: Power loss
G_d: Power demand
n: number of generating units
Inequality Constraint
$G_{imin} \leq G_i \leq G_{imax}$ (3)

Where G_{imin} : Minimum power limits of i[th] unit
G_{imax} : Maximum power of i[th]unit

A. Economic Dispatch

$Eco_i(G_i) = a_i P_i^2 + b_i P_i + c_i$ (4)

Where a_i,$b_i$and c_i represent the fuel cost coefficients

B. Emission Dispatch:

$Emi_i(G_i) = \alpha_i P_i^2 + \beta_i P_i + \gamma_i$ (5)

Where α_i,β_i,and γ_i are the emission coefficients of the generating uniti
$G_L = \sum_{i=1}^{n} \sum_{j=1}^{n} G_i B_{ij} G$ (6)

Where B_{ij}: loss coefficient matrix.

C. Combined Economic Emission Dispatch

The combined objective problem discussed aboveis changedinto aobjective problem by bringing in 'h' factor also known as price penalty factor. The changes that the CEED problem undergoes after introducing 'h' factor can be represented as:

$Min\ F_c = \sum_{i=1}^{n}((\alpha_i P_i^2 + \beta_i P_i + \gamma_i) + h_i(d_i P_i^2 + e_i P_i + f_i))\$/hr$(7)

Where $h_i$is given as:

$h_i = \frac{a_i P_{imax}^2 + b_i P_{max} + c_i}{\alpha_i P_{max}^2 + \beta_i P_{max} + \gamma_i}$ (8)

D. Problem Formulation for PVEnergy Penetration

The power output of PV plant can beshown as:

$P_{gs} = P_{rated}\{1 + (T_{ref} - T_{amb}) * \propto\} * \frac{S_i}{1000}$

(9)

Where P_{rated}- rated power
T_{ref} - Reference temperature
T_{amb}- Ambient temperature
$\propto$ - Temperature coefficient
S_i - Incident PV radiation (PV insolation)

When m numbers of PV plants takepart in dispatch and its share is represented as:

$PV\ share = \sum_{j=1}^{m} P_{gsj} * U_{sj}$ (10)

Where P_{gsj} is power available from jth unit
U_{sj} is status of jth PV unit

The cost of PV power is given as

$PV\ \ cost = \sum_{j=1}^{m} PUcost_j * P_{gsj} * U_{sj}$ (11)

Where $PUcost_j$ is per unit cost of jth unit

E. CEED with PVEnergy Penetration

The present paper has the goal of efficiently using the abundantly available PV power in addition to reducing fuel costs. After the integrationof PVenergy, the objectivefunction becomes

$$Min\ F_T = \sum_{i=1}^{n} \left(a_i P_i^2 + b_i P_i + c_i + h_i * (\alpha_i P_i^2 + \beta_i P_i + \gamma_i)\right) + \sum_{j=1}^{m} PUcost_j * P_{gsj} * U_{sj} K_s \left(\sum_{j=1}^{m} P_{gsj} - \sum_{j=1}^{m} P_{gsj} * U_{sj}\right)$$

(12)

Subject to

$P_d + P_L - \sum_{i=1}^{n} P_i - \sum_{j=1}^{m} P_{gsj} * U_{sj}$
(13)

$P_{imin} \leq P_i \leq P_{imax}$
(14)

$\sum_{j=1}^{m} P_{gsj} * U_{sj} \leq 0.3 * P_d$
(15)

$\forall U_{sj} \in \{0,1\}$
(16)

Where K_s : constant

III. OPTIMIZATION METHOD

Developed by Eberhart and Kennedy in 1995,Particle Swarm Optimizationalgorithm of swarm intelligence was influencedby the behavior of fish and birdswarms.This algorithm combines personal and social knowledgeto arrive at optimum solution for a problem. The algorithm considers swarming particles that move together in a search space in order to obtain optimum value. In the algorithm,swarming particles are solutions and they move togetherin the direction of suitable area to reach an overallperfection. The algorithm correlatesthe unpredictable but orderly movement of a swarm of bird with the changing conditions and available solutions for a given problem. Each particle of the swarm stands for a vector for each particle in search space. This particular vector has an assigned vector (or the velocity vector) that decides the successive movements of particles.

The PSO algorithm helps to update the swarmvelocity. Each particle in the swarm modifiesits velocity basedon the present velocity of the swarm,the best positions it had explored so far and the overalloptimal position explored by the swarm.

Parameters of the PSO algorithm:

P :Population of agents
$\mathbf{p_i}$:agent location$\mathbf{a_i}$ in the solution space
f:Objectivefunction
$\mathbf{v_i}$: Velocity of agent's $\mathbf{a_i}$
$\mathbf{N(a_i)}$: Neighborhood of agent'sa_i (fixed)

Particle update rule

p = p + v
(17)

with,

$v = v + c_1 * rand * (P_{best} - p) + c_2 * rand * (G_{Best} - p)$(18)

where

p: Particle position
v: Particle direction
w_1 : Local particle weights
w_2 : Global particle weights
P_{best}: Optimal position of the particle
G_{Best}: Optimal position of the swarm
rand: Randomness of the variable

ALGORITHM:

- Generate anagent group (particles) which has a uniform distribution over X
- Identify the position of each particle with respect tothe objective function.
- Update the current position of the particle, if it is better than theprevious position
- Determine the best particle from the sequence of previous best of each particle
- Update velocity of each particle using the below equation

$$v_i^{t+1} = v_i^t + c_1 * U_1^t * (pB_i^t - p_i^t) + c_2 * U_2^t * (gB_i^t - p_i^t) \quad (19)$$

- Move the particles to new position by

$$p_i^{t+1} = p_i^t + v_i^{t+1} \quad (20)$$

- Repeat the process from step 2 until convergence criteria is achieved

Table 1: Problem Parameters for the Assessed Method

Algorithm Parameters	Problem Parameters	Initialization of Parameters
Population	Optimum Generation of Generators	30
Swarm	Iteration	1000
Particles	Optimum Generation of Generators	100
Velocity	Turbine speed	0.9,0.99
Inertial(weight) Factor	Moment of inertia of the rotor	1,1.5
P_{best}	Individual best fuel cost/emission parameter of each generator	-
G_{best}	Overall best fuel cost/emission parameter of 6 generators	-

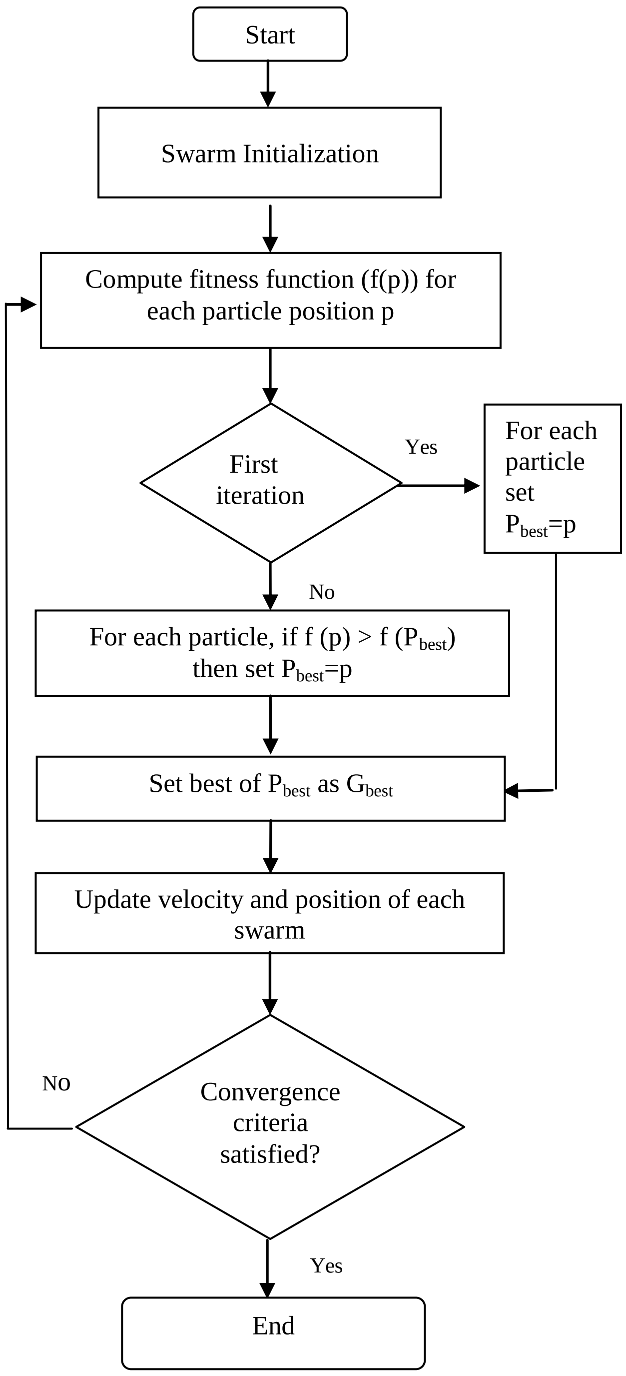

Fig 1: PSO Algorithm Flow Chart

IV. TEST SYSTEM

The method presented is carried out on a standard test system consisting of six thermal power generation units and sixPV plants. The ratings of the PV Photo Voltaic Panel are taken from an independent power producer installedin Tamilnadu. The thermal units ratings are taken from [20].Table 2 presents the fuel cost coefficients. Table 3 represents minimum and maximum power limits. Table 4 represents the emission coefficients of the thermal units.The data for PV plants ispresented in table 5 and 6[20].

Table 5 shows the power ratings and per unit costs of various PV plants and Table 6 provides the global PV radiation data of Kamudhi for the 1st day of January 2016 [23].

Table 2: Thermal Unit cost coefficients

Generator	α($/MW²hr)	β($/MW h)	γ($/h)
1	0.15247	38.53973	756.79
2	0.10587	46.15916	451.32
3	0.02803	40.39655	1049.32
4	0.03546	38.30553	1243.53
5	0.02111	38.32782	1658.56
6	0.01799	38.27041	1356.27

Table 3: Thermal units generation capacities

Generator	G_{min}(MW)	G_{max}(MW)
1	10	125
2	10	150
3	40	250
4	35	210
5	130	325
6	125	315

Table 4: Thermal unit emission coefficients

Generator	d(kg/MW²h)	e(kg/MWh)	f(kg/h)
1	0.00419	0.32767	13.85932
2	0.00419	0.32767	13.85932
3	0.00683	-0.54551	40.2669
4	0.00683	-0.54551	40.2669
5	0.00461	-0.51116	42.89553
6	0.00461	-0.51116	42.89553

Table 5: PV plant power capacity and unit rates

PV Photo Voltaic Plant	P_{rated}(MW)	Unit rate($/KW h)
1	108	0.11
2	108	0.11
3	108	0.11
4	108	0.11
5	108	0.11
6	108	0.11

Table 6: GlobalPV radiation data of the location

Time	Global PV Radiation(W/m²)	Temperature(⁰C)
1:00	0	31
2:00	0	30
3:00	0	30
4:00	0	30
5:00	0	30
6:00	0	30
7:00	209	31
8:00	520	32
9:00	790	33
10:00	1001	33
11:00	1137	33
12:00	1189	34
13:00	1154	34
14:00	1034	34
15:00	837	33
16:00	578	33
17:00	273	32
18:00	0	31
19:00	0	31
20:00	0	31
21:00	0	30
22:00	0	30
23:00	0	30
24:00	0	30

V. RESULTS

The suggested method was implemented in MATLAB 2016a software. The following control settings were used for PSO: velocity w1=0.9, w2=0.99, random numbers between 0 and 1, maximumno.of. iterations=1000, number of particles =100, weight factor =1, 1.5.

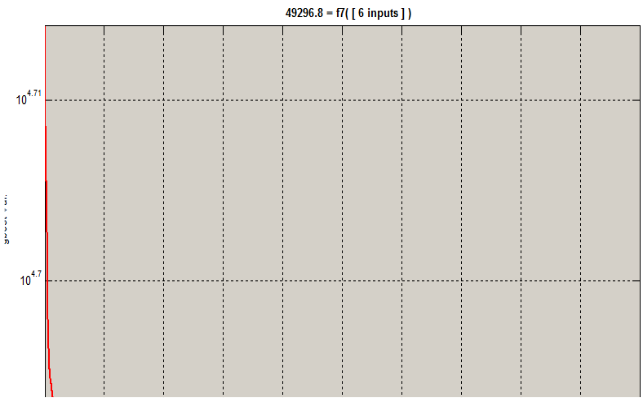

Fig 2: CEED Results for Minimum Fuel Cost

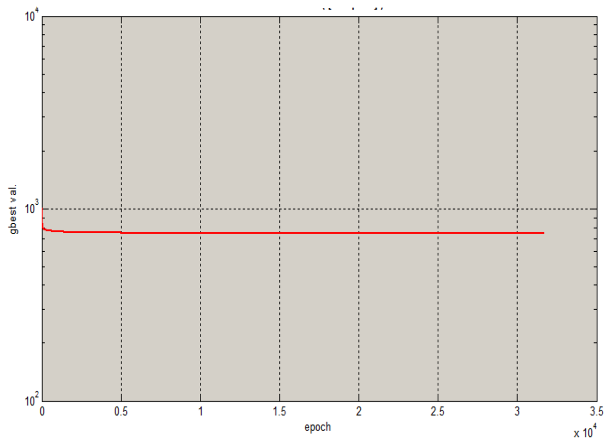

Fig 3: CEED Results for Minimum Emission Value

Table 7: Results of CEED for 900 MW Demand

Thermal Generation	P_1(MW)	103.50
	P_2(MW)	70.10
	P_3(MW)	60.69
	P_4(MW)	139.54
	P_5(MW)	324.99
	P_6(MW)	251.75
Cost	Fuel cost ($/h)	49,296.79
	Emission cost ($/h)	49,296.00
	Total Cost($/h)	98,592
Others	Emission(Kg/h)	749.463

Table 8: CEED results with PV for 900MW Demand

Thermal Generation	P_1(MW)	69.96
	P_2(MW)	44.14
	P_3(MW)	41.81
	P_4(MW)	95.33
	P_5(MW)	247.84
	P_6(MW)	177.80
PVGeneration	PV power share(MW)	270.00
Cost	Fuel cost ($/h)	35,588.84
	Emission cost($/h)	35,588.84
	PV cost	29,700.00
	Total Cost($/h)	1,00,877.68
Others	Emission(Kg/h)	407.46

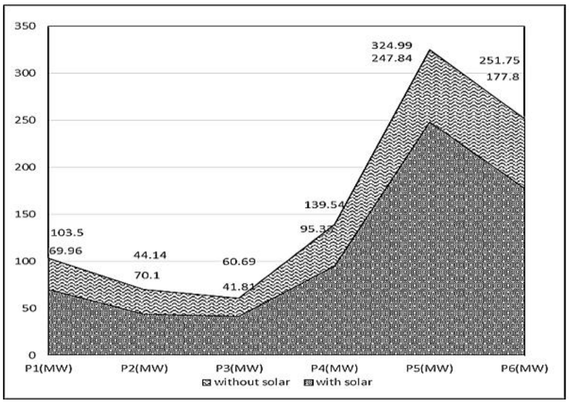

Fig 4: Generation details after rescheduling with PV power.

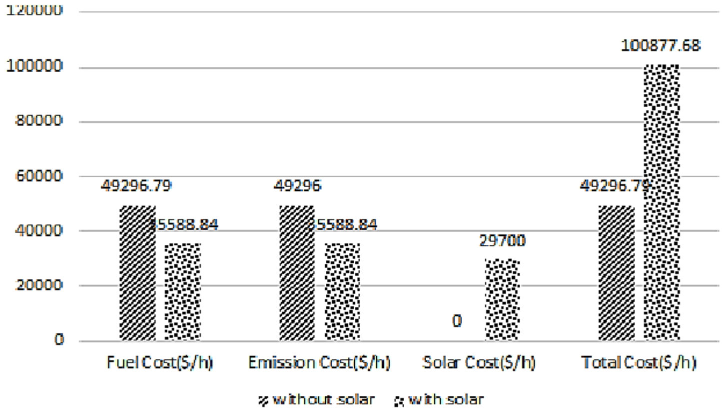

Fig 5: Comparative analysis of cost after CEED with sloar penetration.

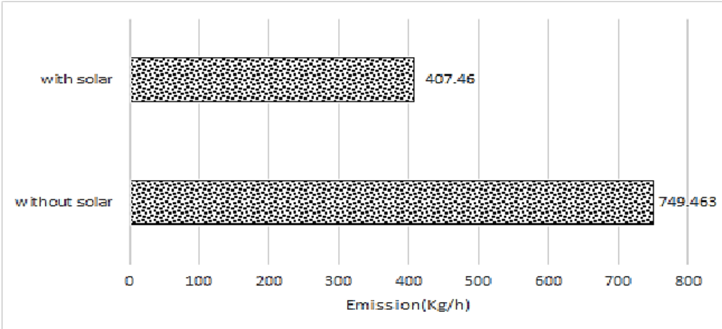

Fig 6 Comparative analysis of emission cost CEED before and after PV penetration.

Tables 7 and 8 shows the results of CEED with PV penetration for the demand of 900MW in IEEE 30 bus system.After the introduction of PV energy, the total power generation of six units in the test system reduced to 273.72MW.PV penetration resulted in considerable reduction of emission from 749.46Kg/h to 407.46Kg/h.Fossil fuel cost for the six units also reduced to 13,707.96$/h. Total cost includes the Tariff cost for IPP produced units from PV plant, maintenance cost for PV Photo Voltaic Plant and the Transmission cost. The results of CEED with PV power penetration in various aspects such as Generation cost and emission cost is depicted pictorially. By switching the connected PV units,the thermal power generation can be increased or decreased accordingly.The additional operating cost of integrating the PV units adds to the overall fuel cost. However, it reduces emissionsand the cost spent on the thermal units.

VI. CONCLUSION

The present paper presents an optimal solution for CEED problem using PV energy as an alternative. It considers the environmental conditions and makes use of renewable PV energy which has not only become essential but inevitable. The study was carried out for a standard system consisting six generators and sixPV plants and using PSO as its optimization method.

The results obtained by PSO for CEED with PVpenetration were compared with CEED without PV penetration. It is important to note that emission levels,related costs and fossil fuel costs were considerably reduced. However, but the overall cost of power generation is increased. Power generation cost of the hybrid plant can be expected to be the same as the unit cost of wind mills.This could become a reality when the manufacturing cost of thin film PV Photo Voltaic cell or single crystalline Photo Voltaic cell is made lesser.The disadvantage of the present method is that the power is considered for a loss account and the gap between generation and demand is increased after PV penetration. This is due to the fact that PV plant requires large area of land for its infrastructure and high insolation area;hence it is not possible to commission the large size PV Photo Voltaic plant very near the load centre. This createsa gap between power generation and power demand which can be considered as transmission loss. This paper is certainly an initiative to counter Global warming and serious hazards of pollution.

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