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Impact of Demand Response Technique on Hybrid Transmission Expansion Planning and Reactive Power planning

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Abstract- *In this paper, a model for hybrid transmission expansion planning (TEP) and reactive power planning (RPP) considering demand response (DR) model has been presented. In this study RPP considered by TEP for its effects on lines capacity and reduction of system expansion costs. On the other hand the expansion of the transmission system is an important subject, especially dealing with the new issues of smart networks like as demand response. Demand response program can change the network expansion planning by shifting elasticity loads and reducing of peak load to improve conditions and decrease the costs. To combine demand response model into the transmission expansion planning and reactive power planning, nonlinear mixed integer meta-heuristic optimization algorithm is used. To evaluate the impact of the proposed expansion planning, this model is exerted to the 30-bus test system. Simulation outcomes display the proposed technique considering demand response model reduces the overall cost of the hybrid TEP-RPP.*

Keyword: Demand response, Transmission expansion planning, Reactive expansion planning.

1. INTRODUCTION

Due to the macro growth of the power grid, the requirement for new and optimum development plan of the power grid is necessary. In the planning of the transmission system, planners deal where the new line should be installed. But since the construction of the new lines in each area is not possible or take heavy cost planners attempt to reduce as much as possible the number of installed lines [1]. On the other hand, reactive power resources have an important assignment in the power grid. One of the important issues in the field of expansion transmission planning is to control of line capacity. So that the proper placement of reactive power sources can control line capacity. In other words, designers by optimal placement of the reactive power sources attempt to increase line capacity and consequently reduce the number of installed lines. In Ref. [2] TEP in the presence of PEV uncertainties is observed. Other research, proposes a stochastic adaptive robust optimization approach for the generation and transmission expansion planning problem [3]. The model of combination TEP-RPP is considered as minimization of investment costs [4]. Zhang. Et al [5] by using an AC model of the power system and N-1 contingency modeling has proposed an improved network model for TEP-RPP. In Ref. [6] the TEPRPP is solved by focusing on the same objective function of the non-convex refined genetic algorithm (RGA). In other research, the combined planning has been studied in the restructured power system while the reliability index is also considered in addition to investment costs [7]. In recent studies TEP-RPP has been analyzed in the electric market considering wind and load uncertainties by the optimization algorithm [8]. In other researches impact of renewable energies are studied [9, 10]. In Ref. [9] impact of incorreption large-size photovoltaic units in TEP-RPP is considered that in which the network expansion project has been studied based on investment cost, voltage deviation, and stability criterion, depending on solar irradiation and ambient temperature. In Ref. [10] an economic analysis of TEP-RPP including wind farms plus FACTS devises is proposed. In recent studies TEP-RPP discussed as in a security constrained model [11].

In addition to transmission and reactive power planning, load request management is also important in power networks. With the development of smart grid, in demand response is sought to adjust the demand for power instead of adjusting the supply. The meaning of demand response expresses as incentive payments designed to induce lower electricity utilization at times of high wholesale market prices or when system reliability is jeopardized

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[12]. Corresponding to this description of demand response, planners of power system use this technique in the transmission expansion planning to achieve better results. From the recent studies, it has been found that the few researchers have implemented demand response models for the TEP study [13, 14]. In Ref. [13], TEP along with wind power incorporating of the demand response model is presented. A kind of demand response model based on price is proposed on the TEP issue in [14]. In other research, TEP has been combined with demand response and large-scale distant wind plants [15]. Zhang et al [16] has studied the effect of the demand response model on the integrated generation and transmission planning model. In RPP and demand response issue Ryuto Shigenobu [17] study's can be mentioned, which is about usage of demand response in the management of active and reactive power incentive in the smart grid. In another study demand response along with FACTS devices are introduced as performing congestion management in the deregulated environment [18]. Also the interaction of demand response and voltage stability in smart grid is indicated in Ref. [19]. In the recent study a model for two-stage adaptive robust transmission expansion planning (AR-TEP) problem considering the uncertainty of future load demand and future wind power production is presented [3].

In Ref. [20] a framework has been presented to protect the voltage instability under wind and load uncertainty condition. A new risk-constrained bidding method formulation in the presence of demand response programs has been studied in Ref. [21]. In this reference, the effect of demand response technique has been included in the formulation. The proposed method has been maximized the profit margin. TEP individually has been surveyed in reference [22] with presence of demand response method and uncertainties of wind power. Optimal energy management of retailer with demand response method has been investigated in Ref. [23]. In this reference, DR technique has been employed to increase retailer profit.

As expressed, TEP, TEP-RPP, TEP-DR, and RPP-DR are studied before, but in this paper according to importance of power system expansion and smart grid, a hybrid AC model of planning, creating by combination of transmission expansion planning and reactive power planning with the integration of DR model is proposed. In this model first considering reactive power planning, line capacity is increased. In the second step, it has been tried to manage load demand incensement using the customer consumption pattern, and so the cost of TEP will be minimized.

In other words, in the demand response issue power network tries to balance its customer demands at peak times by interacting with its customers, this will provide customers demand with a lower cost charge. This model minimizes the entire system cost that involves the cost of new line investment and optimal reactive power sources and DR costs. The PSO-NTVE algorithm is used to solve this nonlinear and complex optimization issue due to its adoption and fast convergence. So it is applied on the IEEE 30 bus test system.

The main features of this paper include:

1) Reactive power planning is considered in transmission expansion planning because of their inherent dependence. As the RPP increases line capacity and thus reduce the number of new lines.
2) The use of modifying pattern of consumption, which reduces demand at peak time by using demand response technique, and thus load increscent can be controlled despite the less new line investment.

Different parts of this paper are classified in several sections as: Section 2 presents an overview on the PSO-NTVE algorithm. Section 3 formulates a hybrid TEPRPP model considering DR technique. In Section 4 the related flow chart is given. Section 5 for showing the effectiveness of presenting model introduces three scenarios. Section 6 analyses numerical study results. Conclusions are summarized in Section 7.

2. PARTICLE SWARM OPTIMIZATION ALGORITHM

Particle swarm optimization (PSO) is one of the popular heuristic global optimization methods, which is based on swarm intelligence. In PSO algorithm, each particle is defined with two values of $par_{jd}(t)$ and $Vel_{jd}(t)$ which $par_{jd}(t)$ is position of the dth dimension of the jth particle in tth iteration and $Vel_{jd}(t)$ is velocity of the dth dimension of the jth particle in tth iteration. Also, $par\_best(t)$ and $g\_best(t)$ are the local and global best solutions. After finding $par\_best(t)$ and $g\_best(t)$, the particles update their velocity and position as given by (1) and (2):

$$Vel_{jd}(t+1) = we.Vel_{jd}(t) + cof_1.rand_1.(par\_best_{jd}(t) - par_{jd}(t)) + cof_2.rand_2.(g\_best_{jd}(t) - par_{jd}(t)) \quad (1)$$

$$par_{jd}(t+1) = par_{jd}(t) + Vel_{jd}(t+1) \quad (2)$$

where $rand_1$ and $rand_2$ is chosen randomly from the range [0,1], cof_1 and cof_2 called acceleration coefficients. *we as* a control parameter creates balance between the algorithm of the local and global search. In general inertia factor *we* is set as follows:

$$we = we_{\max} - \left(\frac{(we_{\max} - we_{\min})}{iter_{\max}}\right) \times iter \quad (3)$$

In the above equation $iter_{max}$, maximum number of repetitions of the current iteration and we_{max} and we_{min}, respectively, are the minimal and maximal values of inertia coefficient.

2.1. Nonlinear time-varying evolution PSO (PSO-NTVE)

In the improved version of PSO, the inertia factor in the maximum number of repetitions non-linearly decreases from we_{max} to we_{min}. Thus, changes in inertia factor will be corresponding to the bellow Eq. (24):

$$we(k) = we_{\min} + \left(\frac{iter_{\max} - iter}{iter_{\max}}\right)^{\alpha_1} . \left(we_{\max} - we_{\min}\right) \quad (4)$$

cof_1 the parameter of cognitive begins nonlinear from cof_{1max} and reduced to cof_{1min}. Meanwhile, social parameter cof_2 starts to increase non-linearly from the lowest amount cof_{2min} to the maximum amount as cof_{2max}. The related equations presents as below [24]:

$$\begin{aligned} &Vel_{jd}(t+1) = we(t).Vel_{jdi}(t) + cof_1(t).r_1. \\ &\left(par\_best_{jd}(t) - par_{jd}(t)\right) + \\ &cof_2(t).r_2.\left(g\_best_{jd} - par_{jd}(t)\right) \quad for\ j = 1,2,...,m \end{aligned} \quad (5)$$

$$cof_1(t) = cof_{1\min} + \left(\frac{iter_{\max} - iter}{iter_{\max}}\right)^{\beta_1} .(cof_{1\max} - cof_{1\min}) \quad (6)$$

$$cof_2(t) = cof_{2\min} + \left(\frac{iter_{\max} - iter}{iter_{\max}}\right)^{\gamma} (cof_{2\max} - cof_{2\min}) \quad (7)$$

The parameters of $\alpha_1, \beta_1, \gamma$ are fixed.

3. PROBLEM FORMULATION

The aim of the proposed expansion planning is to minimize the total cost considering combined TEP-RPP planning along with demand response. The objective function of the suggested scheme in mathematical form is displayed as follows:

Minimizing total planning cost:

Total planning, cost = investment cost of the new line (C_{tep}) + placement of new reactive power sources cost (C_{rpp}) + demand response model cost (C_{DR}) (8)

The above model is made from a combination of three components which will describe as follows:

The first component C_{tep} is sum of new line investment cost which calculated as follows [25]:

$$C_{tep} = \sum_{i,j \in n_b} c_{ij} l_{ij} \quad (9)$$

c_{ij} represents cost of new line investment and l_{ij} is vector of new lines added to the system.

The second part gives the cost of VAR sources placement that is presented by sum of fixed cost and installed cost of reactive power sources. According [26] this cost obtains as bellow:

$$C_{rpp} = \sum_{k \in \Omega} \left(c_{fk} + c_{vk} \times Q_k\right) b_k \quad (10)$$

c_{fk} is install cost of VAR source that is fixed, and c_{vk} is reactive power source purchase cost in per unit. Q_k is VAR size that is installed at bus k. b_k is 1 if the VAR source is installed at bus j, otherwise, it is zero.

The third part of the main objective function of proposed model consists cost of demand response as C_{DR}.

Many models are introduced for a demand response program, but in this paper a model based on curtailable loads and capacity market that is proposed in [27] is used. According to this model, cost of DR is formulated as:

$$El(j) = \frac{\partial(LD(j))}{\partial(c_n)} = \frac{c}{LD_n(j)} * \frac{d\left(LD(j)\right)}{d\left(c_n\right)} \quad (11)$$

In this model elasticity (El) is defined as the demand sensitivity ($LD(j)$) with respect to the electricity price values (c_n). c is the initial price of electricity and c_n is considered the spot price. LD is the initial load demand and LD_n is the new load demand.

Respect to [27]:

$$C_{DR} = -LD_n(j) \times \left[\frac{(Inc(j))^2 \times El(j)}{c}\right] \quad (12)$$

C_{DR} is persuasive award that ISO pays to the consumers when they are associating in DR programs. $Inc(j)$ shows the incentive price paid to the consumer in jth load period.

$El(j)$ that is called Elasticity shows demand dependence to the electricity price.

The above equation is used for a single period load at which price is fixed. For network by multi period elastic loads discussed before, we have:

$$C_{DR}(j) = -LD_n{}^i(j) \times \left[\frac{(Inc^i(j))^2 \times \sum_{i=1}^{24} El(j,i)}{c_{nn}(i)}\right] \quad (13)$$

3.1. A brief review on price elasticity of demand concept

For different periods with different electricity prices, the demand behaves as one of the followings [28]:

The illuminating loads cannot be transferred between different periods. So they could be to in two states as on or off. Such loads just in a single period have sensitivity, which is called ‘‘self elasticity”, and has a negative value. On the other hand, there are some loads which are called process loads that can be moved from the peak period to the off-peak or low periods. Such loads behave in a manner that is called multi-period sensitivity and it is named as ‘‘cross elasticity” that has a positive value.

Accordingly, the self elasticity, *El(j, j)* and the cross elasticity, *El(j, i)* can be expressed as:

$$\begin{cases} El(j,i) \le 0 & if \quad i = j \\ El(j,i) \ge 0 & if \quad i \ne j \end{cases} \tag{14}$$

In demand response model several load buses based on their impact on power system response are selected.
To implement economic demand model according to load elasticity, incentive and penalty price together with the customer benefit is considered for purposes of optimizing demand response on each candidate load bus. The change in load at the *j*th bus after demand response scheme can be shown as below:

$$\Delta LD(j) = LD_n(j) - LD(j) \tag{15}$$

where, it is the difference between load of *j*th bus without *(LD)* and with demand response model (LD_n), respectively.
As said before, for achieving an economical DR an index as incentive price is considered that is calculated using Eq. (15) which has a fixed value and is set by ISO. The other index is penalty price *(Pen)*. If the consumers are participating in DR program and not obeying the rules, the penalty will be charged and the total penalty P_{Pen} will be calculated by Eq. (16) that is also constant.

$$P_{Inc}(\Delta LD(j)) = Inc(j) \cdot [LD_n(j) - LD(j)] \tag{16}$$

$$P_{Pen}(\Delta LD(j)) = Pen(j)[LD_n(j) - LD(j)] \tag{17}$$

On the other hand, the aim of DR is maximizing customer income involved in the demand response scheme, so:

$$\frac{\partial B(LD(j))}{\partial LD(j)} = c_n(j) + Inc(j) + Pen(j) \tag{18}$$

$c_n(j)$ is the price after the demand response, and *B(LD(j))* is the customer income for using *LD(j)*.
After simplifying the above statements according to Ref. [28], it can be expressed as bellow:

$$\frac{\partial(B(LD(j)))}{\partial LD(j)} = c_{nn}(j) \ * \left\{1 + \frac{LD(j) - LD_n(j)}{El(j)LD_n(j)}\right\} \tag{19}$$

El(j,j) is the self-elasticity of the load and $c_{nn}(j)$ is the market price before demand response.
According to Ref. [28], finally demand response model can be expressed as bellow:

$$c_n(j) + Inc(j) + Pen(j) = c_{nn}(j). \left\{1 + \frac{LD(j) - LD_n(j)}{El(j)LD_n(j)}\right\} \tag{20}$$

And, can be written:

$$LD(j) = LD_n(j)\left\{1 + \frac{El(j,j)Inc(j)}{c_{nn}(j)}\right\} \tag{21}$$

The above equation is used for a single period load at which price is fixed. For network by multi period elastic loads discussed before, we have:

$$LD(j) = LD_n(j) + \sum El(j,i).\frac{LD_n(j)}{c_{nn}(j)}. [c_n(j) - c_{nn}(j)] \qquad j = 1,2,3,...,24 \tag{22}$$

In Eq. (20) a 24*h* interval is considered.
Considering the incentive and the penalty prices on the demand response model we will achieve to the multi-period model as the following equation:

$$LD(j) = LD_n(j).\{1 + \sum_{i=1}^{24} El(j,i). \frac{c_n(i) - c_{nn}(i) + Inc(i) + Pen(i)}{c_{nn}(i)}\} \tag{23}$$

3.2. Economic load response model

Considering Eqs. (21) and (19) together, finally an economic demand load model is achieved as follows:

$$C_{DR}(j) = Inci(j) * (LD_n^i(j) - LD^i(j)) \tag{24}$$

or, we have:

$$C_{DR}(j) = -LD_n{}^i(j) \times [\frac{(Inc^i(j))^2 \times \sum_{i=1}^{24} El(j,i)}{c_{nn}(i)}] \tag{25}$$

3.3. Constraints

To have a successful plan, some constraints should be considered during optimization. Mathematical expression of these constraints is as follows:

Equality constraints:
1) Power balance equations:
AC power flow conventional equations are:

$$P(v,\Theta,n) - P_G + P_D = 0 \tag{26}$$

$$Q(v,\Theta,n) - Q_G + Q_D - q = 0 \tag{27}$$

where
P_G and Q_G: Real and reactive power generation vectors (MW and MVAr)
P_D and Q_D: Real and reactive power demand vectors (MW and MVAr)
v and Θ: Magnitude and angle of voltages vectors (p.u. and radian)
q : Total amount of locally reactive sources (MVAr)

Unequal constraints:
1) Real and reactive power limit in each bus:

$$\underline{P_G} \le P_G \le \overline{P_G} \tag{28}$$

$$\underline{Q_G} \le Q \le \overline{Q_G} \tag{29}$$

where
$\bar{P}_G$ and $\bar{Q}_G$: Maximum limit of real and reactive power

generation limits (p.u.)

$\underline{P}_D$ and $\underline{Q}_D$: Minimum limit of real and reactive power generation limits (p.u.)

2) Voltage limits in each bus:

$$\underline{v} \le v \le \overline{v} \tag{30}$$

where

$\overline{v}$ and $\underline{v}$: Maximum and minimum voltage magnitudes (p.u.)

3) Constraints related to apparent power crossing of the line:

$$\left(N+N_0\right)S^{to} \le \left(N+N_0\right)\overline{S} \tag{31}$$

$$(N+N_0)S^{from} \le (N+N_0)\overline{S} \tag{32}$$

where

S^{from} and S^{to} : Apparent power flow through the branches in both terminals (p.u.)

$\overline{S}$: Apparent power flow limits (MVA)

N : Matrices containing the existing lines

N_0 : Matrices containing the new lines

4) The number of authorized lines can be installed in:

$$0 \le n \le n_0 \tag{33}$$

n is added lines vector

5) Limitation in capacity of reactive power: (34)

$\overline{q}$ and $\underline{q}$ are maximum and minimum amounts of reactive sources (p.u.).

In the equations of AC power flow, power balance in the terms of . $P\left(v,\Theta,n\right)$. and $Q\left(v,\Theta,n\right)$ are expressed as:

$$P_j(v,\Theta,n) = v_j \sum_{i\in n_B} v_i[G_{ji}(n)\cos\Theta_{ji} + B_{ji}(n)\sin\Theta_{ji}] \tag{35}$$

$$Q_j(v,\Theta,n) = v_j \sum_{i\in n_B} v_i[G_{ji}(n)\sin\Theta_{ji} - B_{ji}(n)\cos\Theta_{ji}] \tag{36}$$

where

i, j : Bus indices

n_B : Set of all buses

Respect to:

$$\Theta_{ji} = \Theta_j - \Theta_i \tag{37}$$

$$G = \begin{cases} G_{ji}(n) = -(n_{ji}g_{ji} + n_{ji}^0 g_{ji}^0) \\ G_{jj}\left(n\right) = \sum_{i\in\Omega_l} (n_{ij}g_{ij} + n_{ji}^0 g_{ji}^0) \end{cases} \tag{38}$$

$$B = \begin{cases} B_{ji}(n) = -(n_{ji}b_{ji} + n_{ji}^0 b_{ji}^0) \\ B_{jj}(n) = b_j^{sh} + \sum_{i\in\Omega_l} [n_{ji}(b_{ji} + b_{ji}^{sh}) + n_{ji}^0(b_{ji}^0 + b_{ji}^{sh})] \end{cases} \tag{39}$$

g_{ij} and b_{ij} : Conductance and susceptance of the transmission line or transformer *ij* (p.u.)

b_{ij}^{sh} : Shunt susceptance of the transmission line or transformer *ij* (if *ij* is a transformer $b_{ij}^{sh} = 0$) (p.u.)

b_i^{sh} : Shunt susceptance at bus *i* (p.u.)

And the elements of S_{ji}^{to} and S_{ji}^{from} are the apparent power flow in the line calculated by:

$$S_{ji}^{to} = \sqrt{(P_{ji}^{to})^2 + (Q_{ji}^{to})^2} \tag{40}$$

$$S_{ji}^{from} = \sqrt{(P_{ji}^{from})^2 + (Q_{ji}^{from})^2} \tag{41}$$

4. APPLYING PSO-NTVE ALGORITHM FOR THE TEP-RPP ISSUE

This part explains the steps of the PSO-NTVE optimization problem to solve the presented TEP-RPP issue considering demand response model. The related flow chart is proposed in Fig. 1 that is according to the bellow steps:

Step 1: Get all the grid details like candidate lines and the buses that are candidates for reactive power sources placement and the algorithm control parameters, DR model

Step 2: Generate the random primal population using Eq. (1) corresponding to the test system that is considered.

Step 3: Run AC load flow for calculating cost of optimum planning that is solved by simultaneously checking for the network constraints using (27)–(35) and embed the reactive power sources.

Step 4: Calculate the PSO-NTVE fitness function by using the outcomes of OPF.

Step 5: The best solution of part 4 is saved.

Step 6: When the algorithm received the stopping criteria point, the final solution of PSO-NTVE algorithm is the optimal condition that has a minimum transmission line install cost and entire cost, by satisfying all the constraints otherwise the position of particles are updated and the algorithm begins from 3.

5. IMPLEMENTATION

To evaluate the proposed technique, several scenarios have been considered that is described as below:

Scenario 1: In this section the base case is considered, where there are no reactive power planning and no demand response model is performed. In this scenario just AC transmission expansion planning of the chosen network is studied.

Scenario 2: In this scenario, both transmission extension planning and reactive power schematization are carried out, respectively. In other words, in this scenario both planning schemes of TEP and RPP are considered simultaneously to minimize planning cost.

Scenario 3: In this scenario, demand response model is exerted to the considered problem. This technique offers maximum three kinds of price for the customers that were discussed earlier. The number of buses chosen for the DR program is given in Table 1. At this stage we are trying to minimize entire cost of proposed planning by applying the final model (Eq. (23)) on the chosen test system.

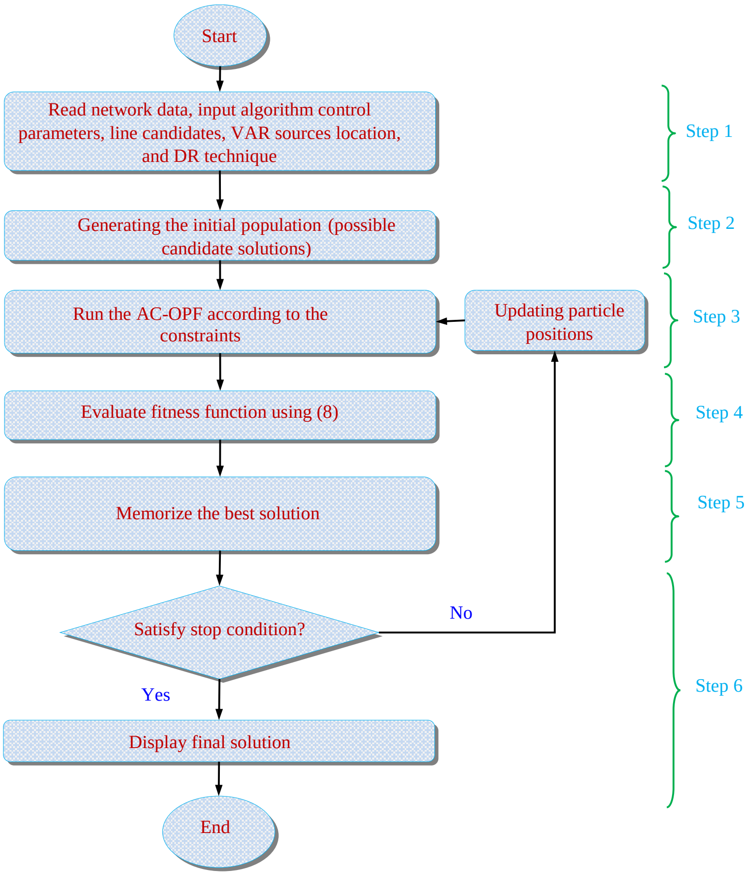

Fig. 1. Flowchart of the proposed planning

6. CASE STUDY

6.1. Data

For analysis of TEP-RPP scheme, the presented planning is exerted on IEEE 30 bus test system by PSO-NTVE optimization algorithm. The single diagram of this test system has been shown in Fig. 2. The system details as Line, generator, and demand data is given in [29]. The lines details and candidate lines for installing in the network are shown in Table 2. Code 1 refers to existing lines and code 0 refers to candidate lines. Additionally, a total of the 30 buses are considered as the candidate bus for placement of reactive power and their related data is shown in Table 3 [26].

The candidate load buses for DR model chosen based on their ability of affecting on transmission line congestion discussed in [29] are given in Table 1.

The price elasticities of the demands based on three periods are shown in Table 4. The value of the incentive and electricity price extracted from [25] are considered as 1000 and 1500.

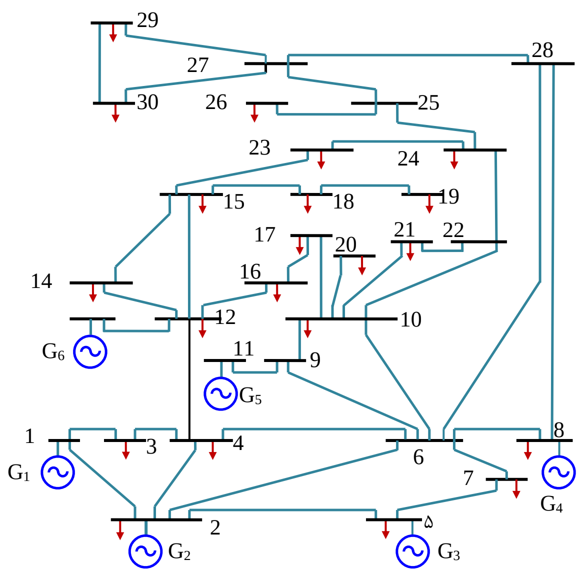

Fig. 2. IEEE 30-bus test system

Table 1. The selected buses for demand response.

Demand response number	Bus number
1	7
2	8
3	12
4	17
5	19
6	21
7	30

Table 2. Line characteristics

Number	Line	Code
1	1-2	1
2	1-3	1
3	2-4	1
4	2-5	1
5	3-4	1
6	4-6	1
7	2-6	1
8	5-7	1
9	6-7	1
10	6-8	1
11	6-9	1
12	6-10	1
13	8-28	1
14	4-12	1
15	6-28	1
16	9-10	1
17	9-11	1
18	10-17	1
19	12-13	1
20	12-15	1
21	23-24	1
22	10-12	1
23	18-19	1
24	19-20	1
25	21-22	1
26	22-24	1
27	24-25	1
28	25-26	1
29	25-27	1
30	27-28	1
31	27-29	1
32	27-30	1
33	10-20	1
34	10-21	1
35	10-22	1
36	12-14	1
37	12-16	1
38	14-15	1
39	15-18	1
40	15-23	1
41	16-17	0
42	10-11	0
43	10-16	0
44	16-18	0
45	17-20	0
46	10-28	0
47	11-28	0
48	12-18	0
49	13-14	0
50	13-16	0
51	15-16	0
52	6-11	0
53	5-6	0

Table 3. Reactive sources data.

S_b	Q_{min}	Q_{max}	C_{fix}	C_{var}
100	-0.1	0.3	1000	30

Table 1. Self and cross elasticity.

	Peak	Off-peak	Low
Peak	-0.1	0.016	0.012
Off-peak	0.016	-0.1	0.01
Low	0.012	0.01	-0.1

6.2. Numerical results

In this paper proposed planning is exerted to the IEEE 30 bus test system and the outcomes of simulation studies and the effect of the demand response model for several scenarios on the IEEE 30 bus test system are analyzed. The new added lines and reactive power sources placement, scheduling for all the scenarios are enumerated in Tables 5 and 9. The details of the DR model results are presented in Table 8. Form Table 5, it is perceived that the entire cost of planning is reduced in case 3 as compared to scenarios 1-2. Also, to show the accuracy and the effectiveness of the PSO-NTVE method, the considered optimization problem is also solved by other versions of PSO and results are compared and given in Table 6. The comprehensive outcomes for various scenarios are discussed as follow:

Scenario 1:In this case the simple TEP model (Eq. (9)) is exerted to the IEEE 30 bus test system. The results of planning are presented in Table 5. The transmission new lines installed cost denoted by the PSO-NTVE algorithm is 447000 US \$. 17 new lines are added to the base grid; these new line topology is: n_{1-4} =1, n_{2-4} =1, n_{4-5}=1 n_{4-6}=1, n_{5-6}=1, n_{5-8}=1, n_{15-18} =1, n_{17-18} =1, n_{18-19} =1, n_{10-11} =1, n_{26-29} =1, n_{3-13} =1, n_{4-11} =1, n_{10-21} =1, n_{1-30} =1, n_{15-30} =1, n_{18-17} =1. Simulation outcomes with statistical analysis of the solution performed for 30 buses are displayed in Table 5. The cost convergence curve for test system is drawn in Fig. 3.

Scenario 2: In scenario 2, reactive power planning is combined with TEP study. Results of optimal simulation are given in the table. The investment cost is 298000 US \$ and 13 new lines added to the base grid. The new lines are: n_{1-4} =1, n_{2-4} =1, n_{4-5}=1, n_{4-6}=1, n_{5-6}=1, n_{5-8}=1, n_{15-18} =1, n_{17-18}=1, n_{18-19} =1, n_{10-11} =1, n_{26-29} =1, n_{3-13} =1, n_{1-30} =1. The total cost of planning is 398000 US \$.

Furthermore, RPP results are given in Table 9. The chosen buses for placement of VAr sources are: 5, 6, 8, 24, 10, and 29. The cost convergence curve for hybrid TEP-RPP is shown in Fig. 4.

Scenario 3: The results from the impact of DR program on the TEP-RPP scheme in this case is line investment cost 205000 US \$, VAr locally cost 65100 US \$, and DR cost 55704 US \$ with the new line configuration of: n_{4-5}=1 n_{4-6}=1, n_{5-6}=1, n_{5-8}=1, n_{15-18} =1, n_{17-18} =1, n_{18-19} =1, n_{10-11} =1, n_{26-29} =1, n_{15-30} =1, n_{1-30}=1. The new buses in place VAR sources are: 6, 8 24, 29.

The new demands of load buses also are given in Table 8. The cost convergence curve for scenario 3 is shown in Fig. 5. Also total cost and investment cost comparing graph is shown in Fig. 6.

Table 2. Results of planning for three scenarios.

	TEP cost	RPP cost	DR cost	Total cost
TEP	4.47×10^5	-	-	4.47×10^5
TEP-RPP	2.98×10^5	1.02×10^5	-	3.98×10^5
TEP-RPP with DR	2.05×10^5	7.28×10^4	5×10^4	3.2780×10^5

Table 3. Comparison of PSO-NTVE, PSO-TVAC and PSO

	TEP cost	RPP cost	Total cost
PSO-NTVE	$2.05*10^5$	$7.28*10^4$	$3.2780*10^5$
PSO-TVAC	$3.33*10^5$	$8.05*10^4$	$4.13*10^5$
PSO	$4.35*10^5$	$9.08*10^4$	$5.25*10^5$

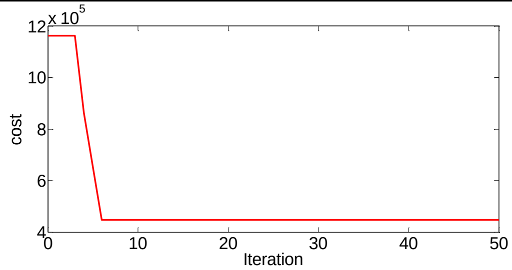

Fig. 3. Cost convergence for static TEP (scenario 1).

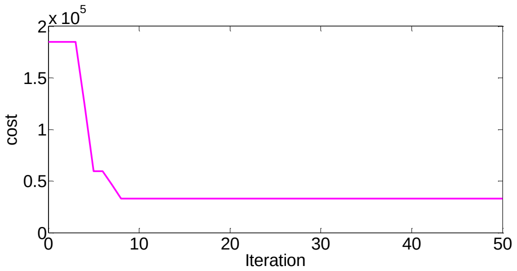

Fig. 4. Cost convergence curve for hybrid TEP-RPP (scenario 2).

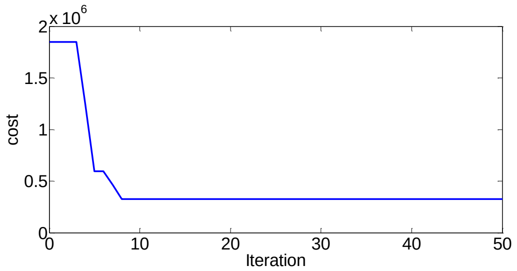

Fig. 5. Integrated DR by TEP-RPP program Cost curve (scenario 3).

6.3. Results: Analysis and discussion

The outcomes obtained from considering optimization algorithm for all scenarios are compared with each other. For obtaining availability of PSO-NTVE compared by another version of PSO the results of simulation for scenario 1 are given in Table 6. For other scenarios the results are not reported. The main observations discovered from the studies are discussed and analyzed as follow:

Scenario 1:

In case 1, it is observed from Table 6 that the PSO-NTVE optimization technique have a better performance than the other PSO versions such as PSO-TVAC, or simple PSO and it was planned less new lines.

Scenario 2:

It is observed that considering of RPP issue in TEP study, the entire investment cost has a reduction compared with scenario 1. This reduction of entire cost with the RPP issue is 33% as compared to case 1. Due to the outcomes given in Table 5 and 7, this implies that combinations of TEP and RPP issues reduce the investment cost and new lines of the network.

Scenario 3:

In this case with the integration of demand response model in the power system planning, the entire cost is observed lower than scenarios 1 and 2. This reduction in cost (54% and 31%, respectively) shows that the demand response model has a great effect to minimize the entire cost of the system. However, the transmission line cost reduction observed is same as that of the scenario 2. In Fig. 7 system load demand with and without DR graphically is shown.

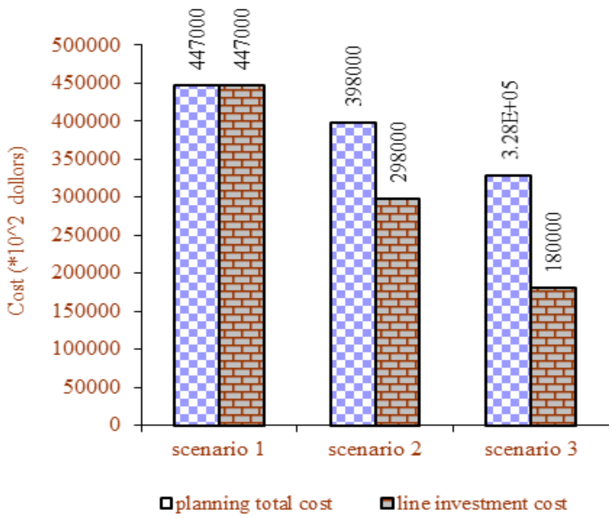

Fig. 6. Cost comparison graphs for all scenarios.

Table 4. Comparison of new lines added to system in 3 scenarios.

	n_{1-7}	n_{1-4}	n_{2-4}	n_{3-9}	n_{4-5}	n_{4-6}	n_{5-6}	n_{5-8}	n_{15-18}	n_{17-18}	n_{18-19}	n_{10-11}	n_{26-29}	n_{3-13}	n_{4-11}	n_{10-21}	n_{25-26}	n_{1-30}	n_{15-30}	n_{18-17}
Scenario 1	0	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	0	1	0	1
Scenario 2	0	1	1	0	1	1	1	1	1	1	1	1	1	1	0	0	0	1	0	1
Scenario 3	0	0	0	0	1	1	1	1	1	1	1	1	1	1	0	0	0	0	1	0

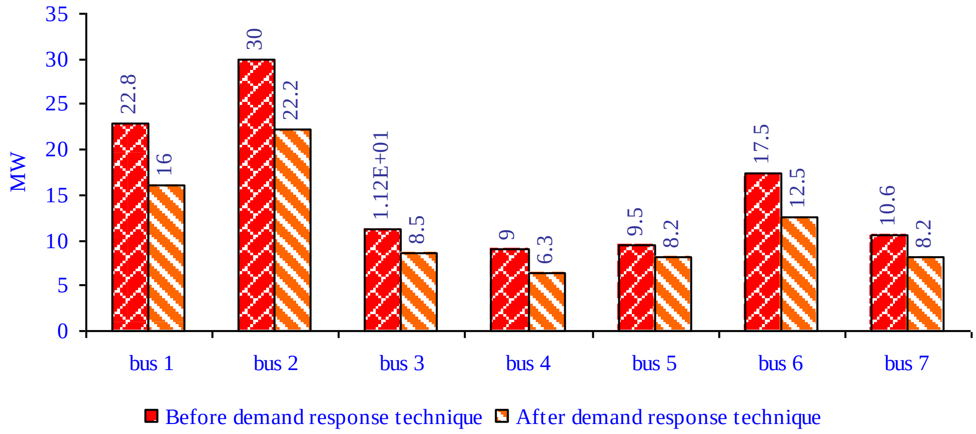

Fig. 7. Load graph for scenario 3.

Table 5. Demand response results.

Bus number	After demand response (MW)
1	16
2	22
3	8.20
4	6
5	8
6	12.5
7	8

Table 6. Reactive power planning results.

Bus number	Chosen buses	VAr size
1	5	0.3
2	6	0.3
3	8	0.3
4	29	-.1
5	10	-.0986
6	24	0.3

7. Conclusion

An achieved planning model for the static TEP issue with the combination of reactive power planning along with a price-based demand response model is presented in this paper. By the meta-heuristic optimization technique, the entire cost of the network is minimized. An inductive analysis of the costs for the different scenarios is also given. It is observed that by consideration of reactive power planning in TEP, the number of new lines added to the power system is decreased and combination of demand response technique with TEP-RPP minimizes the cost of TEP-RPP by management of increasing the load demand and the customer consumption pattern. The IEEE standard test system is considered to appraise the effectiveness of the presented method. The main outcomes of all scenarios are as follows:

(1) The implemented simulation analysis shows that the considered PSO-NTVE optimization algorithm has a better performance than the other versions of PSO.

(2) The integration of RPP program by TEP reduces the added new line and entire cost of the network so it is proved that there is an inherent interaction between transmission line capacity and reactive power sources and should not study them separately.

(3) The impact of DR model on TEP-RPP planning reduces load demand of the network, which leads in decreasing of the total cost of system by supplying load with less new lines. However, the total cost found with DR program is better than RPP. “”

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