Hierarchy Style Application in Line Extension with Responsive Loads Evaluating the Dynamic Nature of Solar Units

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Abstract- This paper presents a model for line extension scheduling to participate responsive loads in power system aiming improvement of techno-economical parameters. The model is studied with presence of photovoltaic generators that produce variable power depending on the geographical condition. The investment cost of transmission expansion plan, demand response operation cost, generation costs and the sum of the voltage deviations are the four indices that optimization problem is designed based on these four criteria. Objective functions are dynamic variables that change daily due to variation in generation and load. Multi-objective optimization method based on analytic hierarchy technique is employed to solve the problem. The Pareto-optimal set is extracted with gravitational search style and the best solution is fund by AHT manner. Studies are carried out on the modified 30-bus and 24-bus IEEE test system to confirm the capability of the presented model. Two frameworks are defined to compare the suggested manner. A different amount of PV penetration is discussed in several scenarios. Also, load uncertainty is formulated and involved based on probability distribution function.

Keyword: Planning, Responsive loads, Photovoltaic unit, Analytic hierarchy technique.

NOMENCLATURE

TLAP Transmission line allocation program
AHT Analytic hierarchy technique
TEP Transmission expansion planning
PV Photovoltaic
DRT Demand response technique
PPU Photovoltaic power unit
$I_{PPU}^{max}$ PV panel current at the maximum power point (A)
$I_{SC}$ Short circuit current of PV panel (A)
$IR_T$ Hourly irradiance on a tilted surface (W/m²)
$V_{PPU}^{max}$ Maximum voltage of PV panel at the reference operating conditions (V)
$V_{PPU}$ Open circuit voltage of PV panel (V)
$TCI$ Temperature coefficient for short circuit current (A/°C)
$T_c$ PV panel operating temperature (C)
$IR_{ref}$ Irradiance at reference operating conditions equal to 1000 W/m²
$V_{PPU}^{max}$ PV panel voltage at the maximum power point (V)
$T_{PPU}^{ref}$ PV panel temperature at reference operating conditions is equal to 25 °C
$T_{PPU}^{ref}$ PV panel voltage at the maximum power point (V)
$T_{ref}$ Temperature at reference operating conditions (V)
$V_{PPU}$ PV panel power at the maximum power point (W)
$P_{PPU}$ Photovoltaic power unit
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1. INTRODUCTION

1.1. Objectives and approach

Demand growth, generation development and worn-out equipment are the main reasons for transmission expansion planning. Developing transmission lines is a complex process with high cost. Therefore, providing an optimal model to better management of the transmission planning problem is a necessary issue. Demand management is a useful solution for TEP process. Profit-based platform existing in demand reduction programs can decrease the cost of the TEP process [1]. Demand response is a technique that enables electrical loads to cooperate in power system condition based on nonstructural solution for transmission expansion [2]. Peak demand happens in a constrained time and DRT can be utilized as a benefit and inexpensive solution to overcome the filling of electric transmission lines [3].

The issue of transmission line expansion will be a complex problem when the electrical power system is in operation with the presence of photovoltaic units. Large-scale photovoltaic units are dependent on environmental situation and generate the intermittent power based on two important parameters, solar irradiation and temperature. Photovoltaic units are non-dispatchable resources that can affect on transmission expansion plans. According to the concepts described above, presenting a precise model for simultaneous investigation of DRT and the effect of large-scale photovoltaic unit seems essential subject that is discussed in this paper.

1.2. Literature review

TEP problem has been discussed in several references. Reference [4] survey the integration of energy storage systems on power systems. In this reference, size, location, scheduling plan and storage system design are determined based on instant prices of power system. Three important factors have been compared with previous methods: grid congestion, generation capacity and nodal costs.

A flexible-based method for TEP has been presented in [5]. To consider uncertainty in the presented model, a new scenario production technique has been discussed. The effect of intermittent behavior of renewable energies on TEP costs has been investigated based on some economic-based analysis. In Ref. [6], constraints of network short-circuit has been modeled and investigated with TEP model. Model linearizing has been done to create a simple model. Incremental technique has been used in Ref. [7] to investigate the reliability criterion in TEP problem. In this paper transmission expansion planning with the incremental method has been done for reliability index.

Also, the demand response algorithm has been discussed in recent previous published references. In Ref. [8], placement of charging center of electric vehicles with the demand response method has been studied. This reference has shown the effect of the demand response technique on general losses. Sizing and placement of load bus for DRT implementation has been scrutinized in Ref. [9]. In this paper the optimal location and size of the load is determined by presenting a new contract technique.

1.3. Contributions

This paper presents a model to incorporate responsive electrical loads in transmission expansion projecting considering the effect of intermittent behavior of photovoltaic units. It is assumed that the generation of photovoltaic unit is a variable parameter and dependent on two important factors, solar irradiation and environmental temperature. First, the economic concept of the TEP and DRT is verified and based on it the economic model of line expansion planning is developed. The presented model is a dynamic definition of the system that its variable parameters are changing daily. The investment cost of TEP problem, generation cost, demand response cost and the sum of voltage deviation are four important objective function defined in model. The mentioned objective functions, are formulated as an optimization problem and it is solved by multi-objective optimization method. Among the Pareto-optimal set obtained by multi-objective optimization algorithm,
planner should select an optimal solution. The Analytic hierarchy method is employed to choose the best plan. The performance of the proposed model is evaluated through modified 30-bus and 24-bus IEEE test systems. Solar irradiation and temperature data of the area that a photovoltaic unit has been installed in it, is extracted and it is employed in the model. The proposed model is compared in two frameworks and four scenarios. An inevitable case in a power system is load uncertainty. A model is developed considering load uncertainty and all parameters have been compared. The main contributions of this study are as bellow:

- Responsive loads have been participated in transmission expansion planning.
- Dynamic behavior of PV unit is investigated in TEP model.
- The problem is solved based on multi-objective optimization technique with the analytic hierarchy method.

1.4. Paper structure
This paper is presented in 10 sections. Photovoltaic power unit is defined in Section II. Model of the presented TEP is developed in Section III. The demand response technique is verified in Section IV. Load uncertainty is surveyed in Section V. The method of optimal solution selection and optimization technique has been explained in Section VI and VII, respectively. Problem flowchart is depicted in Section 8. The result of numerical study is presented in Section 9 and conclusion of paper is discussed in Section 10.

2. PHOTOVOLTAIC POWERUNIT
As shown in Fig. 1 Error! Reference source not found., output power of PPU is given as follows [10]:

\[ P_{PPU} = V_{PPU} I_{PPU} \] (1)

Voltage and current generated by PPU are written as follows [11, 12]:

\[ V_{PPU} = V_{max} + TCV (T_c - T_c^{ref}) \] (2)

\[ I_{PPU} = I_{SC} \left[ \frac{IR_t}{I_r^{ref}} - M_1 \left[ \exp \left( \frac{V_{PPU}}{M_2 V_{OC}} \right) - 1 \right] \right] + TCI (T_c - T_c^{ref}) \] (3)

where

\[ M_1 = (1 - \frac{I_{max}}{I_{SC}}) \exp \left( - \frac{V_{PPU}}{\lambda_2 V_{OC}} \right) \]

\[ M_2 = \left( \frac{V_{PPU}}{V_{OC}} - 1 \right) \left[ \ln \left( 1 - \frac{I_{max}}{I_{SC}} \right) \right] - 1 \]

\[ T_c = T_a + \frac{n_{oc} - 20}{800} IR_t \]

3. PROPOSED MODEL FORMULATION
TEP strategy is based on four important aims: investment cost, generation cost and DRT cost and sum of voltage deviation reduction. DRT-based TEP considering the effect of the PV unit has been formulated as follows:

\[ F = \min \{ J_1^{TLAP}, J_2^{TLAP}, J_3^{TLAP}, J_4^{TLAP} \} \] (4)

Subject to
\[
\left\{ \begin{array}{ll}
P_l - V_i \sum_{j \in N_i} V_j (G_{ij} \cos \delta_{ij} + B_{ij} \sin \delta_{ij}) = 0 & i \in n_g \\
Q_l - V_i \sum_{j \in N_i} V_j (G_{ij} \sin \delta_{ij} + B_{ij} \cos \delta_{ij}) = 0 & i \in n_g 
\end{array} \right.
\]
\[
\sum_{iB} \sum_{1, 2, 3, \ldots, L_i} \sum_{l} \sum_{1, 2, 3, \ldots, G_i} g_{ij} = \{1\} 
\]
\[
\sum_{iB} \sum_{1, 2, 3, \ldots, L_i} \sum_{l} \sum_{1, 2, 3, \ldots, G_i} g_{ij} = \{1\} 
\]
\[
\sum_{iB} \sum_{1, 2, 3, \ldots, L_i} \sum_{l} \sum_{1, 2, 3, \ldots, G_i} g_{ij} = \{1\} 
\]

Investment cost of TEP (\( J_1^{TLAP} \)): Minimization of investment cost of the added lines is the main task of planners in transmission expansion process:

\[
J_1^{TLAP} = \frac{DV (DV+1)^{n_y}}{(DV+1)^{n_y} - 1} \sum_{i} \sum_{j} MC_{ij} ALV_{ij} 
\]

where

\( DV \) : Discount value
\( n_y \) : Lifetime of project in year

\( MC_{ij} \) : Cost vector of the new added line

\( ALV_{ij} \) : The vector of the new added line.

Operational cost of the system (\( J_2^{TLAP} \)): In the proposed model, load demand changes due to demand response effect. Also, PV unit has a mandatory generation that it is a variable parameter dependent on climate conditions. Thus, the cost of production will change at any time, which should be minimized over the study duration.

\[
J_2^{TLAP} = \sum_{d=1}^{365} \sum_{u=1}^{n_u} CF_u (GE_u^d) 
\]

\( CF_u \) : Power generation cost of generator uth

\( GE_u^d \) : Power generation of generator uth at dth day (MW)

Cost of demand response (\( J_3^{TLAP} \)): The participation of responsive loads in a demand response program imposes an extra cost to the independent operator of the system. This cost should be minimized in the TEP process as follows [13, 14]:

\[
J_3^{TLAP} = \sum_{d=1}^{365} \sum_{b=1}^{B_d^b} LC_d^b 
\]

\( B_d^b \) : Price for one MWh demand response at bus bth in th day.

\( LC_d^b \) : The damount of load variation at bus bth in dth day.

Voltage deviation index (\( J_4^{TLAP} \)): Considering the effect of DRT and PV units in the power grids, the fourth target in the TEP process is the minimization of the voltage deviation in yearly duration, that it can be defined as bellow:

\[
J_4^{TLAP} = \sum_{d=1}^{365} \sum_{k=1}^{n_d} |V_k^d - 1| 
\]

\( n_d \) : The number of buses.

\( V_k^d \) : Voltage value in kth bus at dth day.

4. VERIFYING DEMAND RESPONSE TECHNIQUE

In demand response program to maximize the profit of customer, income derivative of customer should be equal to zero [15]:

\[
\frac{\partial}{\partial L(d)} [B(L(d)) - L(d)Ep(d) + Pi(L(d)) - L_o(d)] = 0 
\]

for we have [1]: \( \frac{\partial B (L(d))}{\partial L(d)} = Ep(d) [1 + \frac{L(d) - L_o(d)}{EL(d)L_o(d)}] 

By comparing:

\[
\frac{\partial B (L(d))}{\partial L(d)} = Ep(d) [1 + \frac{L(d) - L_o(d)}{EL(d)L_o(d)} + Pi (d) + pen(d)] 
\]

where

\( L_o (d) \) : Initial load at dth day.
5. Considering Load Uncertainty in Presented Model

To participate the load uncertainty in the presented model, it is assumed that the load on each bus have several limited collections. As shown in Fig. 2, each constrained area is verified a scenario. The weighted sum of each objective function in total scenarios performs the final function. The probability of each scenario is defined as the applied weights. The objective function of model considering the effect of load uncertainty is written as follows:

\[
F = \text{Min } \{J_1^{LU}, J_2^{LU}, J_3^{LU}, J_4^{LU}\} 
\]

where

\[
J_1^{LU} = \frac{DV}{(DV + 1)^{n_s}} \sum_{s=1}^{n_s} \sum_{i=1}^{n_d} \sum_{j=1}^{M} w_{ij}^{s} (GE_{ij}^{d})^{x} \rho_{s}^{x} 
\]

\[
J_2 = \sum_{s=1}^{n_s} \sum_{i=1}^{n_d} \sum_{j=1}^{M} w_{ij}^{s} (GE_{ij}^{d})^{x} \rho_{s}^{x} 
\]

\[
J_3 = \frac{DV}{(DV + 1)^{n_s}} \sum_{s=1}^{n_s} \sum_{i=1}^{n_d} \sum_{j=1}^{M} w_{ij}^{s} (GE_{ij}^{d})^{x} \rho_{s}^{x} 
\]

\[
J_4 = \sum_{s=1}^{n_s} \sum_{i=1}^{n_d} \sum_{j=1}^{M} w_{ij}^{s} (GE_{ij}^{d})^{x} \rho_{s}^{x} 
\]

Probability

![Fig. 2: The scenarios of load uncertainty.](image)

6. Analytic Hierarchy Technique

To select an optimal solution among the Pareto-front set, AHT is used [16]. AHT is based on pairwise comparison of components as given in Figs. 3 and 4.

The pairwise comparison is formed in a pairwise comparison matrix as follows:

\[
CM = \begin{bmatrix}
1 & c_{m1} & \cdots & c_{m1n} \\
\frac{1}{c_{m1}} & 1 & \cdots & c_{m2n} \\
\vdots & \vdots & \ddots & \vdots \\
\frac{1}{c_{m1n}} & \frac{1}{c_{m2n}} & \cdots & 1
\end{bmatrix}
\]

(20)

Geometric mean technique is utilized to create the priority vector as follows:

\[
WE_i = \left(\prod_{j=1}^{n} c_{mij}\right)^{\frac{1}{n}}
\]

\[
\sum_{i=1}^{n} \left(\prod_{j=1}^{n} c_{mij}\right)^{\frac{1}{n}}
\]

(21)

7. Optimization Technique

7.1. Multi-objective optimization

The multi-objective optimization concept, can be explained as [17]:

\[
\text{Minimize } J(X) = (J_1(X), J_2(X), \ldots, J_m(X))
\]

(22)

where \( m \) is the number of objectives and \( J_i(X) \) is the \( i \)-th objective function of the problem.

\( J(X) \) dominates \( J(Y) \), denoted by \( J(X) \prec J(Y) \) if and only if:

\[
\forall i \in [1, 2, \ldots, m] : J_i(X) \leq J_i(Y) \text{ and } \exists i \in [1, 2, \ldots, m] : J_i(X) < J_i(Y)
\]

(23)

\( J(X) \) is non-dominated if there is no \( J(Y) \) that dominates \( J(X) \).

7.2. Multi-objective GSA

Initialization of the agents: The positions of the \( N \) agents are initialized as follows: [18]

\[
P_i = (p_{i1}^1, p_{i1}^2, \ldots, p_{i1}^d, \ldots, p_{i1}^n) \text{ for } i = 1, 2, \ldots, N
\]

(24)

where \( p_{id} \) represents the positions of the \( i \)-th agent in the \( d \)-th dimension.

Gravitational constant: The gravitational constant is
calculated:

$$G(t) = G_0 \exp(-\alpha t/T)$$

(25)

\(t\) and \(T\) are the current and total numbers of iterations, respectively. \(\alpha\) is a constant factor.

**Fitness evaluation for each agent:** Fitness evolution is defined as below:

$$\text{best}(t) = \min_{j \in \{1, \ldots, N\}} \text{fitness}_j$$

(26)

$$\text{worst}(t) = \max_{j \in \{1, \ldots, N\}} \text{fitness}_j$$

(27)

where \(M_i(t)\) represents the fitness of the \(j\)th agent at iteration \(t\).

**Mass of the agents:** Gravitational and inertia masses for each agent are verified as:

$$m_i(t) = \frac{\text{fitness}_i(t) - \text{worst}(t)}{\text{best}(t) - \text{worst}(t)}$$

(29)

where \(M_i(t)\) represent the mass of agent \(i\) at iteration \(t\).

**Accelerations of the agents:** Overall force on the \(i\)th agent is:

$$F_{ij}^d(t) = G(t) \frac{M_{pi}(t)M_{aj}(t)(p_i^d(t) - p_j^d(t))}{R_{ij}(t)}$$

(30)

$$F_{ij}^d(t) = \sum_{j=K\text{best}}^{N} \text{rand}_j F_{ij}^d(t)$$

(31)

\(R_{ij}(t)\) is the Euclidean distance between two agents \(i\) and \(j\) in an \(n\)-dimensional Euclidean space.

**Acceleration of object:** The acceleration of the \(i\)th agent is defined by:

$$a_i^d(t) = F_{ii}^d/M_{ii}(t)$$

(32)

**Update velocity and positions:** The velocity and the position are updated by:

$$\text{Equally preferred} \quad \text{The importance of two criteria is equal} \quad \text{Scale: 1}$$

$$\text{Moderately preferred} \quad \text{The importance of a criterion is slightly greater than the other criterion} \quad \text{Scale: 3}$$

$$\text{Strongly preferred} \quad \text{The importance of a criterion is more than the other criterion.} \quad \text{Scale: 5}$$

$$\text{Very strongly preferred} \quad \text{The importance of a criterion is much greater than the other criterion.} \quad \text{Scale: 7}$$

$$\text{Extremely preferred} \quad \text{The importance of a criterion is much greater than the other criterion, definitely.} \quad \text{Scale: 9}$$

$$\text{Equally preferred} \quad \text{Preferences between strong distances} \quad \text{Scale: 2, 4, 6 and 8}$$

**Fig. 3:** Quantitative scale for pair comparison

**Goal**

**Criteria 1**  ...  **Criteria \(n-1\)**  **Criteria \(n\)**

**Alternative 1**  ...  **Alternative \(n\)**

**Fig. 4:** AHT process
Take solar value IR at th day
Take temperature
Input load amount at
Calculate investment, generation and demand response cost and voltage

Initialize optimization
Initialize the agent positions

\[ s_i^d(t+1) = rand_i \times s_i^d(t) + a_i^d \] (33)

\[ p_i^d(t+1) = p_i^d(t) + s_i^d(t+1) \] (34)

8. PROBLEM SOLUTION FLOWCHART

The problem formulated is optimized in three main steps. In the first step, the required data has is involved in the procedure. Optimization parameters are initialized in the second step and the target functions has been calculated. Pareto-optimal curves are extracted in the second step. In the third step AHT is employed to select the best solution.

9. NUMERICAL STUDY

The presented model has been developed on the modified 24 bus IEEE and 30 bus IEEE test systems. The single line diagrams of the two systems have been depicted in Figs. 6 and 7. The candidate load buses based on their ability to change the condition of a system have been given in Table 1 of one year have been shown in Fig. 8 for two test systems. Load curve for 365 days of one year have been shown in Fig. for two test system.

<table>
<thead>
<tr>
<th>Test system</th>
<th>DRT number</th>
<th>Bus number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test system I</td>
<td>1</td>
<td>29</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>24</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>15</td>
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<td></td>
<td>4</td>
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<tr>
<td></td>
<td>6</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>4</td>
</tr>
<tr>
<td>Test system II</td>
<td>1</td>
<td>16</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>11</td>
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<td></td>
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<tr>
<td></td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>2</td>
</tr>
</tbody>
</table>
Fig. 6: The single line diagram of 30-bus IEEE system.

Fig. 7: The single line diagram of 24-bus IEEE system.
The profiles of electricity price and incentive price have been given in Table 2.

<table>
<thead>
<tr>
<th>Load level</th>
<th>System I</th>
<th>System II</th>
</tr>
</thead>
<tbody>
<tr>
<td>Price ($/MWh)</td>
<td>11</td>
<td>22</td>
</tr>
<tr>
<td>Incentive price ($/MWh)</td>
<td>80</td>
<td>81</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Load level</th>
<th>System I</th>
<th>System II</th>
</tr>
</thead>
<tbody>
<tr>
<td>Price ($/MWh)</td>
<td>12</td>
<td>25</td>
</tr>
<tr>
<td>Incentive price ($/MWh)</td>
<td>81</td>
<td>85</td>
</tr>
</tbody>
</table>

These two systems have been evaluated with the presence of large-scale photovoltaic units. Solar irradiation and temperature data in place of photovoltaic unit have been shown in Figs. 9 and 10.

Contour plots of environmental parameters have been presented in Fig. 11.

The new candidate lines that can be added in the TEP process have been shown in Table 3. Optimization technique is employed and the presented model is solved. Pareto-optimal curve in two-dimensional plane for $J^L_U$ to $J^L_4$ has been illustrated in Figs. 12 and 13.
Table 3: The new candidate lines for system I and II

<table>
<thead>
<tr>
<th>Line</th>
<th>From</th>
<th>To</th>
<th>Capacity (MW)</th>
<th>Reactance (p.u.)</th>
<th>Investment cost ($ 10^6 US)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test system I</td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Line 1</td>
<td>1</td>
<td>2</td>
<td>30</td>
<td>0.0575</td>
<td>10</td>
</tr>
<tr>
<td>Line 2</td>
<td>1</td>
<td>3</td>
<td>30</td>
<td>0.1852</td>
<td>25</td>
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<tr>
<td>Line 3</td>
<td>2</td>
<td>4</td>
<td>30</td>
<td>0.1737</td>
<td>15</td>
</tr>
<tr>
<td>Line 4</td>
<td>3</td>
<td>4</td>
<td>30</td>
<td>0.0379</td>
<td>10</td>
</tr>
<tr>
<td>Line 5</td>
<td>9</td>
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<td>30</td>
<td>0.110</td>
<td>14</td>
</tr>
<tr>
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<td></td>
</tr>
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<td>10.82</td>
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<td>10</td>
<td>175</td>
<td>0.02</td>
<td>10.29</td>
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<tr>
<td>Line 4</td>
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<td>10</td>
<td>175</td>
<td>0.016</td>
<td>8.24</td>
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<tr>
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<td>15</td>
<td>500</td>
<td>0.022</td>
<td>11.13</td>
</tr>
<tr>
<td>Line 6</td>
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<td>24</td>
<td>500</td>
<td>0.011</td>
<td>5.66</td>
</tr>
<tr>
<td>Line 7</td>
<td>14</td>
<td>19</td>
<td>500</td>
<td>0.017</td>
<td>8.76</td>
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<tr>
<td>Line 8</td>
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<td>21</td>
<td>500</td>
<td>0.014</td>
<td>7.21</td>
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<tr>
<td>Line 9</td>
<td>20</td>
<td>22</td>
<td>500</td>
<td>0.014</td>
<td>7.21</td>
</tr>
</tbody>
</table>

Fig. 12: Pareto-optimal curve for system I.
The trend of p1 over the p2 to p10, according to the main criteria $J_1^{LU}$ to $J_4^{LU}$ has been shown in Fig. 14. According to this figure, as for example, from the perspective of criteria $J_1^{LU}$, p1 is superior than p2.

The trend of $p_1$ over the $p_2$ to $p_{10}$, according to the main criteria $J_1^{LU}$ to $J_4^{LU}$ has been shown in . According to this figure, as for example, from the perspective of criteria $J_1^{LU}$, $p_1$ is superior than $p_2$.

To perform AHT, Expert Choice software is implemented. Efficiency sensitivity chart for ten Pareto solution and four criteria $J_1^{LU}$ to $J_4^{LU}$ has been given in Fig. . As for example, according to Fig., for $J_2^{LU}$, $p_1$ has a larger weighting factor. In other words, in $p_1$, $J_2^{LU}$ criterion has greater priority.
Prioritization based on relative weight has been calculated and illustrated in Fig. 17. Based on Fig. 17, Pareto-point $p_1$ is the best solution.

To compare the presented model, two frameworks and four scenarios are considered as follows:

- Framework 1 (F1): Model without DRT.
- Framework 2 (F2): Model with DRT.

Four scenarios are described as:

- Scenario 1 (S1): PU integration with 30 MW capacity (low penetration).
- Scenario 2 (S2): PU integration with 50 MW capacity (base penetration).
- Scenario 3 (S3): PU integration with 70 MW capacity (moderate penetration).
- Scenario 4 (S4): PU integration with 90 MW capacity (high penetration).

Table 4 shows the new added lines for two frameworks, four scenarios and two systems.
9.1. DISCUSSION AND STUDY OF RESULT

The total value of generation without using DRT and PV is higher in comparison with two other options. Also, generation amount reduces in the state of the system with DRT and PV. The results of the studied model in two frameworks and four scenarios have been given in Fig. to Fig. The investment cost of new added lines has been described in Fig. 18. Figure 19 shows the comparative value of generation cost. Cost of demand response has been compared in Fig. 20. Voltage criterion has been discussed in Fig. .

According to Fig. , framework 2 has 11%, 13%, 3% and 11%, for system I and 12%, 7%, 7% and 12% for system II, reduction in costs than framework 2. In general, based on Figs. 18-21 including three costs, investment cost, operational cost and demand response cost, total cost in system I are for framework I, 29.4563×10^6, 29.5819×10^6, 30.0414×10^6, 30.4073×10^6 and for framework II, 28.0063×10^6, 27.4247×10^6, 28.8244×10^6, 28.1575×10^6. In system II, total cost for framework I are 19.401×10^6, 19.9619×10^6, 20.9116×10^6, 20.9116×10^6 and for framework II are 18.7072×10^6, 19.2489×10^6, 18.5191×10^6, 18.3218×10^6. Total cost in both systems has a significant reduction. Also, the cost of investment and the cost of demand response increase with increasing photovoltaic unit capacity.
9.2. UNCERTAINTY STUDY

To study the load uncertainty, it is considered that load on bus 8 and bus 9 in system I and system II have an uncertainty with probability distribution function shown in Figs. 22 and 23.

The result of uncertainty study for two test system I and II, has been compared in Figs. 24 to 26 for two conditions, framework I and II. From these figures, it is obvious that the uncertainty in system will increase the cost of planning.
Fig. 24: $J_1$ value in uncertainty condition, (a) system I, (b) system II.

Fig. 25: $J_2$ value in uncertainty condition, (a) system I, (b) system II.

Fig. 26: $J_3$ value in uncertainty condition, (a) system I, (b) system II.
10. CONCLUSIONS
In this paper a techno-economic model to incorporate the demand response method in extension of transmission lines in power systems considering the effect of large-scale photovoltaic units has been discussed. The proposed model can handle the challenges related to transmission expansion planning. Photovoltaic units have a mandatory generation that it depends on environmental conditions. This inflexible generation of photovoltaic units is changing daily. In this work, demand response is considered as virtual resources to overcome the peak load instead of transmission line construction. Various uncertainties are survived in the proposed model, including the photovoltaic generation output and load demand. The proposed method provides a multi-objective model under smart grid environment. The model is based on three economic targets, investment cost of TEP, DRT cost and generation cost, and one technical target, voltage deviation. Two test systems are determined to evaluate the robustness of the proposed technique. The result shows that the formulated model is a flexible method that can verify the DRT-based transmission planning with PV units. The results indicate that DRT implementation can reduce the cost of transmission planning in the case of systems that are involved with photovoltaic units. Also, transmission planning costs increase by increasing the capacity of PV unit.

REFERENCES


