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Combined Emission Dispatch and Economic Dispatch of Power System Including Renewable Sources

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ABSTRACT: The harmful ecological effect by the emission of gaseous polluted from fossil fuel power plants can be reduced by proper load allocation among various generating units of the plant, but this load allocation may lead to increase operating cost of generating units and non-commensurable fuel cost.Various types of economic dispatch in power systems such as multi area economic dispatch with tie line limits, economic dispatch with multiple fuel options, combined economic and emission dispatch problem.This Combined Economic Dispatch and Emission Dispatch problem is a Multi objective problem. This Multi objective problem can be converted in to single objective problem by using penalty factor. This project presents Combined Economic Dispatch Models developed a system consists of multiple photovoltaic plants and thermal units. Reliable and inexpensive electricity provision is one of the significant objective have been developed in order to address the challenge of continuous and sustainable electricity provision at optimized cost. Problem formulated was implemented on two test cases and results obtained from lambda-iteration, as conventional technique and proposed technique results are compared in terms of Cost, Emission, Convergence and No of iterations.

KEYWORDS*:* Economic Dispatch, Renewable energy, Solar PV generation, Penalty factor.

I INTRODUCTION AND RELATED WORK

An important research has been show up around the world for expansion of continuous, renewable and efficient energy structure in order to meet the requirements of increased population and to reduce the expanded the use of fossil fuels. Expanding energy prices, environmental concerns and expeditious depletion of the known fuel reserves have significantly increased the extension of renewable energy resources. The power sector of Pakistan is designed as an interconnected system and heavily relies on typical sources of generation. This system needs adjustments and improvement in order to meet the twenty first century specifications. Pakistan's energy incorporate span of almost 67% thermal and 30% hydel resources. According to Pakistan's energy year book 2012 [1], total generated electrical energy in Pakistan during 2010–2011 was 95,365 GW hand part of different sources is: thermal power 64.3%; hydel29.9% and nuclear and imported 5.8%. In thermal power, oil include the largest part of 35.2% followed by natural gas 29.0% and coal0.1%. On the other hand, the country has a large hidden of solar energy which has been predicted to be everywhere of 2900 GW in [2]. In [3], the author explain the energy scheme of Pakistan and reviewed conventional and Renewable Energy (RE) resources of the county in detail. The author has been exhibited the supply, generation and using of available resources in significant manner. The paper is focused on RE advancement projects in the country, recent progress, planning and public sector goals in this field. Onaverage, solar global insolation of 5–7 kW h/m2/day in almost95% areas of Pakistan with persistence factor of over 85% has been reported in [4,5]. Economic Dispatch (ED) is a significant and most constant step inpower system operational planning [6]. ED is a development complication that set aside power to each committed generating unitso as to underestimate the total operational cost, subject to constraints. Different constraints build power balance, power limits ofgenerators, prohibited operating zones, ramp rate limits etc. Several optimization capacities with equality and non-equalityconstraints have been used for ED and reported inliterature [7].

In the past of ED dates back to 1920 [8]. Up till 1930 development methods used were the base load method and first-rate point loading. In early 30s, equal additional price tag method was take advantage to complete better conclusions [8]. In those days analog computers were used for computational achievement. First computer for transmission loss penalty factor was built up in 1954. By 1955 electronic prong commentator was developed. Digital computers were used for ED first time ever in 1954 and are being used till date [9]. The authors in [10] have approach the capacity of ED used during 1977–1988; optimal power flow, dynamic dispatch, ED in relation to Automatic Generation Control (AGC) and ED with non-conventional sources has been evaluated. Power system subsist of thermal generators has been broadly used to evaluate ED problem. Input–output (consultation productivity) cost curves of thermal generating units are mandatory for ED. The input–output price-tag curve of a thermal generating unit is achieved by multiplying cost per unit heat and its input–output (consultation productivity) heat rate curve[11]. In present days multi-valve steam turbines and multiple fuel turbines are regularly used in generating units.

The ED with piecewise quadratic cost function (EDPQ) and ED with restricted operating zones (EDPO) are the two non-convexED problems [12]. Valve point effects producing a ripple like no convex input–output heat rate curve. Complex constrained ED is forwarded by intelligent methods including Genetic Algorithm (GA), PSO [13,14], Neural Network (NN), Evolutionary Programming(EP), Tabu search etc. [15–17]. Kennedy and Eberhart introducedPSO in 1995 [18]. In this method, movement of particles is dependent on local and social components of velocity. Moreover, maximum value of velocity, Vmax, is also an important parameter. Its low value results in local exploitation while a higher value results in global international analysis. To obtain a better control over local exploitation and global research, an inertia factor x is introduced in[19]. ED with both cost and emission minimization becomes multiobjectiveoptimization problem and is named as Combined Emission Economic Dispatch (CEED). Using PSO, CEED has been solved by Selvakumar et al. [20]. Zhao et al. [21] solved bid based ED using Constriction Factor PSO (CFPSO) and inertia weight. In [22], a hybrid PSO, a combination of PSO and Sub sequent Quadratic Programming (SQP), is introduced in order to solve a non-convex constrainedED problem with valve point effects. In [23], CEED has been solved using a novel PSO scheme taking into account the generator limits and power balance constraints. An improved PSO has been proposed to solve ED problem of hydro-thermal co-ordination in[24]. Authors in [25]have expected scheduled an added to PSO(EPSO) for hydro-thermal scheduling problem which takes into account discrete constraints such as power balance, hydro and thermal generation limit, reservoir storage volume, initial and terminal storage limit, water balance equation and hydro discharge limit. In[26], PSO has been used to evaluate CEED problem with equality constraints handled by different manner and multi-objective optimization problem transformed into a single objective one.

A lot of research on Economic Dispatch (ED) problem has been carried out during last five years. A few instances are as follows. In[8], a non-convex ED problem has been addressed by various hybrid development methods. The problem has been addressed first by developing an extensible and flexible soft computationalframework called ‘‘PED Frame’’, used as a platform for the computer application of different algorithms under scrutiny. This framework has been used to implementGenetic Algorithm (GA) based models and Hybrid models for ED. In [27], a PSO based technique with constriction factor (CFPSO) has been proposed for ED with valve point effects; CFPSO technique proved to be fast converging. In [28], amulti-objective CEED solution has been proposed by using Artificial Bee Colony (ABC) algorithm. For the solution of the problem, multiobjectiveCEED has been converted into single-objective CEED byusing penalty factor. In [29], iteration PSO with time varying acceleration coefficients (IPSO-TVAC) has been proposed for ED with valve-point effects; Iteration term in velocity equation and time varying acceleration coefficients improved the achievement (searching ability) of PSO technique. In [30], a novel optimization methodology has been proposed to solve a large scale non-convexED problem. The proposed approach is based on a hybrid Shuffled Differential progression (SDE) algorithm that combined the benefits of shuffled frog leaping algorithm and differential evolution. The proposed algorithm integrated a new differential mutation operator in order to address the problem of ED.

In [31], Economic Environmental Dispatch (EED) has been carried out using one Photo Voltaic (PV) plant and one wind turbine. Authors used Strength Pareto Evolutionary Algorithm (SPEA) and tests have been conducted for an IEEE bus system with 30 nodes,8 machines and 41 lines. Dynamic Economic Emission Dispatch (DEED) model with security constraints has been used for ED in[32]. The authors have carried out their work on a system incorporating three thermal units, two solar PV plants and two wind turbines. Authorsin [33]have presented altered good will search algorithm to solve Combined Economic and Emission Load Dispatch (CEELD) problem. Practical constraints of real-world power systems have been used and the experiments carried out on seven systems in order to check the effectiveness and behavior of the proposedalgorithm. This paper presents a Combined Emission Economic Dispatch (CEED) using 13 PV plants and 6 thermal units. Two test cases ofStatic Combined Emission Economic

Dispatch (SCEED) andDynamic Combined Emission Economic Dispatch (DCEED) have been considered. SCEED is performed for full solar radiation level as well as for reduced emission level due to clouds effect whereasDCEED for full radiation only. PSO is used for optimization of the problem and simulation results have been computed in MATLAB. The proposed model contains various different solar plants unlike the workdiscussed in [31, 32]. Power demand data has been obtained from Islamabad Electric Supply Company (IESCO) [34].

II PROBLEM FORMULATION

This area is enthusiastic for question formulation of CEED for apower system having thermal and solar PV generations. As specified earlier, an ED problem can be formulated either statically or dynamically. The mathematical formulation for both cases is worked out in the following subsections.

(a) Mathematical formulation of SCEED with solar power

CEED is a multi-objective optimization problem subsist ofboth economic and environmental dispatch. The CEED problem can be formulated as:

$$min_G = \sum_{i=1}^{n} (F_t(P_t) + E_t(P_t)) (1)$$

Where G is objective function to be minimized, Fi(Pi) represents fuel cost and Ei(Pi) denotes the emissions of ith generating unit. This function is to be minimized subject to following constraints.

Equality constraint:

$$\sum_{i=1}^{n} p_i - P_L - P_d = 0 \qquad (2)$$

Where Pi is power generated by ith unit, PL represents power loss, Pdis power demand and n is the total number of generating units.

Inequality constraint:

$$p_{min} \leq p_i \leq p_{imax} \, (3)$$

WherePiminandPimax are the minimum and maximum power limits ofi_{th} generating unit, respectively.

$$F_i(p_i) = a_i p_i^2 + b_i p_i + c_i + |e_1 * \sin(f_1 * (p_{min} - p_i))| \, {}^{S}/_{h} (4)$$

Fi(Pi), Ei(Pi) in Eq. (1) and PL in Eq. (2) can be formulated as follows[35].

$$E_i(p_i) = \alpha_i p_i^2 + \beta_i p_i + \gamma i + |\epsilon_i * exp(\delta_i - p_i))| \, {}^{kg}/_{h} (5)$$

Where a_i, bi, ci, ei and fi are fuel cost coefficients of i^{th}generating unit.

$$E_i(p_i) = \alpha_i p_i^2 + \beta_i p_i + \gamma i + |\epsilon_i * exp(\delta_i * \ p_i))| \, {}^{kg}/_{h} (6)$$

Where /i, bi, ci, ei and di are emission coefficients of ithgenerating unit.

Power losses can be calculated using the equation:

$$P_L = \sum_{i=1}^{n} \sum_{j=1}^{n} p_i B_{ij} p_J \qquad (7)$$

Where B is loss coefficient matrix.

By introducing a price penalty factor ‘h’, the multi-objective optimization function presented by Eq. (1)can be converted into single objective optimization function. Therefore, by substituting and Ei from Eqs.(4) and (5) respectively and introducing ‘h’ inEq. (1), the CEED objective function can be defined as [28]:

$$F_i(p_i) = a_i p_i^2 + b_i p_i + c_i + |e_1 * \sin(f_1 * (p_{min} - p_i))| +$$

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$$h_i(\alpha_i p_i^2 + \beta_i p_i + \gamma i + |\epsilon_i \, exp(\delta_i * p_i))| \, {}^{S}/_{h} (8)$$

Where hi is given as:

$$h_i = \frac{a_i p_i^2 + b_i p_i + c_i + |e_1 * \sin(f_1 * (p_{min} - p_i))|}{(\alpha_i p_i^2 + \beta_i p_i + \gamma i + |\epsilon_i \, exp\,(\delta_i * p_i))|} (9)$$

The power generated by a solar plant can be represented as [31]:

$$p_{gs} = p_{rated}\left\{1 + \left(T_{ref} - T_{amb}\right) \times \alpha\right\} \times \frac{S_i}{1000} (10)$$

Where Prated is its rated power, $T_{ref}$is the reference temperature, $T_{amb}$is the ambient temperature, α is temperature coefficient, S_i isthe incident solar radiation. With m solar plants taking part in the dispatch, the solar share (the scheduled solar power) is given as:

$$\text{Solar share} = \textstyle\sum_{i=1}^{m} pgs_j \times us_j \qquad (11)$$

WhereP_{gsj} is power available from j_{th} solar plant and U_s denotes status of j_{th} solar plant which is either 1 (ON) or 0 (OFF).The cost of solar power is represented as follows.

Solar cost=$\sum_{j=1}^{m} pucost_j \times pgs_j \times us_j$ (12)

WherePUCostj is per unit cost of j_{th} solar plant. Along with cost minimization, another objective is to minimize the difference between the total available solar power and the solar share in plan to achieve the property benefit of solar availability. Therefore, with solar generation included in the dispatch, the objective function in Eq. (7) becomes:

$$\text{Min}F_R = \textstyle\sum_{i=1}^{n} a_i p_i^2 + b_i p_i + c_i + \left|e_1 * \sin\left(f_1 * (p_{min} - p_i)\right)\right| + h_i(\alpha_i p_i^2 + \beta_i p_i + \gamma i + |\epsilon_i \, exp(\delta_i * p_i))| + \sum_{j=1}^{m} pucost_j \times pgs_j \times us_j \; k_s(\sum_{j=1}^{m} pgsj - \sum_{j=1}^{m} pgs_j \times US_J \qquad (13)$$

Subject to

$$p_d + p_l - \textstyle\sum_{i=1}^{n} p_i - \sum_{j=1}^{m} pgs_i \times us_j = 0 \; (14)$$

$$p_{min} \le p_i \le p_{imax} \; (15)$$

Where Ks is a constant used to make the last term of Eq. (12) compatible with the other terms. Moreover this allows us to control the relative importance of the difference term compared to other terms.

(b) Mathematical formulation of dynamic CEED with solar power

DCEED is a further constructive case in which it is aimed to give appropriate powers to generating units for minimum cost of procedure ina organizing horizon over twenty-four hours a day. The ramp rate limits are treated in this problem. In case of DCEED problem, the mathematical formulation in Eq. (12) becomes:

$$\text{Min}F_R = \textstyle\sum_{t=1}^{N} \sum_{i=1}^{n} (a_i p_i^2 + b_i p_i + c_i + \left|e_1 * \sin\left(f_1 * (p_{min} - p_i^t)\right)\right| h_i(\alpha_i p_i^2 + \beta_i p_i + \gamma i + |\epsilon_i \, exp(\delta_i *$$

pit)j=1mpgsjt−j=1mpgsjt×Usjt)   j=1mpucostj×pgsj×usjtks(j=1mpgsjt−j=1mpgsjt×Usjt)

(16)

The ramp rate limits regulate the range within which the generation of a thermal unit may increase or decrease. The power generation of thermal units is strained by the ramp rate limits as follows:

$$p_i^t - p_t^{t-1} \le uR_i (17)$$

$$p_i^{t-1} - p_t^t \le DR_i \qquad (18)$$

Where $_{U}$ri and D_{Ri} are the up rate and down rate of i_{th}generating unit respectively. Due to ramp rate limits, the minimum and maximum generating limits of thermal units are modified as follows:

$$\max(p_{imin}, UR_i - p_i^t) \le p_i^t \le \min(p_{imax}, p_i^{t-1} - DR_i^t \ (19)$$

The power balance constraint for DCEED can be formulated as:

$$p_d^t + p_L^t - \sum_{i=1}^{n} P_t^t - \sum_{j=1}^{m} pgs_j^t \times US_J^t = 0$$

The share of solar power at any time, based on 30% upper limit[31], is constrained as:

$$\sum_{j=1}^{m} pgs_j^t \times US_J^t \le 0.3 \times pd^t \forall Us_j^t \epsilon \{0,1\} (21)$$

(c) Optimization method

It is accessible from the above mentioned problem formulation that CEED with solar generation is a Mixed Integer Optimization Problem (MIOP). The decision variables for thermal machines arecontinuous whereas the variables for solar plants are binary. In order to solve this problem, PSO for MIOP is used in this work. The PSO for MIOP is essentially a combination of classical PSOand Binary PSO (BPSO).

(a.1)Classical PSO

PSO is an development and expansion technique inspired by bird flocking. To define PSO we can imagine a block of birds searching for food. This swarm flocks to search the food anyway in a specializedregion. All the birds are supposed to be searching for a single piece of food. At any time during search, each bird has a environment andmomentum. Birds move with familiarity of distance to food but not its exact location. Terrific blue print planned by birds is to follow a bird neighbouring to food. PSO generates use of above mentioned scheme to solve optimization problems. In PSO each bird is well asparticle which is a possible solution in search space. Number of all particles in a search space represents size of swarm (or population). Each particle has a position in search space, velocity and fitness value. Fitness value for a particle is obtained by objective (fitness) function evaluation. Following are the steps of PSO procedure._

- Starts with decision of swarm/population size which is problem specific i.e. it depends on complexity of problem.
- Particles are then initialized randomly for their positions andvalocities. In an N dimensional optimization problem, the position

$$X_t = [x_{in}, X_{i2}, , , , , , , , , X_{iN}] (22)$$

of an i_{th} particle is an array of 1 _ N. i.e.,

$$v_t = [v_{in}, v_{i2}, , , , , , , , , v_{iN}] (23)$$

- Fitness for each particle is obtained by evaluating the objective function given as:

$$f_t = f[X_{in}, X_{i2}, , , , , , , , , X_{iN}] \quad (24)$$

- Two best positions pbest and gbest. are selected for next iteration.
  pbest is personal best position obtained by a particles.
  gbest is global best position among all pbest. Incase of first iteration, pbest is same as randomly initialized position of a particle while in case of next iterations, it is the position of a particle having best fitness value up to that defenite iteration.
- Velocity of each particle is updated using following equation.

$$V_i^{k+1} = \omega^k v_i^k + c_1 r_1 \left(pbest_i^k - X_i^k\right) + c_2 r_2 \left(gbest^k - X_i^K\right) \quad (25)$$

WhereV$_{kii}$svelocity of i$_{th}$ particle at iteration k. x$_k$ is a parameter known as inertia weight at iteration k. C1 and C2 are acceleration coefficients. r$_1$ and r$_2$ are random numbers between (0, 1). pbestkiis best position of i$_{th}$ particle at iteration k. X$_{kiis}$ position of i$_{th}$particle at iteration k. gbestk is global best position at iteration kand Vkþ1i is updated velocity at iteration k + 1. V$_{ki}$which is the velocity of i$_{th}$ particle at k$_{th}$ iteration should bewithin range of its minimum and maximum values, i.e.,

$$v_{min} \le v_i^k \le V_{max} \quad (26)$$

Inertia weight, x$_k$, at each iteration is modified using following equation.

$$\omega^k = \omega_{max} - \frac{\omega_{max} - \omega_{min}}{iter_{max}} \times k \qquad (27)$$

Whereω_{max} is maximum value of inertia weight. $\omega_{min}$is minimum value of inertia weight. Iter$_{max}$ is maximum number of iterations.

- After having value of updated velocity, position of each particle

is updated using following equation.

$$X_i^{K+1} = X_i^k + v_i^{k+1} \qquad (28)$$

- Fitness is evaluated for updated position of each particle; *pbest*and *gbest* are procedure for next iteration.
- The process is repeated until a convergence criterion is satisfied.

All the above specified steps for PSO agenda are depicted in the flow chart given in Fig. 1.

(a.2) Binary PSO (BPSO)

Binary version of PSO is used to better the complication having binary decision variables i.e. having values either 0 or 1. The steps of BPSO procedure are same as that of real valued PSO except following

Differences: As the variables in BPSO are binary, therefore particles are initialized anyway for their binary positions.

$$X_i = [x_{in}, X_{i2}, , , , , , , , , X_{iN}]\ \forall x_{in}, X_{i2}, , , , , , , , , X_{iN}\ \epsilon\{0,1\} \qquad (29)$$

Each aspect of a particle is assigned a binary value with a probability of 0.5 as following:

$$X_{ie} = f(x) = \begin{cases} 1, & if\ rand > 0.5 \\ 0, & otherwise \end{cases} (30)$$

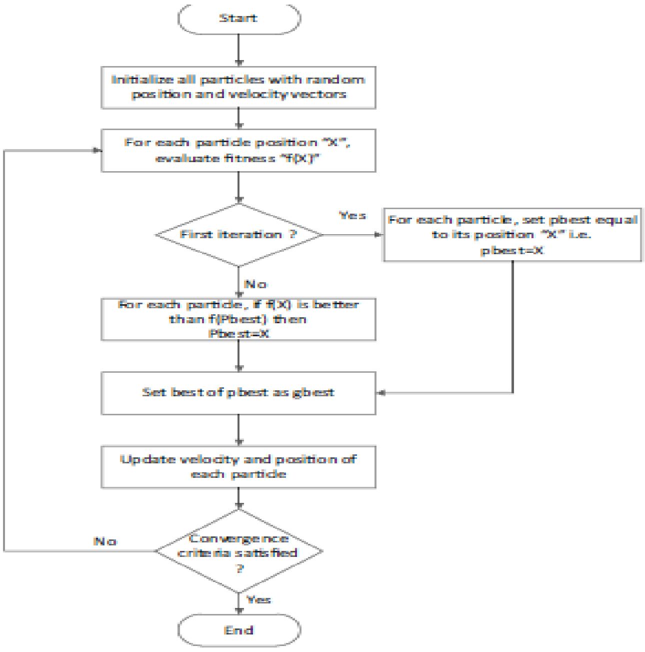

Fig. 1. Flow chart of PSO algorithm.

- Position is updated as following:

$$X_{id}^{k+1} = f(x) = \begin{cases} 1, & if\ rand < sigmoid(v_{ik}^{k+1}) \\ 0, & otherwise \end{cases} (31)$$

The elliptical function in above equation, used to scale velocitiesbetween 0 and1, is calculated as:

$$\text{Sigmoid } (v_{id}^{k+1}) = \frac{i}{1+e^{-v_{id}^{k+1}}} (32)$$

(a.3) PSO for MIOP applied to CEED with solar power

Following are the steps to optimize the SCEED problem (Eqs.(12)–(15)) by means of PSO.

- _Control parameters are selected.
- Initialization of position and velocity for each particle. Each particle contains continuous as well as binary variables.

$$X_i = P_{in}, P_{i2}, ,,,,,,,,, P_{in,} u_{sn}, u_{s2}, ,,,,,,,, us_{in,} (33)$$

Wherein and Usi_D are the power of d_{th} thermal unit and D_{th}solar plant in i_{th}particle. EachP_{id} is initialized randomly using following equation:

$$P_{ld} = LB + rand \times (UB - LB) (34)$$

LB and UB represent lower bound and upper bound of thermal unitsrespectively. Each Us_{iD} is initialized randomly using Eq. (30).Where D = 1, 2. . . m

- Velocity for each particle is initialized between 0 and 1. Fitness for each particle in Eq. (12)is evaluated and pbest and gbest areselected.
- _Velocity is updated using Eq. (25)while positions are updated usingEqs. (28) and(31)for thermal and solar generators respectively.

- Fitness in Eq. (12)is evaluated for each updated position, pbestand gbest are obtained for next iteration. The process is repeated until the convergence criterion is satisfied.

III TEST SYSTEM

In this section the proposed model has been implemented ontwo test systems in order to investigate both SCEED and DCEED.

(a)Test system-I

The test system-I add 6 thermal units and 13 solar plantsand is supposed to be operated in Islamabad region of Pakistan. The data for thermal units has been taken from [36] and ispresented in Tables 1 and 2.Table 1 present's fuel cost coefficients as well as minimum andmaximum power limits whereas Table 2 contains emission.

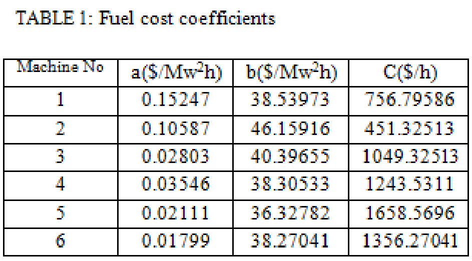

TABLE 1: Fuel cost coefficients

Machine No	a($/Mw^{2}h)	b($/Mw^{2}h)	C($/h)
1	0.15247	38.53973	756.79586
2	0.10587	46.15916	451.32513
3	0.02803	40.39655	1049.32513
4	0.03546	38.30533	1243.5311
5	0.02111	36.32782	1658.5696
6	0.01799	38.27041	1356.27041

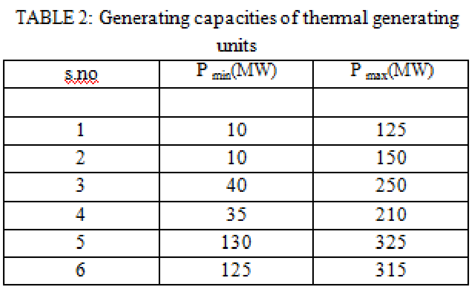

TABLE 2: Generating capacities of thermal generating units

s.no	P $_{min}$(MW)	P $_{max}$(MW)
1	10	125
2	10	150
3	40	250
4	35	210
5	130	325
6	125	315

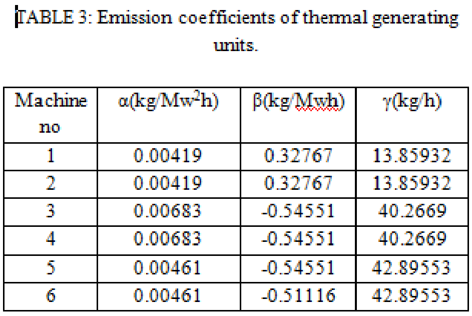

TABLE 3: Emission coefficients of thermal generating units.

Machine no	α(kg/Mw^{2}h)	β(kg/Mwh)	γ(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	-0.54551	42.89553
6	0.00461	-0.51116	42.89553

Coefficients for the preferred machines. The data for solar plants hasbeen presented in Tables 3 and 4.

Table 3 presents power appraisal and per unit costs of different solar plants, approximated to be within the range provided in[37]. Table 4 encompasses global solar radiation as well as temperature and load profiles of Islamabad for the 17th day of July 2012.In this paper, global solar radiation data has been generated using Geospatial Toolkit, data related to power demand of Islamabad region has been taken from IESCO [34] and temperature profile has been taken from [38]. The 17th day of July has been selected arbitrarily from the only available demand data of July, 2012.

(b)Test system-II

The test system-II is also comprised of 6 thermal units and 13solar plants. The data used for solar plants is the same as given in test system-I whereas the data for thermal units and load demand has been taken from [38] and are presented in Tables 5and 6 respectively.

V MATLAB RESULTS

This section shows the results for proposed PSO based MIOPmodel. The above mentioned method was implemented inMATLAB R2013a. The proposed model has been implemented on two cases as follows. Case I: In case I, the proposed model has been implemented on test system-I to investigate the problem of Seedcase II: In case II, the proposed model has been implemented ontest system-II to investigate the problem of DCEED.Control settings used for

PSO were: C1, C2 = 2; r1, r2 = random numbers between 0 and 1; Maximum number of iterations = 1500; swarm size = 10. Maximum and minimum values of velocity are0.5 ⁄ Pmax and _0.5 ⁄ Pmin respectively. Best results were obtained by setting maximum and minimum values of x to 0.4 and 0.1respectively, as evident from Table 7.The table presents the best values of objective function (Eq.(12)) obtained with various settings of solar plants are considered to be operating for 6 h a day, from10:00 to 16:00 h, as In Pakistan, these hours provide maximum radiation and are free of shadow effects in almost all the seasons. Following are the results and discussions for both cases.

(a) Case I

In this case, the simulations have been carried out for both full and reduced solar radiation; later is the case of cloudy weather. Simulation results of static CEED are depicted in Figs. 2–4 as wellas in Tables 8–13. Graphs in Figs. 2–4 show simulation results in terms of the fitness value (FT) versus iterations. As evident fromFigs. 2–4, the algorithm converges within 1000 iterations.

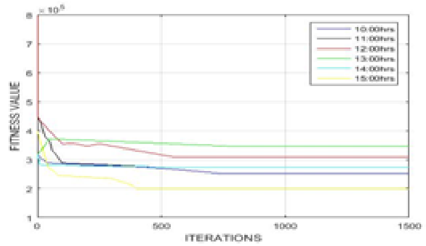

Fig. 2. Simulation results for full solar radiation.

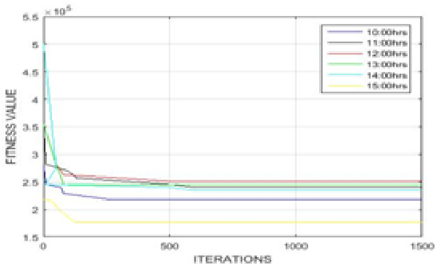

Fig. 3. Simulation results for 15% reduced solar radiation.

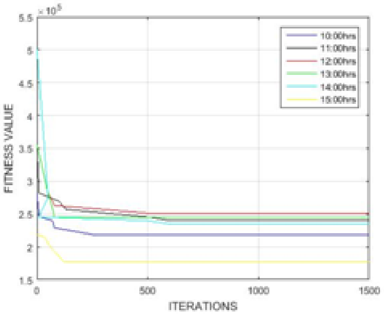

Fig. 4. Simulation results for 30% reduced solar radiation.

Coincide to a maximum of 3.56 s using 1.8 GHz core i5 processor. Generation of thermal units in MW is given in Tables 8–13for the timings 10:00, 11:00,15:00respectively. Us1, Us13correspond to prominence of solar plants which is either ON (represented by 1) or OFF (represented by 0). Power balance pressure encroachment is represented by demand-generation gap. Positive value of demand-generation gap means that generation is greater than demand while the negative value corresponds to generation not coping up with the demand. It can be seen from all tables that the proposed algorithm is well behaved. For instance, in Table 8:

Table 4: Results of CEED with solar power for 1244MW demand at 10:00 h.

Thermal Generations	P1(MW)	120.447
	P2(MW)	92.2947
	P3(MW)	155.806
	P4(MW)	76.4153
	P5(MW)	257.908
	P6(MW)	302.284
Solar Generation	Us1…Us13	1,1,0,1,0,1,0,1,1,1,10,1
Costs	Fuel cost($/h)	1.0+04*5.2626
	Environmental emission (Ton/h)	1.0+04*4.2322
	Total Cost $/h	1.0+04*1.5727

Table 5: Results of CEED with solar power for 1088MW demand at 11:00 h.

Thermal Generations	P1(MW)	10.106
	P2(MW)	10
	P3(MW)	99.1
	P4(MW)	168.682
	P5(MW)	235.878
	P6(MW)	246.780
Solar Generation	Us1…Us13	1,1,0,1,0,1,0,1,1,1,10,1
Costs	Fuel cost($/h)	1.0+04*4.676
	Environmental emission (Ton/h)	1.0+04*3.832
	Total Cost $/h	1.0+04*0.607

Table 6: Results of CEED with solar power for 1240 MW demand at 12:00 h.

Thermal Generations	P1(MW)	10
	P2(MW)	10.219
	P3(MW)	194.931
	P4(MW)	177.401
	P5(MW)	224.868
	P6(MW)	303.564
Solar Generation	Us1…Us13	1,1,0,1,0,1,0,1,1,1,10,1
Costs	Fuel cost($/h)	1.0+04*4.676
	Environmental emission (Ton/h)	1.0+04*3.832
	Total Cost $/h	1.0+04*1.675

Table 7: Results of CEED with solar power for 1135 MW demand at 13:00 h.

Thermal Generations	P1(MW)	10.859
	P2(MW)	118.131
	P3(MW)	147.927
	P4(MW)	186.363
	P5(MW)	150.771
	P6(MW)	221.081
Solar Generation	Us1…Us13	1,1,0,1,0,1,0,1,1,1,10,1
Costs	Fuel cost($/h)	1.0+04*4.413
	Environmental emission (Ton/h)	1.0+04*3.072
	Total Cost $/h	1.0+04*1.531

Table 8: Results of CEED with solar power for 1318 MW demand at 14:00 h.

Thermal Generations	P1(MW)	65.283
	P2(MW)	97.289
	P3(MW)	250
	P4(MW)	107.640
	P5(MW)	252.794
	P6(MW)	297.757
Solar Generation	Us1…Us13	1,1,0,1,0,1,0,1,1,1,10,1
Costs	Fuel cost($/h)	1.0+04*5.508
	Environmental emission (Ton/h)	1.0+04*4.701
	Total Cost $/h	1.0+04*1.667

Table 9: Results of CEED with solar power for 1074 MW demand at 15:00 h.

Thermal Generations	P1(MW)	82.760
	P2(MW)	60.696
	P3(MW)	249.257
	P4(MW)	96.2554
	P5(MW)	182.725
	P6(MW)	190.648
Solar Generation	Us1…Us13	1,1,0,1,0,1,0,1,1,1,10,1
Costs	Fuel cost($/h)	1.0+04*4.505
	Environmental emission (Ton/h)	1.0+04*3.243
	Total Cost $/h	1.0+04*1.328

Units P1–P6 are well within constraint limits. It can be noted from Tables8–13that the solar power percentage is well within the upper bound. The optimized cost values are consistent with the various shares of thermal and solar power generation. The innovation increases or decreases the solar share based on accessible solar radiation and temperature at any time as obvious from **Fig. 5**.

The solar share is increased or decreased by turning ON or OFF the applicable solar units. For instance, the number of solar units that are OFF in both Tables 8 and 10 is 4. Turning OFF the solar unit number 1, 3, 8 and 11 at time 10:00 h, as clear from Table 8, results in the solar share of 238.825 MW. On the other hand, Table 10 depict that turning OFF the solar unit number 3, 7, 8 and 12 at time 12:00 h version for the solar share of 319.1076 MW. As the solar share is increased, thermal share gets reduced for a given load demand. Therefore by increasing the solar share, the solar cost is increased whereas fuel cost, emission cost and emissions get reduced; which is evident from Tables 8 and 10 where the load demands are approximately equal, i.e. 1244MW and 1240MWrespectively. In Table 8, the solar cost is 1.0e + 04 ⁄ 6.2322 $/h and the fuel cost, emission cost and emissions are 1.0e + 04 ⁄5.2626 $/h, 1.0e + 04 ⁄ 4.2322 $/h and 1.0e + 03 ⁄ 0.8808 kg/respectively, with solar share of 238.825MW whereas in Table 10,the solar cost is increased to 1.0e + 04 ⁄ 8.2436 $/h while the fuel cost, emission cost and emissions are shortened to 1.0e + 04 ⁄ 4.6762 $/h, 1.0e + 04 ⁄ 3.8326 $/h and 1.0e + 03 ⁄0.8607 kg/h respectively, for increased solar share of 319.1076 MW. The consequence of solar share on total cost is much greater as compared to thermal share because of higher per unit costs of solar generating units. Therefore, the total cost is higher in Table 10 as compared to that in Table 8. This effect can also be seen in Fig. 2, where the fitness value increases from time 10 to12 as the solar share is increased. Complementary relations can be found by analyzing the results in Tables 9 and 13where the load demands are 1088MW and 1074MW respectively. The value of Ks has been experimentally set to 1.0e + 03 which results in maximum solar share of 319.1076MW which is 25.73%of load demand, a value near to the solar share upper bound. By decreasing the value of Ks, the consequence of difference in accessible solar power and the solar share in Eq. (12)gets reduced and vice versa; the resulting solar past varies respectively. Display Fig.5shows the solar share for various levels of solar radiation. The solar radiation often gets reduced due to clouds, depending on various parameters like thickness, height, amount, etc. of clouds. As we have taken into account the global solar radiation which is less afflicted by clouds as difference to beam radiation, therefore Tests have been carried out for estimated reductions of 15% and30%in solar radiation. It is evident from Fig.5that the solar share gets reduced for reduced solar radiation, in an normal manner.

5.2. Case IITable14presents the results of DCEED problem which is identical to SCEED save an additional further constraint of ramp rate limits and the problem have been enlarge over the time horizon of 1 day. Fascinate the results in Table 14 satisfy all the constraints discussed in Section2.2. The achieve operates from hour 1 to hour 10 and from hour 15 to hour 24 with only thermal generation and therefore is dealt with as an everyday DCEED problem. The solar power contributes from hour 10 to hour 15 as in case of SCEED. The solar share varies in a manner similar to that of SCEED. The results at hour12 can be compared with that of hour 14 due to proportionate load demands of 1235MW and 1251MW respectively. The larger solar share of 335.063MW results in less fuel cost, emission cost and emissions while higher solar cost and total cost at hour 12 as compared to the respective quantities at hour 14, where solar share is239.192 MW, for the same logic discussed earlier in the case of SCEED. When solar generation is admitted to or removed from the system, the load ramp seen by the alternative plants gets increased. The greater the amount of solar share included or removed the considerable the load ramp seen by thermal which may cause failure of operation due to ramp rate limits of thermal units.

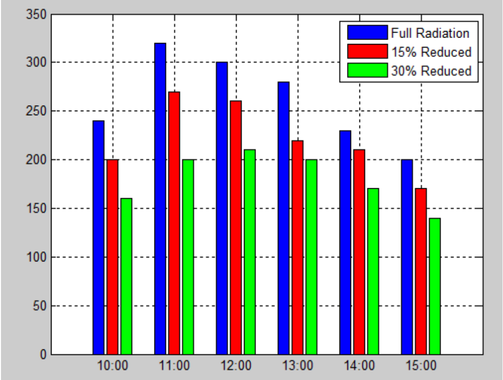

Fig. 5. Solar shares at different solar radiation levels.

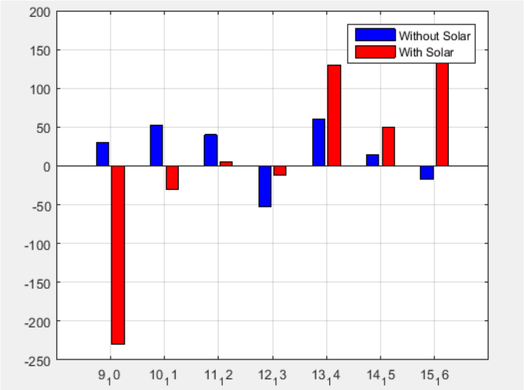

Fig.6.Load ramp seen by thermal units at different hours.

VI. CONCLUSIONS

We have conferred a new dispatch model to solve CEED problem for a system accombidate conventional thermal and solar PV plants. Two case studies with six thermal units and thirteen solar plants, occupies PSO as an optimization tool, have been checked. SCEED problem has been investigated for full and reduced solar radiation and DCEED problem is solved for full radiation only with constraints of thermal generator limits, power balance and renewable energy limits. However, the ramp rate limits have been treated as an further constraint in the case of DCEED. The largest solar shares of 319.1076MW (25.73% of 1240 MW) and335.063MW (27.13% of 1235 MW) have been recorded at12:00 h in case of SCEED and DCEED, respectively. It confirms that higher solar radiations devote larger solar shares in both the cases. Larger solar share for a given load demand results in higher solar cost and total cost as well as lower fuel cost, emission cost and emissions. The dispatch during 12:00 h resulted in highest operation cost of 167,520 $/h because of highest share of solar power. In case of DCEED, although the load ramp seen by thermal units were increased at the points of addition and elimination of solar generation, the algorithm assemble successfully and solved DCEED without tamper with any constraint. The simulation results demonstrate satisfactory operation of the proposed model. For the wellbeing of purity, in this work, power losses have been to avoid as well as thermal units with simple convex characteristics have been preferred. The future planned work is aimed at investigating the CEED problem containing thermal units with non-convex characteristics, taking losses into account and utilization of proposed model on large power systems. New constraints description and assimilation in the dispatch problem is also under consideration.

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