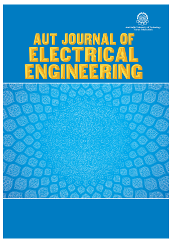

AUT Journal of Electrical Engineering

AUT J. Elec. Eng., 49(1)(2017)63-74
DOI: 10.22060/eej.2016.813

Solving Multiple Fuels Dynamic Environmental/Economic Dispatch Problem and Incentive Based Demand Response Considering Spinning Reserve Requirements

F. Mohammadi, H. Abdi*, E. Dehnavi

Department of Electrical Engineering, Engineering Faculty, Razi University, Kermanshah, Iran.

ABSTRACT: In this paper, a new integrated model of the dynamic environmental/economic dispatch (DEED) problem and emergency demand response program (EDRP) has been presented by which their interactions are investigated. DEED schedules the online generators power output over the whole dispatch period subject to some practical constraints so that the fuel costs and emission are reduced simultaneously. EDRP is one of the incentive-based demand response programs in which incentives are paid to the customers to reduce their consumption during peak hours or shift it to the off-peak or valley hours. The proposed integrated model is a multi-objective optimization problem which aims to minimize both the fuel costs and emission and determines the optimal incentive of EDRP under some practical constraints of units such as valve-point loading effect, multiple fuels, prohibited operating zones, and spinning reserve requirements. The proposed model has been applied on a ten generation units test system. The results indicate the effectiveness of the integrated model in reducing fuel costs and emission, improving load curve characteristics, spinning reserve, and consequently the network reliability.

Review History:

Received: 16 March 2016
Revised: 4 October 2016
Accepted: 25 October 2016
Available Online: 30 October 2016

Keywords:

Dynamic environmental/economic dispatch
Demand response
Optimal incentive
Multiple fuels
Spinning reserve requirements

1- Introduction

Dynamic economic dispatch (DED) problem schedules the power output of all generators during the whole dispatch period so that the total fuel cost is minimized while satisfying various system constraints [1]. The traditional DED strategies are designed in such a way that the fuel cost is minimized neglecting emission constraints. The emission of gaseous pollutants from fossil fuels fired thermal plants affects human health directly or indirectly [2]. DEED is an approach in which the emission dispatch is incorporated into the DED problem. In other words, DEED is a multi-objective optimization problem which minimizes both the fuel cost and emission simultaneously under ramp rate constraints and the other ones [3]. In recent years, the computational intelligence methods have had a good performance in solving economic load dispatch problems. In this regard, many types of research have been carried out to solve the DED problem [4-6]. But, a few papers have been written to solve the DEED problem. Some methods such as hybrid method which combines differential evolution and sequential quadratic programming (DE-SQP), particle swarm optimization and sequential quadratic programming (PSO-SQP) [2], modified adaptive multi-objective differential evolution (MAMODE) [7], opposition-based harmony search algorithm (OHS) [8], multi-objective self-adaptive learning bat algorithm (SALBA) [9], hybrid bacterial foraging with nelder–mead algorithm (called BF–NM algorithm) [10], ε- multi-objective genetic algorithm variable (εv-MOGA) [11]. [2], [7], and [8] use different algorithms to reduce the economic and environmental operating costs of the power units. T. Niknam et al. in [9] have added three types of spinning reserve requirements (SRRs) to the DEED problem. In [10, 11], besides the usual constraints of the DEED problem, new methods to consider the SRRs, frequency constraint, and maximum pollution are presented as well.

The DEED problem mainly focuses on the optimal output power at the supply side without considering issues on the demand side. On the other hand, demand response programs (DRPs) can change the energy consumption patterns of consumers, improve market efficiency, and reduce price volatilities [12]. In fact, DR focuses on modifying the consumption pattern at the demand side. Due to the natures of DR and DEED problem which focus on the demand side and supply side respectively, for a more comprehensive investigation, integrating these two problems i.e. DEED and DR seems very useful. DR prevents undesirable effects of failures that usually impose financial costs and inconveniences to the customers. Hence, quantifying the impact of DRPs on the reliability improvement of the new power systems is an important challenge for the independent system operators (ISO) and the regional transmission organizations. DRPs are divided into two main categories, namely price-based and incentive-based programs. This paper focuses on the EDRP which is a price-based program. One of the main concerns in the incentive-based DRPs is determining the optimal incentive. If the incentive is not determined through a reasonable and economical approach, it may impose high additional costs on the manufacturers or create a new peak after the program ends.

Modeling DRPs based on the customers' benefit function and price elasticity matrix (PEM) is one of the most common and powerful methods in this field [22, 23, 29].

There are few papers which consider the DEED problem and DR simultaneously. Yonghong Chen and Juan Li compared three formulations of the security constrained economic

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Corresponding author; Email: hamdiabdi@razi.ac.ir

dispatch (SCED) to facilitate the participation of DRRs in the Midwest ISOs energy and the ancillary service market. They mainly focused on the interruptible loads [13]. Ahsan Ashfaq et al. presented a combined model of the economic dispatch problem integrating with demand side response [14]. In their model, at the peak hours, the price signal is set by the generation company one hour ahead and sent to the residential area. They have neglected some constraints such as the POZs, SRRs, and Ramp Rate limits in the economic dispatch problem and like the previous mentioned work the emission objective of the generating units has not been taken into account. Also, in their model, just peak hours have been considered and it has not been applied to the whole day. Nnamdi I. Nwulu and Xiaohua Xia investigated the game theory based DR integrating with the economic and environmental dispatch [15]. Some practical constraints such as valve-point loading effect (VPE), prohibited operating zones (POZs), and SRRs have not been taken into account in their model. In their DR model, by paying incentives to the customers, at all hours of the operation (even at off-peak hours) the demand is decreased which may not be always realistic, practical, and economical. Also, this may not be based on the ISO point of view. In other words, customers who participate in DRPs can decrease or shift their demand during peak hours to off-peak hours. Actually, they have neglected the shift-able loads. Hamdi Abdi etal. proposed an approach which investigates the DED and DR problems under some constraint such as VPE, POZs, SRRs [16]. Ref. [16] mainly focuses on cost minimizing and load forecasting by considering different nonlinear models of demand response economic models and tries to select the best one in the load forecasting. The main drawback of [16] is that the impacts of generating unit emissions are not considered in their proposed model. However, the optimal scheduling of power generation units only based on fuel costs may increase the generation of some units which results in increasing emission that has undesirable effects on the environment. Recently, many countries around the world have focused on the optimal scheduling of generation units based on pollution-reducing due to the fuel consumption in power plants in addition to the fuel costs reduction [17]. It is because of the fact that the thermal fossil fuels power plants release a significant amount of harmful pollutants such as oxides of carbon, sulfur, and nitrogen which not only affect human, animals and plant health but also contribute to the global warming. Thus, the production cost optimization should not be the only objective, the emission reduction must also be considered. Moreover, none of the above-mentioned papers consider multi-fuel sources (MFs) in their integrated combined economic dispatch and DR models. However, many generating units especially those which are supplied with the multi-fuel sources (coal, nature gas, or oil), have the problem of determining the most economic fuel to burn. In this paper, the optimal power production based on minimization of both fuel costs and emissions under some practical constraints such as MFs, VPE, POZs, and SRRs is considered. It should be noted that none of the above-mentioned papers consider all above-listed constraints simultaneously. However, it helps in comprehensively reviewing the system.

The main contributions of this paper are (i) Integration of the DEED problem with EDRP program (DEED-EDRP) to schedule the online generators power output and determine the optimal incentive. (ii) Consideration of some practical constraints such as the MFS, VPE, POZs and SRRs, simultaneously. (iii) Investigating the effectiveness of the proposed model in improving the load curve's characteristics and SRRs.

By imposing the real practical constraints of the system, the proposed combined model i.e. DEED-EDRP becomes a complicated non-linear optimization problem with non-smooth and non-convex cost function. The traditional methods because of getting caught in local optimum points do not work effectively for this complicated problem. On the other hand, the population-based metaheuristic algorithms (PBMHAs), by exhaustive search in the solution space work properly in finding the global solution [1-11, 16, 18]. Hence, to illustrate the application of the proposed combined model, it has been solved by five PBMHAs by applying the model on the ten units test system in three different case studies.

The rest of this paper is organized as follows. In section two, the formulation of the DEED problem is presented. Modeling of EDRP is developed in section three. In section four, the combination of DEED and EDRP is presented. The proposed model is applied to the ten units test system in section five. Finlay, in section six the conclusion is drawn.

2- Deed Problem Formulation

Objectives functions of the DEED problem are as follows.

2- 1- Fuel cost minimization

Usually, the fuel cost of the generating units is approximated by a quadratic function. In practical conditions of the power system operation, thermal generating units can be supplied with MF sources and their boilers also have valve points for controlling their power outputs. Many of the thermal generating units are supplied with MF sources such as coal, natural gas, and oil. Therefore, their fuel cost functions may be segmented as piecewise quadratic cost functions for different fuel types [19]. Also, the DEED with VPE is a non-smooth and non-convex problem with multiple minima considering ripples in the heat-rate curves of boilers [20]. The model of VPE has been proposed in [21] by adding a sinusoidal function to the quadratic fuel cost function. Therefore, the total fuel cost during the tth time interval is given by Eq. (1).

$$\mathrm{Fc(t)} = \sum_{i=1}^{Ng} \begin{cases} f_{c1}\left(P_{i,t}\right), fuel1, & P_i^{min} \le P_{i,t} \le P_{i1} \\ f_{c2}\left(P_{i,t}\right), fuel2, & P_{i1} \le P_{i,t} \le P_{i2} \\ \dots & \\ f_{cl}\left(P_{i,t}\right), fuel\, l, & P_{il-1} \le P_{i,t} \le P_i^{max} \end{cases} \tag{1}$$

Where, the cost function of the ith unit with the fuel type j is as follows.

$$\begin{aligned} f_{cj}\left(P_i\right) = [&a_{ij} + b_{ij} P_i + c_{ij}\left(P_i\right)^2 + \\ &\left| d_{ij}\ sin\left(e_{ij}\left(P_i^{min} - P_i\right)\right)\right|] \end{aligned} \tag{2}$$

Where, a_{ij}, b_{ij}, c_{ij}, e_{ij} ,and d_{ij} are the fuel cost curve coefficients of the *ith* unit, e_{ij} and d_{ij} reflecting valve-point effects; *l* represents the number of fuel type for each unit. *T* is the number of hours in the time horizon; Ng is the total number of the committed generating units; $P_{i,t}$ is the generating output power of the ith unit during the *tth* time interval; P_i^{min} and P_i^{max} are the minimum and maximum capacities of the *ith* generating unit, respectively.

2- 2- Emission minimization

Among the various pollutants of the fossil fuel power plants, the greatest effect is relevant to *SOx*, and *NOx* gases [2,7,8]. Therefore, in this paper the minimization of *SOx*, and *NOx* is taken into account. Generally, the impact of these polluting emissions is modeled by the sum of an exponential and a quadratic functions [22]. The equation of the total emission during the *tth* time interval with respect to the MF sources is expressed as Eq. (3).

$$\mathrm{Em(t)}=\sum_{i=1}^{Ng}\begin{cases} e_{m1}\left(P_{i,t}\right), fuel1,\; P_i^{min}\le P_{i,t}\le P_{i1} \\ e_{m2}\left(P_{i,t}\right), fuel2,\; P_{i1}\le P_{i,t}\le P_{i2} \\ \dots \\ e_{ml}\left(P_{i,t}\right), fuel\,l,\; P_{il-1}\le P_{i,t}\le P_i^{max} \end{cases} \tag{3}$$

Where, the emission function of the ith unit with the fuel type *j* is as follows.

$$e_{mj}(P_i)=\left[\alpha_{ij}+\beta_{ij}P_i+\gamma_{ij}\left(P_i\right)^2+\eta_{ij}\,exp\left(\delta_{ij}P_i\right)\right] \tag{4}$$

Where, α_{ij}, β_{ij}, γ_{ij}, η_{ij} and δ_{ij} generator emission curve coefficients.

3- Emergency Demand Response Program (Edrp)

The customer's behavior modeling based on customers' benefit function and PEM is one of the most feasible and powerful methods in this field. Also, to obtain the optimal consumption at the demand side, the elasticity is defined as the sensitivity of the demand with respect to the price as Eq.

$$E\left(t,t'\right)=\frac{\rho_0(t')}{d_0(t)}\frac{\partial d\left(t\right)}{\partial\rho\left(t'\right)}\begin{cases}E\left(t,t'\right)\le 0 & if\; t=t' \\ E\left(t,t'\right)\ge 0 & if\; t\ne t'\end{cases} \tag{5}$$

(5) [23, 24].

Where; E is the elasticity; $d_0(t)$ and d(t) are the customer's demand in the period t before and after responding to the DR program; ρ(t`) is the elasticity price during period t`; ρ_0(t`) is the initial amount of the electricity price at the period t`.

Actually, loads are divided into two main categories. (I): Some loads cannot be transferred to the other periods (such as lighting systems). These loads just can be on or off. Load's elasticity in this state is called self-elasticity and always gets a negative value. (II): Some loads, unlike the first group can be transferred from peak periods to the off-peak periods. Load's elasticity in this state is called cross-elasticity and always gets a positive value.

For 24 hours in a day, self and cross elasticity values can be given as a 24×24 matrix as Eq. (6).

$$\begin{bmatrix}\frac{\Delta d\left(1\right)}{d_0\left(1\right)}\\ \frac{\Delta d\left(2\right)}{d_0\left(2\right)}\\ \frac{\Delta d\left(3\right)}{d_0\left(3\right)}\\ \dots \\ \frac{\Delta d\left(24\right)}{d_0\left(24\right)}\end{bmatrix}=\begin{bmatrix}E\left(1,1\right) & \cdots & E\left(1,24\right)\\ \vdots & \ddots & \vdots \\ E\left(24,1\right) & \cdots & E\left(24,24\right)\end{bmatrix}\times\begin{bmatrix}\frac{\Delta\rho\left(1\right)}{\rho_0\left(1\right)}\\ \frac{\Delta\rho\left(2\right)}{\rho_0\left(2\right)}\\ \frac{\Delta\rho\left(3\right)}{\rho_0\left(3\right)}\\ \dots \\ \frac{\Delta\rho\left(24\right)}{\rho_0\left(24\right)}\end{bmatrix} \tag{6}$$

Incentive based demand response programs create a motivation for customers to reduce their consumption. Total payment given to the customers is as Eq. (7).

$$\mathrm{INC}(\Delta \mathrm{d(t)})=\mathrm{inc(t)}\times[\Delta \mathrm{d(t)}] \tag{7}$$

Where, inc (t) is the amount of incentive to reduce consumption per MW.h and Δd(t) is the amount of the reduced load. Some programs impose a penalty for the customers who promise to participate in the DRP, but they do not (Eq. (8)).

$$PEN\left(\Delta d\left(t\right)\right)=pen\left(t\right)\times\left\{IC\left(t\right)-\left[\Delta d\left(t\right)\right]\right\} \tag{8}$$

Where IC(t) is the amount of demand for which the customer is responsible to reduce or shift. The net-profit of the customer is as follows.

$$\begin{gathered}\mathrm{NP(t)}=\mathrm{B(d(t))}-\mathrm{d(t)}\rho\mathrm{(t)}\\ +\mathrm{INC}(\Delta\mathrm{d(t)})-\mathrm{PEN}(\Delta\mathrm{d(t)})\end{gathered} \tag{9}$$

Where B is the profit which customers obtain by consuming power. To obtain maximum customer benefit, the derivative of Eq. (9) should be zero.

$$\frac{\partial NP}{\partial d\left(\mathrm{t}\right)}=\frac{\partial B\left(d\left(t\right)\right)}{\partial d\left(t\right)}-\rho\left(t\right)+\frac{\partial INC}{\partial d\left(t\right)}-\frac{\partial PEN}{\partial d\left(t\right)}=0 \tag{10}$$

$$\frac{\partial B\left(\mathrm{d(t)}\right)}{\partial d\left(t\right)}=\rho\left(t\right)+inc\left(t\right)+pen\left(t\right) \tag{11}$$

Taylor series expansion of B is as follows.

$$\begin{gathered}\mathrm{B(d(t))}=B\left(d_0\left(t\right)\right)+\frac{\partial B\left(d_0\left(t\right)\right)}{\partial d\left(t\right)}\left[d\left(t\right)-d_0\left(t\right)\right]+\\ \frac{1}{2}\frac{\partial^2 B\left(d_0\left(t\right)\right)}{\partial d^2\left(t\right)}\left[d\left(t\right)-d_0\left(t\right)\right]^2\end{gathered} \tag{12}$$

To obtain the optimal consumption by which the customers get maximum profit, from Eq. (12):

$$\begin{gathered}\mathrm{B(d(t))}=\mathrm{B(d_0(t))}+\rho_0\mathrm{(t)[d(t)}-\mathrm{d_0(t)]}+\\ \frac{1}{2}\frac{\rho_0\mathrm{(t)}}{\mathrm{E(t,t)d_0(t)}}\mathrm{[d(t)}-\mathrm{d_0(t)]}^2\end{gathered} \tag{13}$$

Differentiating:

$$\frac{\partial\mathrm{B(d(t))}}{\partial\mathrm{d(t)}}=\rho_0\mathrm{(t)}(1+\frac{\mathrm{d(t)}-\mathrm{d_0(t)}}{\mathrm{E(t,t)d_0(t)}}) \tag{14}$$

By combining Eqs. (11) and (14), for the single-period model of the load:

$$\mathrm{d(t)}=\mathrm{d_0(t)}\times(1+\frac{\rho\mathrm{(t)}-\rho_0\mathrm{(t)}+\mathrm{inc(t)}+\mathrm{pen(t)}}{\rho_0\mathrm{(t)}}\mathrm{E(t,t)}) \tag{15}$$

For the multi-period model of the load:

$$\begin{gathered}\mathrm{d(t)}=\mathrm{d_0(t)}\times\{1+\sum_{\substack{t'=1\\ t'\ne 1}}^{24}\mathrm{E(t,t')}\times\\ \frac{[\rho\mathrm{(t')}-\rho_0\mathrm{(t')}+\mathrm{inc(t')}-\mathrm{pen(t')}]}{\rho_0\mathrm{(t')}}\}\end{gathered} \tag{16}$$

The combined model, including the single and multi- period models of the load is as Eq. (17).

$$\begin{gathered}\mathrm{d(t)}=\mathrm{d_0(t)}\times\{1+\frac{\rho\mathrm{(t)}-\rho_0\mathrm{(t)}+\mathrm{inc(t)}-\mathrm{pen(t)}}{\rho_0\mathrm{(t)}}\mathrm{E(t,t)}\\ +\sum_{\substack{t'=1\\ t'\ne 1}}^{24}\mathrm{E(t,t')}\times\frac{[\rho\mathrm{(t')}-\rho_0\mathrm{(t')}+\mathrm{inc(t')}-\mathrm{pen(t')}]}{\rho_0\mathrm{(t')}}\}\end{gathered} \tag{17}$$

4- The Combined Model Of Deed Integrated With The Edrp

DEED-EDRP is a multi-objective optimization problem with the objective of minimizing cost and emission and determining the optimal incentive simultaneously. The additional cost which should be added to the total cost of the DEED problem is as Eq. (18).

$$C_{EDRP}(t) = \left(d_0(t) - d(t)\right) inc(t) \tag{18}$$

The final objective function considering the cost and emission of the generating unit and the cost of implementing EDRP is the minimization of the Eq. (19).

$$\begin{aligned} \mathrm{TOF}(t) = {} & \mathrm{W}_{\mathrm{FC}} \times \mathrm{FC}(t) + \mathrm{W}_{\mathrm{FC}} \times \mathrm{C}_{\mathrm{EDRP}}(t) \\ & + \mathrm{W}_{\mathrm{EC}} \times \mathrm{Em}'(t) \end{aligned} \tag{19}$$

Where, $W_{FC}+W_{EC}=1$ and Em\`(t) is determined as follows:

$$\mathrm{Em}'(t) = \sum_{i=1}^{N_g} \mathrm{ppf}(i) \times \mathrm{Em}(t) \tag{20}$$

Where, ppf is the price penalty factor of the ith generating unit with the fuel type j and it is determined as follows:

$$\begin{aligned} ppf(i) &= \frac{Fc\left(P_i^{max}\right)}{Em\left(P_i^{max}\right)} = \\ & \frac{a_{ij} + b_{ij} P_i^{max} + c_{ij}\left(P_i^{max}\right)^2 + \left|d_{ij}\sin\left(e_{ij}\left(P_i^{min} - P_i^{max}\right)\right)\right|}{\alpha_{ij} + \beta_{ij} P_i^{max} + \gamma_{ij}\left(P_i^{max}\right)^2 + \eta_{ij}\exp\left(\delta_{ij} P_i^{max}\right)} \end{aligned} \tag{21}$$

Considering some linear and non-linear constraints such as the real power generation limits, POZs, ramp-rate limits, and SRRs, makes the DEED-EDRP problem more complicated which is difficult to be solved. Most of the traditional optimization methods cannot successfully solve the mentioned problem because they are very sensitive to the initial estimate, thus they may just converge to a locally optimal solution. Hence, in this paper, some PBMHAs have been used to solve the DEED-EDRP problem. These methods have a higher capability of solving the multi-objective non-linear problems than the traditional methods. These methods are the particle swarm optimization (PSO) [25], harmony search (HS) algorithms [26], artificial bee colony (ABC) [27], cuckoo search algorithm (CS) [20], gravitational search algorithm (GSA) [28], random drift particle swarm optimization (RDPSO) [29] and firefly algorithm (FA) [30].

4- 1- Constraints

In the proposed DEED-EDRP optimization problem, some equality and inequality constraints should be met which are described as follows.

4- 1- 1- Power balance equality constraint

$$\sum_{i=1}^{N_g} (\mathrm{P}_{i,t}) - \mathrm{P}_{D,t} - \mathrm{P}_{\mathrm{Loss},t} = 0,\ \ t = 1,\ldots,T \tag{22}$$

Where $P_{D,t}$ and $P_{Loss,t}$ are the load demand and the power loss of transmission line at the tth time interval. Generally, $P_{Loss,t}$ is calculated by Kron's loss formula which can be expressed as follows.

$$\mathrm{P}_{\mathrm{Loss},t} = \sum_{i=1}^{N_g} \sum_{j=1}^{N_g} \mathrm{P}_{i,t} \mathrm{B}_{i,j} \mathrm{P}_{j,t} \tag{23}$$

Where $B_{i,j}$ is the power loss coefficient of the transmission network.

4- 1- 2- Generation capacity constraints

Under normal system operations; the ith generator output must be a value between P_i^{min} and P_i^{max} as Eq. (24).

$$\mathrm{P}_i^{\min} \le \mathrm{P}_{i,t} \le \mathrm{P}_i^{\max},\ i = 1,\ldots,\mathrm{Ng}, t = 1,\ldots,\mathrm{T} \tag{24}$$

Where P_i^{max} is the maximum capacity of the ith generating unit.

4- 1- 3- Incentive constraint

$$inc(t)^{min} \le inc(t) \le inc(t)^{max} \tag{25}$$

Referring to [31] $inc(t)^{min}$ and $inc(t)^{max}$ are usually considered to be $0.1\times\rho_0(t)$ and $10\times\rho_0(t)$ respectively.

4- 1- 4- Prohibited Operating Zones (POZs)

In practice, generators should not work in some POZs. The main reason for this limitation is the vibration of shaft bearing. Otherwise, some faults may occur. The feasible operating zones of the ith generator are as follows

$$\begin{cases} P_{(i,t)}^{min} \le P_{i,t} \le P_{(i,t),1}^{l} & or \\ P_{(i,t),q-1}^{u} \le P_{i,t} \le P_{(i,t),q}^{l} & or \\ P_{(i,t),n_i}^{u} \le P_{i,t} \le P_{(i,t)}^{max} \end{cases} \\ i = 1,\ldots,\mathrm{Ng}, t = 1,\ldots,\mathrm{T}, q = 2,3,\ldots,n_i \tag{26}$$

Where, for each generating unit, n_i is the number of the POZs.

4- 1- 5- Ramp Rate Limits

The ramp rate constraints for the ith generation unit are as Eq. (27)

$$\begin{aligned} & \mathrm{P}_{i,t-1} - \mathrm{P}_{i,t} \le \mathrm{DR}_i && \text{In the case of decrease in the generation process} \\ & \mathrm{P}_{i,t} - \mathrm{P}_{i,t-1} \le \mathrm{UR}_i && \text{In the case of increase in the generation process} \end{aligned} \tag{27}$$

Where, $P_{i,t-1}$ is the power output of the previous time interval, UR_i and DR_i are the upper and down ramp limits of the ith generating unit (MW/h).

4- 1- 6- Spinning reserve constraint (SRRs)

As the increase rates in the output power of generation units (pickup rates) are different and it usually takes time to reach to their maximum values, spinning reserve should be considered as an additional constraint to make sure that in the case of losing a generating unit, the rest of the units are able to compensate for the lost power in a specific timeframe (for example, 10 min or 60 min). In this paper, SRRs for DEED problem are expressed by Eqs. (28)-(30).

$$Delta1_t = \sum_{i=1}^{Ng} P_i^{max} - \left(P_{D,t} + P_{Loss,t} + SRR_t\right) \ge 0 \\ t = 1,\ldots,T \tag{28}$$

$$\mathrm{Delta2}_t = \sum_{i=1}^{Ng} (\min(\mathrm{P}_i^{\max} - \mathrm{P}_{i,t}, \mathrm{UR}_i)) - \mathrm{SRR}_t \ge 0 \\ t = 1,\ldots,T \tag{29}$$

$$\mathrm{Delta3}_t = \sum_{i=1}^{Ng} (\min(\mathrm{P}_i^{\max} - \mathrm{P}_{i,t}, \frac{\mathrm{UR}_i}{6})) - \mathrm{SRR}'_t \ge 0 \\ t = 1,\ldots,T \tag{30}$$

Constraints (28) and (29) are generally applied in DED problems within 60 min. of being required. Using (30) will exactly satisfy the SRRs in each time within 10 min. of being required and its amount is related to the ramp up rate of the generating unit. For time interval t to t+1 the ramp up rate of the ith unit is UR_i (MW/h), the corresponding amount for 10 min. is $UR_i/6$ [5, 9].

4- 2- Solving the DEED-EDRP problem

In this section, a general procedure to solve the DEED-EDRP problem by PBMHAs is presented. Actually, in PBMHAs the population includes some possible solutions of the optimization problem. In different types of PBMHAs, the possible solutions have different names. For example, in GSA they are called masses (agents), in ICA colonies, in PSO particles, etc. To facilitating the description, in this section every possible solution is called a candidate. In DEED-EDRP, every scheduled generating units output at each hour comprises a component of the population. In other words, it is a candidate for DEED-EDRP optimization problem at each hour. If N_g is the number of operating units that provide power to loads, then the kth candidate i.e. PG_k at each hour is defined as Eq. (31).

$$PG_k = \left[pg_{k,1}, pg_{k,2}, ..., pg_{k,j}, ..., pg_{k,N_g} \right] \quad (31)$$

$$\mathrm{k} = 1, 2, ..., \mathrm{PS}$$

Where, PG_k is the current position of the kth vector, N_g is the number of generation units, PS is the population size, j is the generator number and $pg_{k,j}$ the power output of the jth generation unit for the kth candidate.

Constraint (22) can be handled by using a penalty term in Eq. (19). Therefore, the evaluation function used in DEED-EDRP can be written as Eq. (32).

$$EVF(t) = TOF(t) + K_n.abs\left(\sum_{i=1}^{Ng} P_{i,t} - P_{D,t} - P_{Loss,t}\right) \quad (32)$$

Where K_n is a positive real number as the penalty factor [8]. As the algorithm iterations increases, the amount of K_n at each hour increases as well. K_n can be written as Eq. (33) where N_{iter} is the maximum number of iterations at each hour.

$$K_n = 500 \times \sqrt{\mathrm{n}} \quad \mathrm{n} = 1, 2, ..., \mathrm{N}_{\mathrm{iter}} \quad (33)$$

4- 3- Solution method and constraint handling

To solve proposed DEED-EDRP model and meet the other practical constraints, the overall process is as follows. The computational methodology of solution method is given in Figs. 1 and 2. It should be noted that in this paper, the Gravitational Search Algorithm (GSA) is used to solve the proposed model. However, the solution method is similar and extensible for the other optimization algorithm.

Step 1: Defining the initial data such as the characteristics of generation units, initial load curve, initial electricity price, PEM, initial incentive, determining the dispatch interval (T=24 hours), determining of the optimization iteration, and the population size which both are set to be 100 for all algorithms in this paper.

Step 2: Increasing the amount of incentive by ISO. In this paper, the step of changing incentive is considered to be 0.25 \$/MWh (inc=inc+0.25).

Step 3: Setting the number of the hour to zero (t=0).

Step 4: t=t+1.

Step 5: Determining the hourly demand in 24 hours by (17).

Step 6: Determining the initial population of optimization algorithm (some possible solutions of DEEDEDRP) as following:

1.k=1, k is the number of candidates.
2.Based on previous explanation, the kth candidate (the output of generation units for the kth component of the population) is generated randomly in the permissible ranges for each unit described in (24).
3.Calculating the transmission line losses for the kth candidate based on (23).
4.For the kth candidate, the following constraints are evaluated.

(i): The power output of each generating units should not be in POZs (See (26)).

(ii): The ramp rate limits are evaluated so that increase and decrease rates of each generating units from the previous hour are in acceptable ranges defined by (27). If the initial power outputs of generating units are not given, it is supposed that initial power outputs of all generating units are in acceptable ranges and there is no need to consider this constraint at the first hour.

(iii): The power outputs of generating units meet SRRs based on (28)-(30).

5.If all above constraints are met, add one unit to k (k=k+1).
6.If the amount of k is smaller or equal to the selected population size (PS), return to number 2 in this step.

Step 7: Execution of the main loop of the selected optimization algorithm.

It should be noted that the main difference between the evolutionary algorithms is the way of population's convergence to the optimal solution. In this paper, GSA has been used in which every population member (candidate) is a mass (agent). After generating the initial masses based on steps 1-6, all these masses attract each other by the gravity force, and this force causes a global movement of all masses towards the objects with heavier masses (corresponding to the best solutions). In other words, each mass presents a solution, and the algorithm is navigated by properly adjusting the gravitational and inertial masses. Finally, it is expected that masses be attracted by the heaviest mass. This mass will present an optimum solution in the search space. For more information about the masses' movement, calculation of their acceleration, velocity, and updating masses' position refer to [28].

To meet the constraints of DEED-EDRP, the main loop of GSA algorithm is as follows.

1. iteration=1
2. k=1 (k is the number of mass in the population)
3. Calculation of transmission line losses for the kth mass as (23).
4. Calculating the cost of implementing EDRP as (18).
5. Calculating the evaluation function for the kth mass by (32).
6. Updating the gravitational constant and best and worst evaluation functions of the kth mass.
7. Calculation of the acceleration and velocity of the kth mass and updating the velocity and position of the kth mass.
8. Evaluation of following constraints for the kth mass.

(i): the output power of each generating unit should not be POZs (See (26)), otherwise, it is modified toward the near margin of the feasible solution.

(ii): Similar to Step 6, Number 4, Constraint 2; but if violated, then it should be modified toward the near margin of the feasible solution.

(iii): The power outputs of generation units meet SRRs described in (28) to (30).

9. If all the above constraints are met, plus one unit to k (k=k+1).

10. If the amount of k is smaller or equal to the selected population size (PS), return to 3 in this step.
11. Determining the best mass (best agent or possible solution) in the masses group.
12. Plus one unit to the iteration (iteration=iteration+1).
13. If the number of iterations has not been finished return to number 2 in this step. Otherwise, save the best mass as the solution of the problem in the tth hour.

Step 8: If the tth hour is not equal to T (t≠T), go to step 4. Otherwise, save the final solution (optimal generation power outputs over the whole dispatch period i.e. 24 hours) for the related incentive.

Step 9: If the amount of incentive has not reached its maximum value (See (25)), return to step 2. Otherwise, select the incentive related to the best solution as the optimal incentive and save the related parameters to this incentive as the optimal outputs and consequently solution of the DEED-EDRP problem.

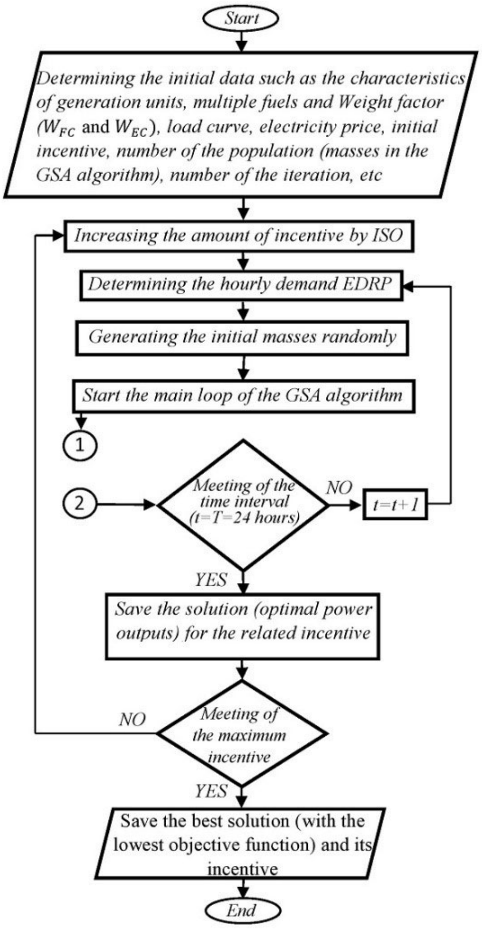

Fig. 1. Flow chart for DEED-EDRP solution method

5- Simulation Results And Discussion

5- 1- Test system

To show the effectiveness and practical benefits of the proposed model, it is applied to the ten units test system. In this section, the characteristics of the ten units system are described (Tables 1 and 2).

To consider the SRRs, the 60 and 10 min SRRs (SRR_t, and SRR`$_t$) have been set to 10% and $\left(\frac{10}{60}\right)\times 10\%$ of the load demand as shown in Eqs. (27)-(29). Also, the daily load demand is shown in Table 3. Moreover, the transmission line coefficients are as Eq. (34).

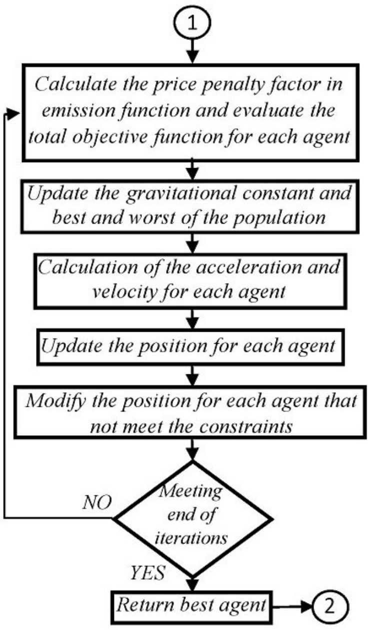

Fig. 2. Flow chart for DEED-EDRP solution method

The daily load curve is divided into the peak period (10.00 A.M-14.00 P.M. and 20.00-24.00 P.M.), off-peak period (6.00-9.00 A.M. and 15.00-19.00 P.M.), and valley period (00.00 – 5.00 A.M.) period. DR implementation potential is considered 20%. It means that 20 percent of the total load participates in the DR.

The daily load curve is divided into the peak period (10.00 A.M-14.00 P.M. and 20.00-24.00 P.M.), off-peak period (6.00-9.00 A.M. and 15.00-19.00 P.M.), and valley period (00.00 – 5.00 A.M.) period. DR implementation potential is considered 20%. It means that 20 percent of the total load participates in the DR. The price elasticity is considered to be 20, 25, and 30 \$/MWh at valley period, off-peak period, and peak period, respectively. PEM is shown in Table 4 and is taken from [32].

$$B=\begin{bmatrix} 49 & 14 & 15 & 15 & 16 & 17 & 17 & 18 & 19 & 20 \\ 14 & 45 & 16 & 16 & 17 & 15 & 15 & 16 & 18 & 18 \\ 15 & 16 & 39 & 10 & 12 & 12 & 14 & 14 & 16 & 16 \\ 15 & 16 & 10 & 40 & 14 & 10 & 11 & 12 & 14 & 15 \\ 16 & 17 & 12 & 14 & 35 & 11 & 13 & 13 & 15 & 16 \\ 17 & 15 & 12 & 10 & 11 & 36 & 12 & 12 & 14 & 15 \\ 17 & 15 & 14 & 11 & 13 & 12 & 38 & 16 & 16 & 18 \\ 18 & 16 & 14 & 12 & 13 & 12 & 16 & 40 & 15 & 16 \\ 19 & 18 & 16 & 14 & 15 & 14 & 16 & 15 & 42 & 19 \\ 20 & 18 & 16 & 15 & 16 & 15 & 18 & 16 & 19 & 44 \end{bmatrix}\times 10^{-6} \quad (34)$$

5- 2- Simulation

In this section, the cost based, emission based, and cost-emission based DEED integrated with EDRP through three different case studies are investigated. The impacts of different values of incentive and elasticity are investigated in each case study. Three different groups with different values of PEM are taken into account (three different customers' consumption patterns have been taken into account). In the first case study, ten scenarios have been defined with different PEMs and

Table 1. Characteristics Of The Ten-Unit System

Unit	Generation							Fuel type	Cost coefficients					Emission coefficients				
	min		P_1		P_2		max		a_i (\$/h)	b_i (\$/MWh)	c_i (\$/MW^{2}h)	d_i (\$/h)	e_i (rad/MW)	α_i (lb/h)	β_i (lb/MWh)	γ_i (lb/MW^{2}h)	η_i (lb/h)	δ_i (1/MW)
		F_1		F_2		F_3												
1	150		250		370		480	1	958.20	21.60	0.00043	38	0.205	360.00	-3.9864	0.0470	0.4535	0.00204
		3		1		2		2	1000.30	23.24	0.00084	40	0.221	630.24	-5.5165	0.0958	0.7321	0.00480
								3	600.40	18.26	0.00015	24	0.173	440.05	-4.3254	0.0662	0.5532	0.00323
2	135		235		350		470	1	1313.60	21.05	0.00063	52	0.200	350.00	-3.9524	0.0865	0.4374	0.00204
		2		3		1		2	970.53	17.26	0.00031	38	0.164	534.50	-6.0187	0.1150	0.6753	0.00551
								3	1500.20	27.75	0.00253	60	0.264	210.54	-1.0246	0.0324	0.5489	0.00401
3	73		185		265		350	1	604.97	20.81	0.00039	24	0.198	330.00	-3.9023	0.0465	0.4468	0.00201
		3		1		2		2	700.20	22.53	0.00098	28	0.214	110.54	-0.7406	0.0247	0.7838	0.00416
								3	200.36	16.23	0.00013	8	0.154	623.49	-6.2605	0.0953	0.5757	0.00364
4	60		140		230		325	1	471.60	23.90	0.00070	18	0.227	330.00	-3.9023	0.0465	0.4468	0.00201
		1		2		3		2	680.40	28.36	0.00211	27	0.270	110.54	-0.7406	0.0247	0.7838	0.00416
								3	550.12	25.78	0.00153	22	0.245	623.49	-6.2605	0.0953	0.5757	0.00364
5	73		140		190		253	1	480.29	21.62	0.00079	19	0.205	13.85	0.3277	0.0042	0.0507	0.00022
		1		3		2		2	450.43	19.70	0.00038	18	0.187	25.35	0.8613	0.0065	0.0932	0.00051
								3	660.56	27.84	0.00103	26	0.265	8.64	-0.206	0.0024	0.0765	0.00036
6	57		90		130		170	1	601.75	17.87	0.00056	24	0.710	13.85	0.3277	0.0042	0.0507	0.00022
		2		1		3		2	370.25	15.06	0.00022	14	0.143	25.35	0.8613	0.0065	0.0932	0.00051
								3	224.64	14.03	0.00009	8	0.133	8.64	-0.0206	0.0024	0.0765	0.00036
7	20		60		95		130	1	502.70	16.51	0.00138	20	0.157	40.26	-0.5455	0.0068	0.0515	0.00025
		3		1		2		2	480.90	14.74	0.00079	19	0.140	10.83	-0.1256	0.0031	0.0796	0.00042
								3	680.21	18.63	0.00204	27	0.177	60.05	-0.8652	0.0078	0.0655	0.00033
8	47			80			120	1	639.40	23.23	0.00480	25	0.221	52.34	-0.6524	0.0094	0.0515	0.00025
		1			2			2	660.20	24.92	0.00513	26	0.237	10.83	-0.1256	0.0055	0.0326	0.00019
9	20			45			80	1	455.60	19.58	0.00908	18	0.186	42.89	-0.5112	0.0046	0.0524	0.00028
		1			2			2	665.10	27.27	0.00222	26	0.259	84.05	-1.0024	0.0070	0.0768	0.00039
10	10			33			55	1	692.40	22.54	0.00951	27	0.264	42.89	-0.5112	0.0046	0.0524	0.00028
		1			2			2	670.30	27.79	0.00173	26	0.214	84.05	-1.0024	0.0070	0.0808	0.00041

incentives. Scenario 1 is the base case without implementing EDRP, scenarios 2-4 (group one with a PEM equals to E as Table 4) have incentives 5, 10, and 15 \$/MWh, scenarios 5-7 (group two with PEM equals to 0.5×E) have incentives 5, 10, and 15 \$/MWh, scenarios 8-10 (group three with PEM equals to 2×E) have incentives 5, 10, and 15 \$/MWh, respectively. In the second case study, the results have been obtained for the optimal incentive at each group. It should be noted that GSA has been used in the previous cases for solving DEED-EDRP. However, as the proposed model is a new one and has not been investigated yet, there is no similar work to compare the results; therefore, to validate results and show the correctness of the proposed model, cost-emission based DEED integrated with EDRP for the optimal incentive value of group one in case two has been solved with different optimization algorithms in the third case study.

To evaluate the impacts of implementing EDRP on the improvement of the load curve characteristics, some factors are defined as Eqs. (35)-(37). The load factor is defined as Eq. (35) to evaluate the smoothness of the load curve. Ideally, it is 100% which means that at all hours of the operation the amount of demand is constant and does not change with the time.

$$\mathrm{Load-factor\%} = 100 \times \left(\frac{\sum_{t=1}^{T} d(t)}{T \times d^{max}(t)}\right) \tag{35}$$

Peak-to-valley, peak-compensate, and.. are the other important factors which are defined as Eqs. (36), (37).

$$Peak-to-valley\% = 100 \times \left(\frac{d^{max}(t) - d^{min}(t)}{d^{max}(t)}\right) \tag{36}$$

$$Peak-compensate\% = 100 \times \left(\frac{d_0^{max}(t) - d^{max}(t)}{d_0^{max}(t)}\right) \tag{37}$$

5- 2- 1- Case Study 1: Cost-Based DEED integrating with optimal EDRP

In this case, the impacts of implementing EDRP on the overall cost of the generation units are evaluated. Thus, W_{FC} and W_{EC} are considered to be 1 and 0, respectively. Results are shown in Table 5. In all scenarios, after implementation EDRP, the total cost decreases. Implanting EDRP imposes an additional cost (C_{EDRP}) which is paid as the incentive to the customers. However, the total cost which is the sum of the cost of the generating units and the total incentive, decreases. Scenario 8 has the most reduction of the total cost by 28896.9660 $ and scenario 5 has the least one by 5776.9494 $. On the other hand, the customer's benefit in each group increases with the incentive value and PEM and decreases with the generation cost of units. For example scenario 10 has the most total incentive (59775 $) and scenario 5 has the least one (1660.4167 $).

Table 2. Characteristics Of The Ten-Unit System

Units	P_{max} (MW)	P_{min} (MW)	UR_i (MW/h)	DR_i (MW/h)	Prohibited zones (MW)
1	480	150	100	100	—
2	470	135	100	100	[165–205] [295–315] [435–445]
3	350	73	90	90	—
4	325	60	90	90	[80–120] [170–210] [255–285]
5	253	73	60	60	—
6	170	57	60	60	[65–105] [120–155]
7	130	20	50	50	[30–55] [70–85] [90–115]
8	120	47	50	50	—
9	80	20	40	40	[25–40] [55–70]
10	55	10	40	40	—

Table 3. The Initial Daily Load Demand

Hour	1	2	3	4	5	6
Load(MW)	1600	1500	1600	1650	1750	1800
Hour	7	8	9	10	11	12
Load(MW)	1850	1875	1900	2000	2050	2100
Hour	13	14	15	16	17	18
Load(MW)	2075	2025	1900	1850	1800	1850
Hour	19	20	21	22	23	24
Load(MW)	1900	2025	2000	1950	1900	1800

Table 4. Price Elasticity Matrix

	Valley	Off-peak	Peak	Period
Valley	-0.1	0.01	0.012	[1–5]
Off-peak	0.01	-0.1	0.016	[6–9],[15–19]
Peak	0.012	0.016	-0.1	[10–14],[20–24]

The optimal incentives for three different groups are determined as shown in Table 6. Also, total losses decrease in all scenarios. All characteristics of the load curve, including the load factor, peak to valley, and peak compensate are improved for three groups as shown in Table 6.

The load curves for three different groups (for their optimal incentives), before and after implementing EDRP are shown in Fig. 3. Customers with the highest PEM have more willingness to reduce or shift their consumption during peak hours (group three of the customers) and vice versa (group two of the customers). Actually, by implementing the EDRP, the load curve smoothens which consequently improves the network reliability.

Table 5. Comparison Of Total Cost For Different Scenarios In Case 1

Scenario Number	Cost of Generating Units($)	Total Incentive ($)	Total Cost ($)
1	1136951.3930	—	1136951.3930
2	1115003.5071	3320.8333	1118324.3404
3	1101567.2865	13283.3333	1114850.6198
4	1087761.3406	29887.5000	1117648.8406
5	1129514.0269	1660.4167	1131174.4436
6	1123503.3878	6641.6667	1130145.0545
7	1116085.1256	14943.7500	1131028.8756
8	1101412.7603	6641.6667	1108054.4270
9	1082063.9787	26566.6667	1108630.6454
10	1049853.0365	59775.0000	1109628.0365

Table 6. Comparison Of Optimum Value, Total Cost, And Load Curve For All Groups In Case1

Group Name	Optimal Incentive ($/MWh)	Cost of Generating Units ($)	Total Incentive ($)	Total Cost ($)
Base case	—	1136951.3930	—	1136951.3930
one	9.25	1101844.1839	11365.5521	1113209.7360
two	12.50	1117643.4802	10377.6042	1128021.0843
three	7.75	1089069.4718	15956.6042	1105026.0760
Group Name	Load Factor %	Peak Compensate%	Peak to Valley %	Total power losses(MW)
Base case	88.79	—	28.57	1711.8526
one	92.50	6.16	23.31	1617.6848
two	91.24	4.16	25.09	1661.5843
three	92.91	8.02	21.37	1588.2599

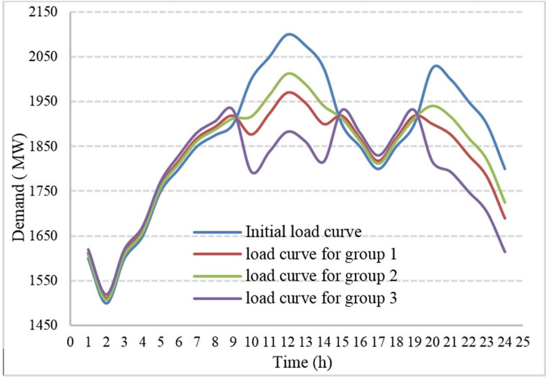

Fig. 3. The load curve before and after implementing EDRP for three different groups

5- 2- 2- Case Study 2: Cost-emission based DEED integrating with optimal EDRP

In this case, the cost-emission based DEED integrated with EDRP is investigated. Depending on the system operator, different weights can be assigned. Thus, it is assumed that

Table 7. Comparison Of Total Cost And Emission For Different Scenarios In Case 2

Group Name	Optimal Incentive ($/MWh)	Cost of Generating Units($)	Total emission (Ib)	Total Incentive ($)	Load Factor %	Peak Compensate%	Peak to Valley %	Total power losses (MW)	Objective function
Base case	—	1144361.9893	729529.8494	—	88.79	—	28.57	1706.1343	1058386.1688
one	13.25	1109737.6120	601020.0518	23320.5521	93.66	8.24	21.32	1575.6313	1019159.7008
two	19.5	1111992.7781	697025.8369	25254.9375	92.72	6.50	23.01	1620.2128	1031219.3385
three	11.75	1080961.2466	586869.3086	36678.6042	90.28	7.25	22.06	1511.4442	1001007.1830

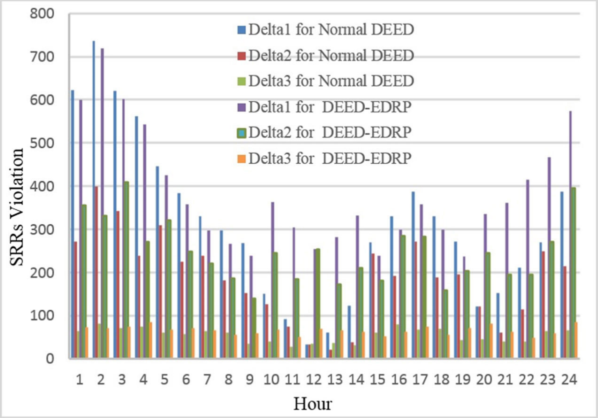

Fig. 4. Satisfying the SRRs for the 10-unit test system in case 2

there is a trade-off between the cost and the emission. In other words, W_{FC} and W_{EC} are both considered to be 0.5. Results are shown in Table 7. From Table 7, it can be observed that in all groups the reduction of pollution is significant compared to the base case (without implementing the DEED-EDRP model). On the other hand, in all groups the cost of generating units (fuel costs) has been reduced compared to the base case. Therefore, it can be seen that the proposed DEED-EDRP model has a good performance on reducing the fuel costs and pollution.

The most objective function reduction is for group three of customers. It is because of the fact that they have largest PEM which means that they have most willingness to reduce their consumption during the peak period or shift it to the valley or off-peak periods.

To compare DEED with DEED-EDRP in meeting three SRRs constraints described in Eqs. (28)-(30), the amounts of Delta1_t, Delta2_t, and Delta3_t for DEED and group 1 (Table 7) are given in Fig. 4. As it is clear from Fig. 4, all three constraints are bigger than zero. Also, after implementing EDRP, these amounts are improved and get bigger values at the peak hours. The optimal generators power output for group 1 of customers has been shown in appendix

5- 2- 3- Case study 3: Cost-emission based DEED integrating with optimal EDRP considering different optimization methods

This case is similar to the previous one. The proposed DEED-EDRP model with different constraints is a new model. The other references with the similar test system (mainly due to the multiple fuels) are not available for comparison. But, to validate results, ensure the performance of optimization algorithms in solving the proposed model, and also inform the efficiency to reduce fuel costs and emission, the DEED-EDRP problem was answered by six different optimization algorithms. As GSA was used to solve the problem in the previous cases, in this case, results have been obtained by the six optimization algorithms, namely CS, RDPSO, PSO, HS, ABC, and FA.

For more information about applied algorithms in optimization problems, refer to [20], [29], [25], [26], [27], and [30], respectively. Results are shown in Table 8. It should be noted that according to Table 7 for all algorithms the optimal incentive of the first group is calculated as 13.25 $/MWh. Table 8 validates results and shows that the used method i.e. GSA has better results than the other ones and also for all optimization problems the objective function is reduced after implementing EDRP.

Table 8. Total Cost And Emission Obtained By Different Optimization Algorithms In Case 3

Method	Cost of Generating Units($)	Emission (lb)	Objective Function
GSA	1109737.6120	601020.0518	1019159.7008
FA	1105793.6857	609919.7602	1019358.3200
RDPSO	1102746.0716	665524.2134	1019540.6962
CS	1107388.0255	659762.4954	1019801.4438
ABC	1098192.0059	686844.9027	1019901.4207
PSO	1111964.6548	624367.2954	1020485.9052
HS	1108878.2720	654761.1015	1022492.6781
Base case	1144361.9893	729529.8494	1058386.1688

6- Conclusion

In this paper, the dynamic environmental/economic dispatch (DEED) problem was integrated with the emergency demand response program (EDRP) to minimize the fuel cost and emission and determine the optimal incentive concurrently. Some practical constraints such as the valve-point effects, multiple fuels sources, POZs, and SSRs have been taken into account in the proposed model. The proposed model is actually a new way which connects the demand and supply sides leading desired results at each side. The proposed model results in reducing cost and emission, determining the optimal incentive and increasing customers' benefit. Improving load curve characteristics, network reliability, and SRRs are the other important benefits of intelligent integration of DEED and EDRP. The EDRP has been developed based on the customers' benefit function and price elasticity matrix (PEM) which is one of the powerful methods in the responsive load modeling in DRPs. To show the practical benefits of the proposed model, it was applied on the ten units test system and evaluated through three different case studies. The effects of changing PEM and incentive were investigated and it was shown that not carefully determining the optimal incentive may impose high additional cost on the supply side. In the last case study, the problem was solved with some meta-heuristic algorithms such as GSA, RDPSO, FA, CS, ABC, PSO, and HS as well. In the future work, some constraints in DEED such as the minimum-maximum voltage limitation of the load buses, maximum emission limit, and line flow constraints will be,too, taken into account.

Appendix. Best Dispatch Found By Deed-Edrp For Group 1 In Case 2

Hour	1		2		3		4		5		6	
Load(MW)	1616.9600		1515.9000		1616.9600		1667.4900		1768.5500		1825.4400	
Unit	Fuel Type	Power Gen	Fuel Type	Power Gen	Fuel Type	Power Gen	Fuel Type	Power Gen	Fuel Type	Power Gen	Fuel Type	Power Gen
P_1(MW)	1	353.2992	1	253.2992	1	338.4434	1	276.0243	2	376.0243	1	276.0243
P_2(MW)	1	354.7335	1	352.5655	1	354.0301	1	435.0000	1	358.4189	1	458.4189
P_3(MW)	1	264.9655	3	182.4205	1	213.6572	3	146.5217	1	236.5217	1	254.4020
P_4(MW)	1	80.0000	1	73.8391	2	163.8391	3	253.8391	2	170.0000	3	251.8012
P_5(MW)	2	247.0546	2	246.7576	3	186.7576	1	138.8659	2	198.8659	2	239.8289
P_6(MW)	2	62.2684	1	105.0000	3	165.0000	3	155.0000	3	170.0000	1	118.6415
P_7(MW)	2	130.0000	2	119.2288	1	69.2288	2	119.2288	2	115.0000	2	128.8213
P_8(MW)	2	91.5541	2	120.0000	1	77.2650	2	92.5614	2	97.7226	1	79.9205
P_9(MW)	1	49.6696	1	55.00000	1	79.1298	1	74.0529	1	79.4410	1	52.9995
P_{10}(MW)	2	37.3560	2	53.7093	1	22.2015	1	32.5161	1	29.2996	1	31.5656
Hour	7		8		9		10		11		12	
Load(MW)	1876.1466		1901.5000		1926.8533		1823.3333		1868.9166		1914.5000	
Unit	Fuel Type	Power Gen	Fuel Type	Power Gen	Fuel Type	Power Gen	Fuel Type	Power Gen	Fuel Type	Power Gen	Fuel Type	Power Gen
P_1(MW)	2	376.0243	2	446.2920	1	362.7396	1	262.7396	1	362.7396	2	393.5953
P_2(MW)	1	408.6110	1	401.2319	1	425.5632	1	373.0219	1	470.0000	1	370.0000
P_3(MW)	2	268.8869	3	178.8869	3	177.4121	2	267.4121	3	181.2829	2	271.2829
P_4(MW)	2	161.8012	3	251.8012	3	285.0000	3	314.8835	3	290.3665	3	251.3373
P_5(MW)	2	218.6086	2	205.5139	2	214.6675	2	233.6934	2	194.5261	2	243.8924
P_6(MW)	3	170.0000	3	170.0000	3	170.0000	3	170.0000	3	168.9453	3	170.0000
P_7(MW)	2	115.0000	2	130.0000	2	124.2797	1	89.8801	3	55.0000	1	90.0000
P_8(MW)	2	106.9494	2	87.8583	2	120.0000	1	76.0926	2	91.3802	2	100.8781
P_9(MW)	1	80.0000	1	49.2412	1	72.3047	1	71.2570	1	78.8993	1	70.4457
P_{10}(MW)	2	41.4010	2	55.0000	2	49.5180	1	29.1503	2	47.8153	1	26.3942
Hour	13		14		15		16		17		18	
Load(MW)	1891.7083		1846.1250		1926.8533		1876.1466		1825.4400		1876.1466	
Unit	Fuel Type	Power Gen	Fuel Type	Power Gen	Fuel Type	Power Gen	Fuel Type	Power Gen	Fuel Type	Power Gen	Fuel Type	Power Gen
P_1(MW)	1	295.0970	1	363.8097	1	341.1576	2	403.1709	1	362.0448	1	309.0672
P_2(MW)	1	374.5747	1	425.4367	1	433.1834	1	355.7050	1	406.3598	1	413.8684
P_3(MW)	2	342.3175	2	348.7146	1	258.7146	2	292.4058	1	226.6497	2	316.6497
P_4(MW)	2	210.0739	1	133.2327	2	217.4255	3	238.3190	3	254.9940	2	164.9940
P_5(MW)	2	244.4993	2	229.0027	2	253.0000	2	196.9669	2	202.9967	2	253.0000
P_6(MW)	3	157.5095	1	120.0000	3	170.0000	3	170.0000	3	160.6516	3	170.0000
P_7(MW)	2	115.8637	2	120.4057	2	130.0000	2	123.6696	2	124.6231	2	122.0517
P_8(MW)	2	96.8070	1	66.5480	2	87.3656	1	71.5759	1	47.0000	1	79.9307
P_9(MW)	1	80.0000	1	54.0878	1	70.0000	2	40.0000	1	54.5081	1	80.0000
P_{10}(MW)	2	45.1720	2	55.0000	2	40.3142	2	55.0000	2	52.8768	2	36.7161
Hour	19		20		21		22		23		24	
Load(MW)	1926.8533		1846.1250		1823.3333		1777.7500		1732.1666		1641.0000	
Unit	Fuel Type	Power Gen	Fuel Type	Power Gen	Fuel Type	Power Gen	Fuel Type	Power Gen	Fuel Type	Power Gen	Fuel Type	Power Gen
P_1(MW)	2	409.0672	1	309.0672	3	217.0303	3	249.2559	1	349.2559	1	303.0138
P_2(MW)	1	450.0987	1	350.0987	1	450.0987	1	350.0987	1	375.1800	1	386.6276
P_3(MW)	1	226.6497	2	316.6497	1	255.2009	2	345.2009	1	255.2009	1	228.2057
P_4(MW)	3	254.9940	3	255.0000	3	255.0000	2	165.0000	1	75.0000	2	165.0000
P_5(MW)	2	193.0000	2	223.2986	2	247.0277	2	225.2157	2	253.0000	2	193.0000
P_6(MW)	3	170.0000	3	157.0936	3	170.0000	3	170.0000	3	166.4071	3	155.0624
P_7(MW)	2	115.0000	2	115.0000	2	128.4106	1	89.9443	2	130.0000	1	85.0000
P_8(MW)	2	85.8512	2	113.0217	2	90.9656	2	119.5731	1	69.5731	2	93.6253
P_9(MW)	1	70.0000	2	40.6819	1	47.0456	1	70.0000	1	70.0000	1	55.0000
P_{10}(MW)	1	28.3383	1	32.6971	1	28.0196	2	54.9419	2	49.4533	1	30.3635

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Please cite this article using:

S. Yousefi, M. M. Hosseini Biyouki, A. Zaboli, H. Askarian Abyaneh, S. H. Hosseinian," Harmonic Elimination of 25 kV AC Electric Railways Utilizing a New Hybrid Filter Structure", *AUT J. Elec. Eng.*, 49(1)(2017)63-74.

DOI: 10.22060/eej.2016.811