

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 found 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	V_{PPU}	PV panel voltage at the maximum power point (V)
AHT	Analytic hierarchy technique	TCV	Temperature coefficient for open circuit voltage (V/°C)
TEP	Transmission expansion planning	I_{max}^{LPU}	Maximum current of PV panel at the reference operating conditions (A)
PV	Photovoltaic	T_a	Ambient temperature of the site under consideration (C)
DRT	Demand response technique	n_{oc}	Normal operating cell temperature (C)
PPU	Photovoltaic power unit	P_{PPU}	PV panel power at the maximum power point (W)
I_{PPU}	PV panel current at the maximum power point (A)	TLAP	Transmission line allocation program
I_{SC}	Short circuit current of PV panel (A)	AHT	Analytic hierarchy technique
IR_T	Hourly irradiance on a tilted surface (W/m ²)	TEP	Transmission expansion planning
V_{max}^{PPU}	Maximum voltage of PV panel at the reference operating conditions (V)	PV	Photovoltaic
V_{OC}^{PPU}	Open circuit voltage of PV panel (V)	DRT	Demand response technique
TCI	Temperature coefficient for short circuit current (A/°C)	PPU	Photovoltaic power unit
T_c	PV panel operating temperature (C)	I_{PPU}	PV panel current at the maximum power point (A)
IR_{ref}	Irradiance at reference operating conditions equal to 1000 W/m ²	I_{SC}	Short circuit current of PV panel (A)
T_c^{ref}	PV panel temperature at reference operating conditions is equal to 25 °C	IR_T	Hourly irradiance on a tilted surface (W/m ²)
		V_{max}^{PPU}	Maximum voltage of PV panel at the reference operating conditions (V)

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V_{OC}^{PPU}	Open circuit voltage of PV panel (V)
TCI	Temperature coefficient for short circuit current ($A/^{\circ}C$)
T_c	PV panel operating temperature (C)
IR_{ref}	Irradiance at reference operating conditions equal to 1000 W/m^2
T_c^{ref}	PV panel temperature at reference operating conditions is equal to $25^{\circ}C$
V_{PPU}	PV panel voltage at the maximum power point (V)
TCV	Temperature coefficient for open circuit voltage ($V/^{\circ}C$)
I_{max}^{LPU}	Maximum current of PV panel at the reference operating conditions (A)
T_a	Ambient temperature of the site under consideration (C)
n_{oc}	Normal operating cell temperature (C)
P_{PPU}	PV panel power at the maximum power point (W)
TLAP	Transmission line allocation program
AHT	Analytic hierarchy technique
TEP	Transmission expansion planning
PV	Photovoltaic
DRT	Demand response technique

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 Re. [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 follow:

- 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.**,

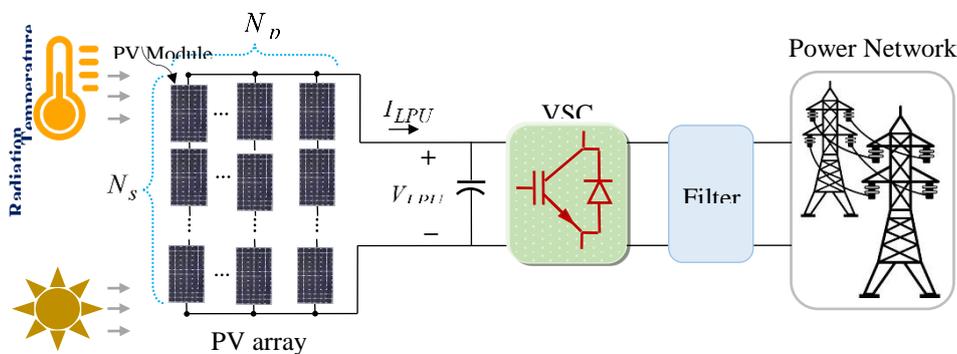


Fig. 1. PPU in an n-machine power grid

output power of PPU is given as follows [10]:

$$P_{PPU} = V_{PPU} I_{PPU} \tag{1}$$

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

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

$$I_{PPU} = I_{SC} \left\{ \frac{IR_T}{IR_{ref}} - M_1 \left[\exp\left(\frac{V_{max}^{PPU}}{M_2 V_{OC}^{PPU}}\right) - 1 \right] \right\} \tag{3}$$

$$+ TCI (T_c - T_c^{ref})$$

where

$$\begin{cases} M_1 = \left(1 - \frac{I_{max}^{PPU}}{I_{SC}}\right) \exp\left(-\frac{V_{max}^{PPU}}{\lambda_2 V_{OC}}\right) \\ M_2 = \left(\frac{V_{max}^{PPU}}{V_{OC}} - 1\right) \left[\ln\left(1 - \frac{I_{max}^{PPU}}{I_{SC}}\right)\right]^{-1} \\ T_c = T_a + \frac{n_{oc} - 20}{800} IR_T \end{cases}$$

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:

$$F = Min \{J_1^{TLAP}, J_2^{TLAP}, J_3^{TLAP}, J_4^{TLAP}\} \tag{4}$$

Subject to

$$\begin{cases} P_i - V_i \sum_{j \in N_i} V_j (G_{ij} \cos \delta_{ij} + B_{ij} \sin \delta_{ij}) = 0 & i \in n_g \\ Q_i - V_i \sum_{j \in N_i} V_j (G_{ij} \sin \delta_{ij} + B_{ij} \cos \delta_{ij}) = 0 & i \in n_g \end{cases} \quad (5)$$

$$\begin{cases} P_{Gi}^{\min} \leq P_{Gi} \leq P_{Gi}^{\max}, & i \in n_g \\ Q_{Gi}^{\min} \leq Q_{Gi} \leq Q_{Gi}^{\max}, & i \in n_g \end{cases} \quad (6)$$

$$\begin{cases} V_i^{\min} \leq V_i \leq V_i^{\max}, & i = 1, 2, 3, \dots, N_B \\ \delta_i^{\min} \leq \delta_i \leq \delta_i^{\max}, & i = 1, 2, 3, \dots, N_B \\ S_{Li} \leq S_{Li}^{\max} & i = 1, 2, 3, \dots, N_l \end{cases} \quad (7)$$

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:

$$J_1^{TLAP} = \frac{DV (DV+1)^{n_y}}{(DV+1)^{n_y} - 1} \sum_i \sum_j MC_{ij} ALV_{ij} \quad (8)$$

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.

$$J_2^{TLAP} = \sum_{d=1}^{365} \sum_{u=1}^{n_u} CF_u (GE_u^d) \quad (9)$$

CF_u : Power generation cost of generator u th

GE_u^d : Power generation of generator u th at d th 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]:

$$J_3^{TLAP} = \frac{DV (DV+1)^{n_y}}{(DV+1)^{n_y} - 1} \sum_{d=1}^{365} \sum_{b=1}^{N_b} B_d^b LC_d^b \quad (10)$$

B_d^b : Price for one MWh demand response at bus b th in d th day.

LC_d^b : The amount of load variation at bus b th in d th 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 below:

$$J_4^{TLAP} = \sum_{d=1}^{365} \sum_{k=1}^{n_b} |V_k^d - 1| \quad (11)$$

n_b : The number of buses.

V_k^d : Voltage value in k th bus at d th 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]:

$$\frac{\partial}{\partial L(i)} \{B(L(d)) - L(d)Ep(d) + PI(L(d) - L_o(d)) - pe(L(d) - L_o(d))\} = 0 \quad (12)$$

for we have [1]: $\partial B(L(d)) / \partial L(d)$

$$\frac{\partial B(L(d))}{\partial L(d)} = Ep(d) \left\{ 1 + \frac{L(d) - L_o(d)}{EL(d)L_o(d)} \right\} \quad (13)$$

By comparing:

$$L(d) = L_o(d) \left\{ 1 + \frac{EL(d)[Ep(d) - Ep_o(d) + PI(d) + pen(d)]}{Ep_o(d)} \right\} \quad (14)$$

where

$L_o(d)$: Initial load at d th day.

- $EL(d)$: Elasticity of load at d th day
- $EP_o(d)$: Original and spot electricity price at d th day.
- $PI(d)$: Incentive price in d th day.
- $pen(d)$: Penalty at load in d th 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:

$$F = Min \{ J_1^{LU}, J_2^{LU}, J_3^{LU}, J_4^{LU} \} \tag{15}$$

where

$$J_1^{LU} = \frac{DV(DV+1)^{n_y}}{(DV+1)^{n_y-1}} \sum_{s=1}^{n_s} \sum_i \sum_j MC_{ij}^s ALV_{ij}^s p_s \tag{16}$$

$$J_2 = \sum_{s=1}^{n_s} \sum_{d=1}^{365} \sum_{u=1}^{n_u} CF_u^s (GE_{u,s}^d) p_s \tag{17}$$

$$J_3 = \frac{DV(DV+1)^{n_y}}{(DV+1)^{n_y-1}} \sum_{s=1}^{n_s} \sum_{d=1}^{365} \sum_{b=1}^{N_b} B_{d,s}^b LC_{d,s}^b p_s$$

$$J_4 = \sum_{s=1}^{n_s} \sum_{d=1}^{365} \sum_{k=1}^{n_b} |V_{k,s}^d - 1| p_s \tag{19}$$

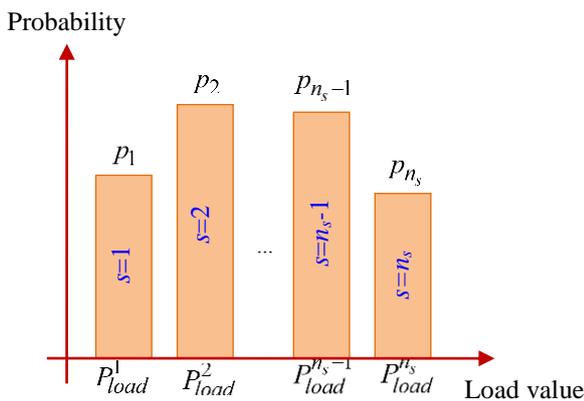


Fig. 2: The scenarios of load uncertainty.

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:

$$CM = \begin{bmatrix} 1 & cm_{12} & \dots & cm_{1n} \\ \frac{1}{cm_{12}} & 1 & \dots & cm_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \frac{1}{cm_{1n}} & \frac{1}{cm_{2n}} & \dots & 1 \end{bmatrix} \tag{20}$$

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

$$WE_i = \frac{\left(\prod_{j=1}^n cm_{ij} \right)^{\frac{1}{n}}}{\sum_{i=1}^n \left(\prod_{j=1}^n cm_{ij} \right)^{\frac{1}{n}}} \tag{21}$$

7. OPTIMIZATION TECHNIQUE

7.1. Multi-objective optimization

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

$$Minimize J(X) = (J_1(X), J_2(X), \dots, J_m(X)) \tag{22}$$

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:

$$\begin{cases} \forall i \in \{1, 2, \dots, m\} : J_i(X) \leq J_i(Y), \text{ and} \\ \exists i \in \{1, 2, \dots, m\} : J_i(X) < J_i(Y) \end{cases} \tag{23}$$

$J(X)$ 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]:

$$P_i = (p_i^1, \dots, p_i^d, \dots, p_i^n) \text{ for } i = 1, 2, \dots, N \tag{24}$$

where p_i^d represents the positions of the i th agent in the d th dimension.

Gravitational constant: The gravitational constant is

calculated:

$$G(t) = G_0 \exp(-\alpha t/T) \tag{25}$$

t and T are the current and total numbers of iterations, respectively. α is a constant factor.

Fitness evaluation for each agent: Fitness evolution is defined as bellow:

$$best(t) = \min_{j \in \{1, \dots, N\}} fitness_j \tag{26}$$

$$worst(t) = \max_{j \in \{1, \dots, N\}} fitness_j \tag{27}$$

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:

$$m_i(t) = \frac{fitness_i(t) - worst(t)}{best(t) - worst(t)} \tag{29}$$

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:

$$F_{ij}^d(t) = G(t) \frac{M_{pi}(t) \cdot M_{aj}(t) (p_j^d(t) - p_i^d(t))}{R_{ij}(t)} \tag{30}$$

$$F_i^d(t) = \sum_{\substack{j=Kbest \\ j \neq i}}^N rand_j F_{ij}^d(t) \tag{31}$$

$R_{ij}(t)$ 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:

$$a_i^d(t) = F_i^d / M_{ii}(t) \tag{32}$$

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

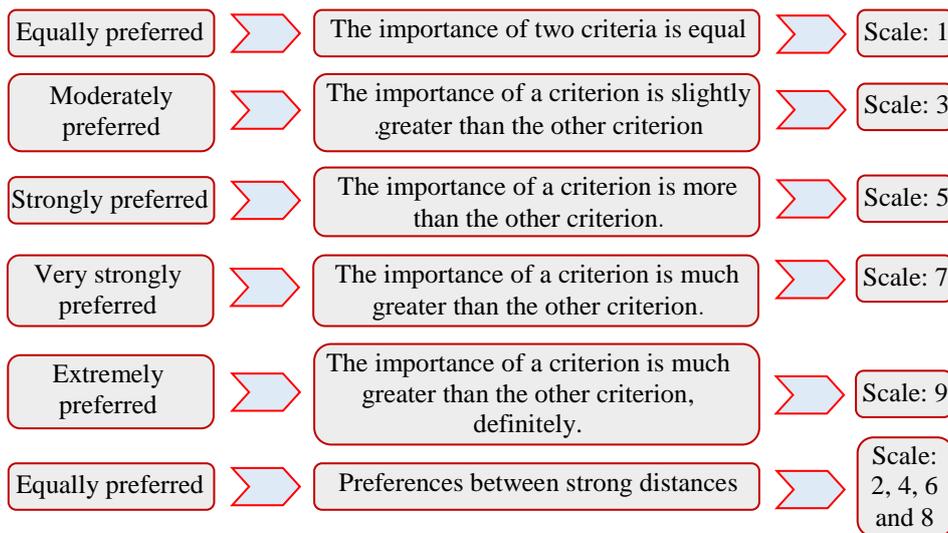


Fig. 3: Quantitative scale for pair comparison

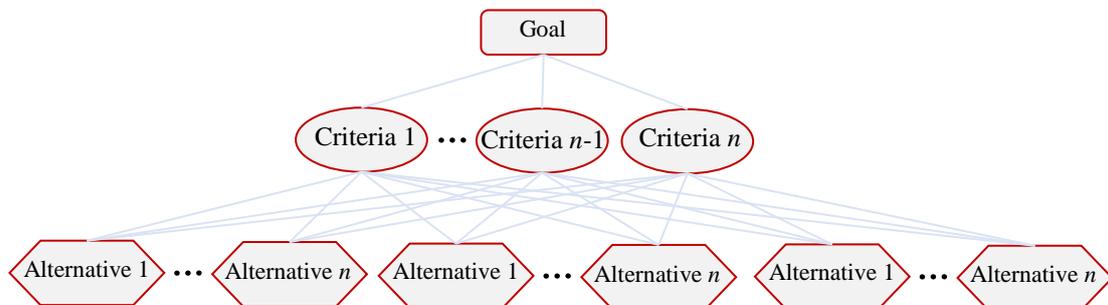


Fig. 4: AHT process

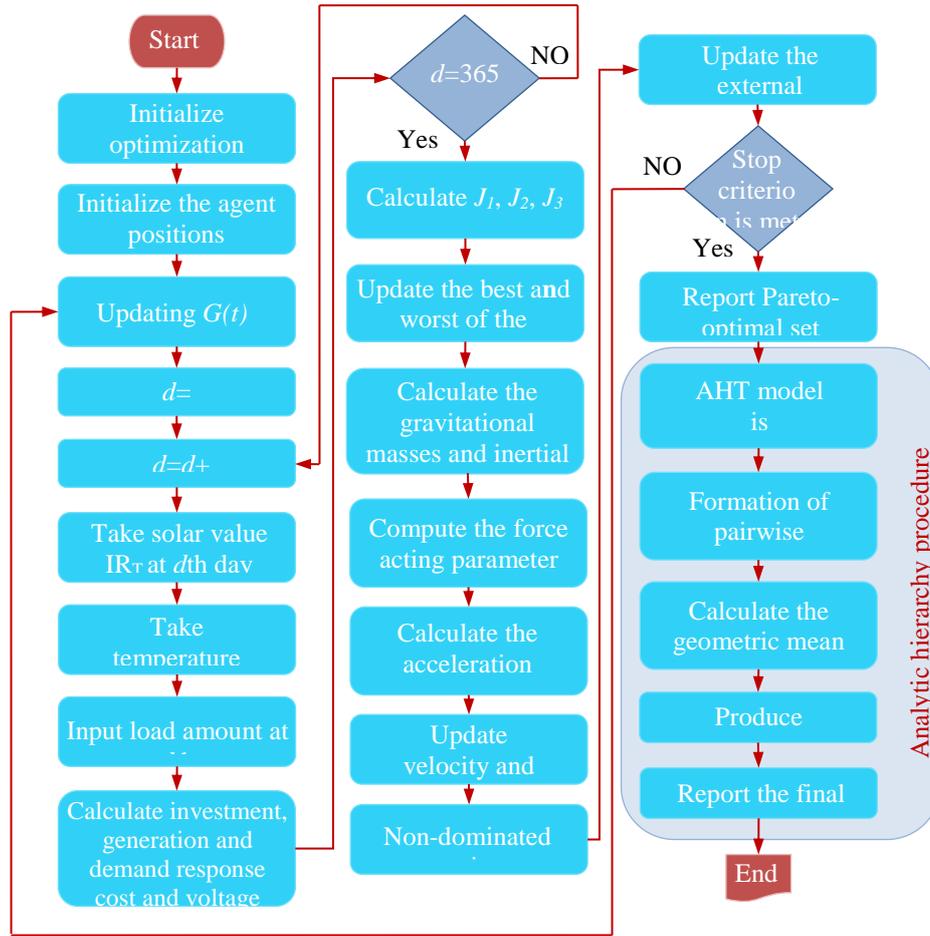


Fig. 5: The flowchart of the proposed method

$$s_i^d(t+1) = rand_i \times s_i^d(t) + a_i^d \tag{33}$$

$$P_i^d(t+1) = p_i^d + s_i^d(t+1) \tag{34}$$

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 1: The selected buses for DRT

Test system	DRT number	Bus number
Test system I	1	29
	2	24
	3	15
	4	17
	5	16
	6	10
	7	4
Test system II	1	16
	2	20
	3	11
	4	4
	5	6
	6	2

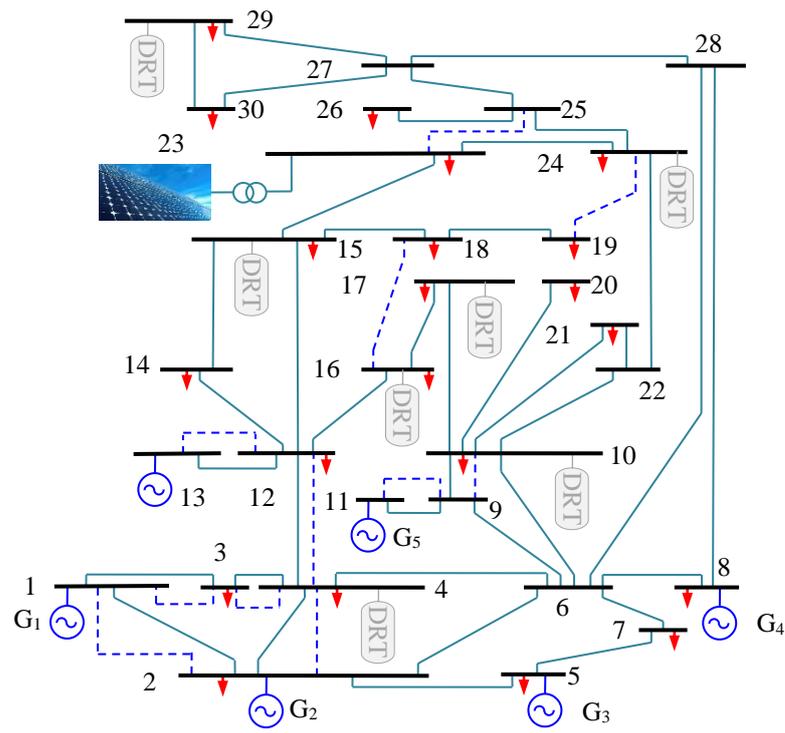


Fig. 6: The single line diagram of 30-bus IEEE system.

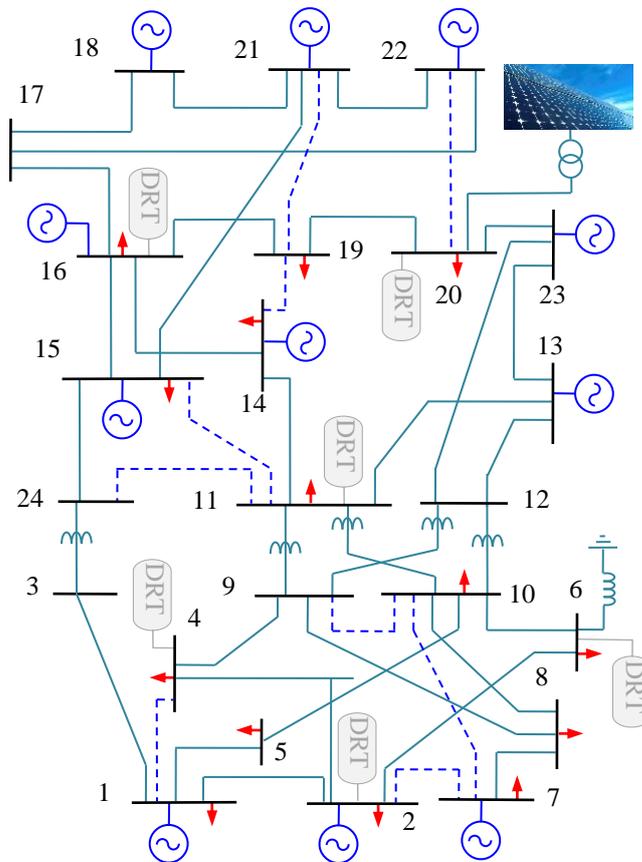


Fig. 7: The single line diagram of 24-bus IEEE system.

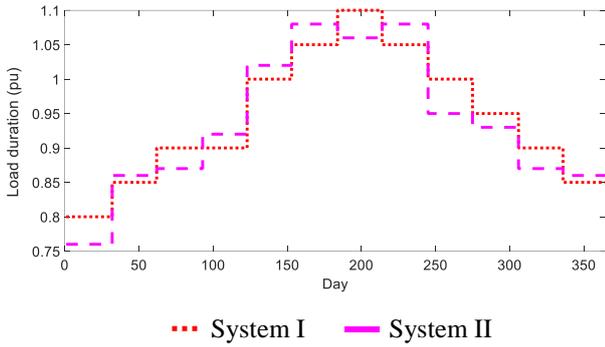


Fig. 8: Load curve for 365 days for test system I and II.

The profiles of electricity price and incentive price have been given in Table 2.

Table 2: The electricity and incentive price for 12 load levels.

	Load level	1	2	3	4	5	6	7	8	9	10	11	12
System I	Electricity price (\$/MWh)	11	11	12	12	12	13	13	13	12	12	11	12
	Incentive price (\$/MWh)	80	81	85	89	93	95	100	96	93	89	85	83
System II	Electricity price (\$/MWh)	22	23	25	26	28	30	32	30	28	26	25	24
	Incentive price (\$/MWh)	8	9	11	13	14	15	16	15	14	13	11	10

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.

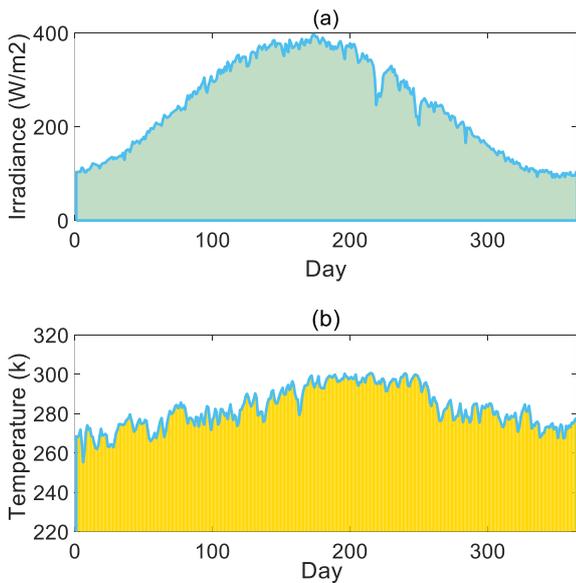


Fig. 9: Irradiation and temperature data for test system I (a) irradiation and (b) temperature.

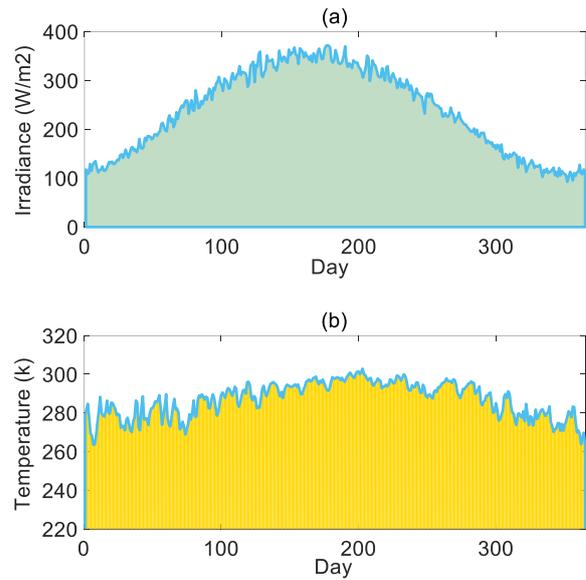


Fig. 10: Irradiation and temperature data for test system II (a) irradiation and (b) temperature.

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

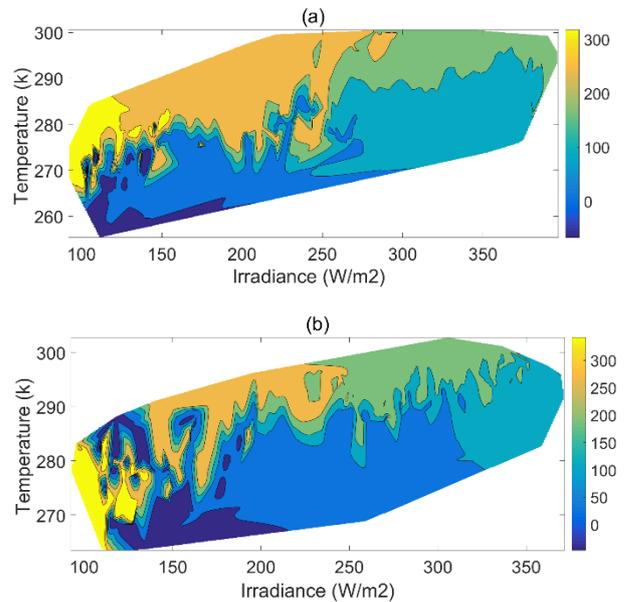


Fig. 11: Contour plot for data of the area of installed photovoltaic unit (a) test system I and (b) test system II.

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_1^{LU} to J_4^{LU} has been illustrated in Figs. 12 and 13.

Table 3: The new candidate lines for system I and II

	Candidate lines	From	To	Capacity (MW)	Reactance (p.u.)	Investment cost (\$ 10 ⁶ US)
Test system I	Line 1	1	2	30	0.0575	10
	Line 2	1	3	30	0.1852	25
	Line 3	2	4	30	0.1737	15
	Line 4	3	4	30	0.0379	10
	Line 5	9	10	30	0.110	14
	Line 6	12	13	65	0.140	9
	Line 7	9	11	30	0.208	8
	Line 8	4	12	65	0.256	5
	Line 9	16	18	50	0.139	15
	Line 10	19	24	30	0.512	8
	Line 11	23	25	40	0.671	14
Test system II	Line 1	1	4	175	0.015	7.72
	Line 2	2	7	175	0.021	10.82
	Line 3	7	10	175	0.02	10.29
	Line 4	9	10	175	0.016	8.24
	Line 5	11	15	500	0.022	11.13
	Line 6	11	24	500	0.011	5.66
	Line 7	14	19	500	0.017	8.76
	Line 8	19	21	500	0.014	7.21
	Line 9	20	22	500	0.014	7.21

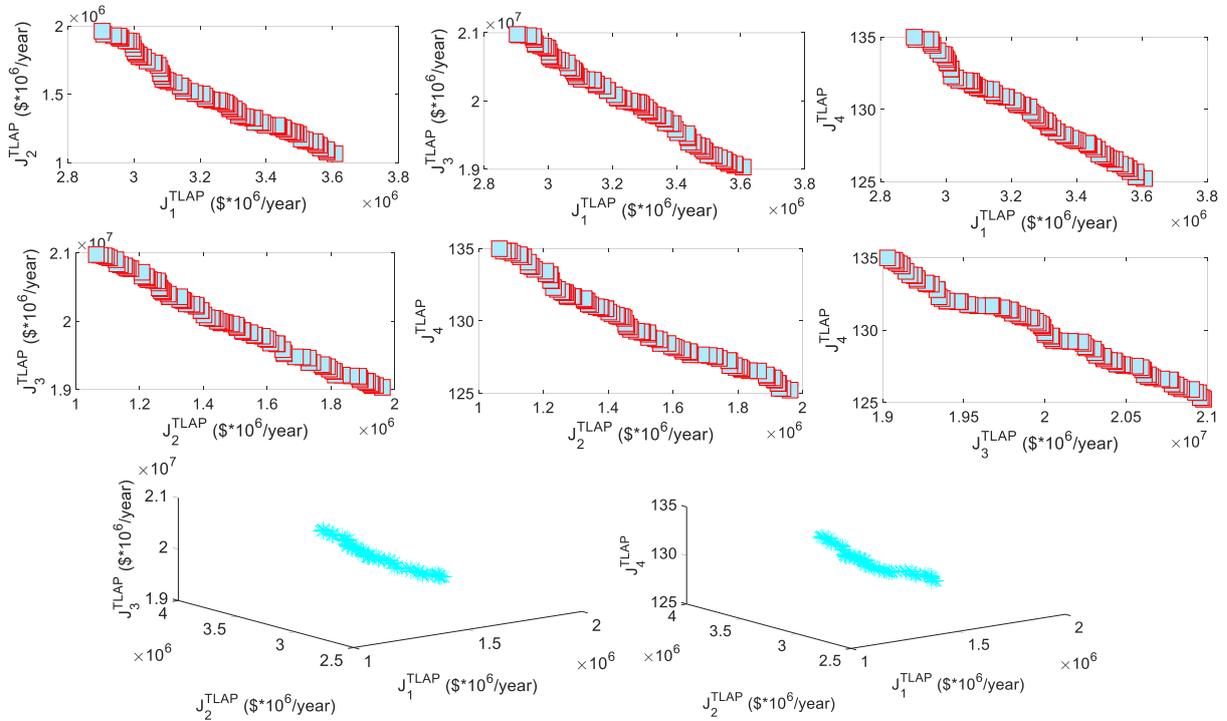
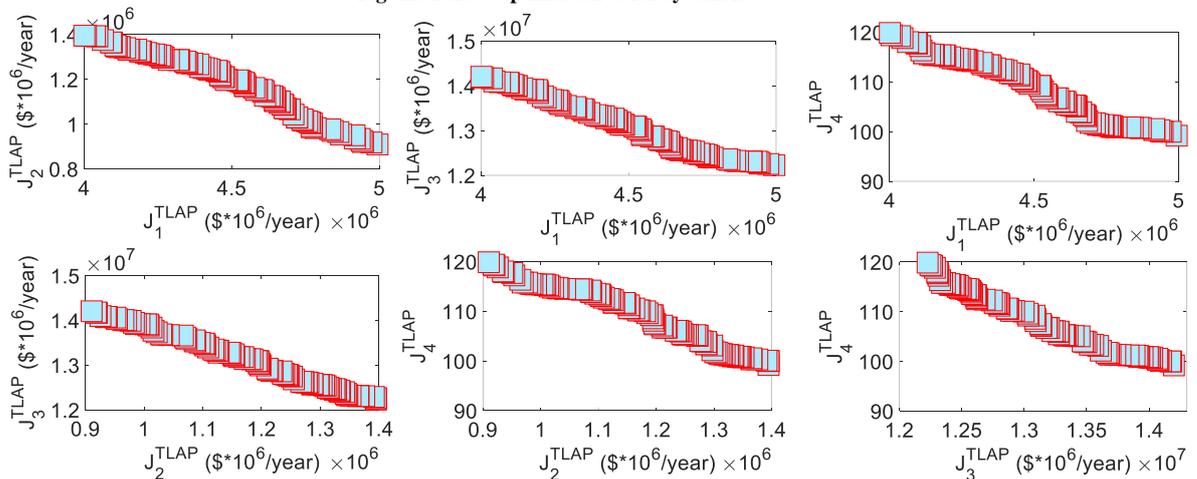


Fig. 12: Pareto-optimal curve for system I.



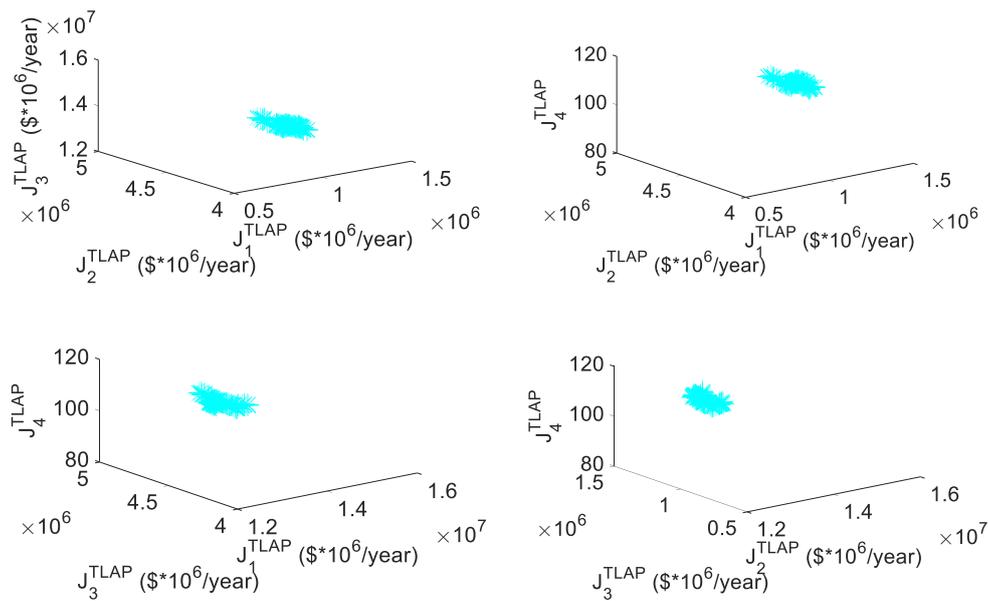


Fig. 13: Pareto-optimal curve for system II

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 Fig. 14. According to this figure, as for example, from the perspective of criteria J_1^{LU} , p_1 is superior than p_2 .

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 .

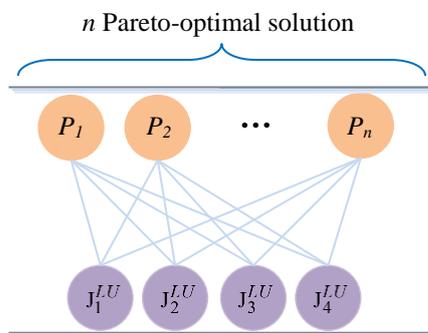


Fig. 14: The desired hierarchical model.

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.

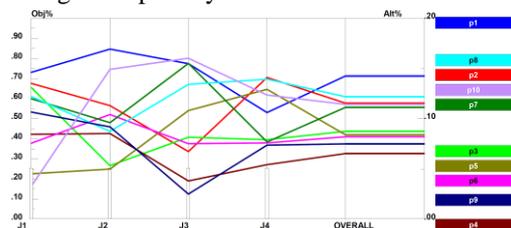
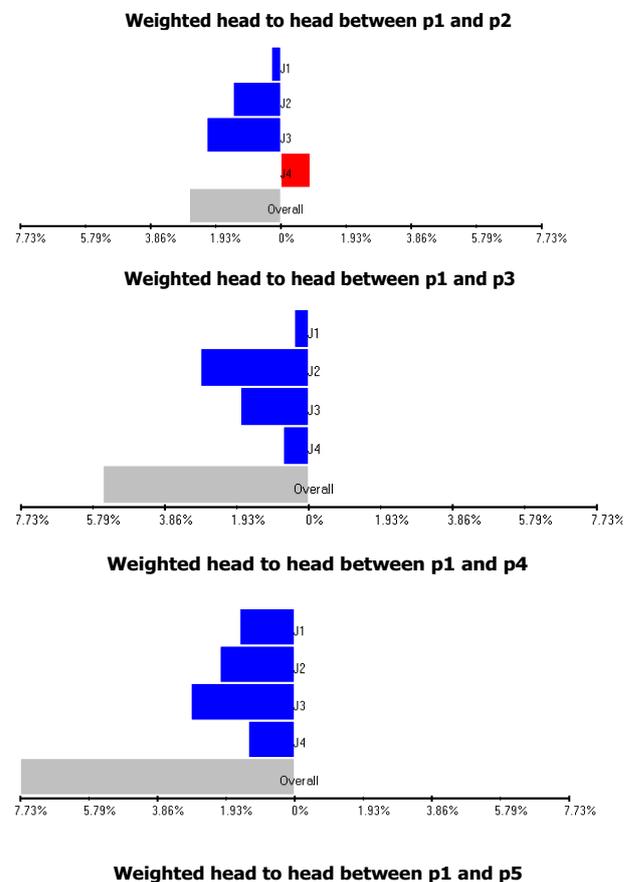


Fig. 15: Efficiency sensitivity chart

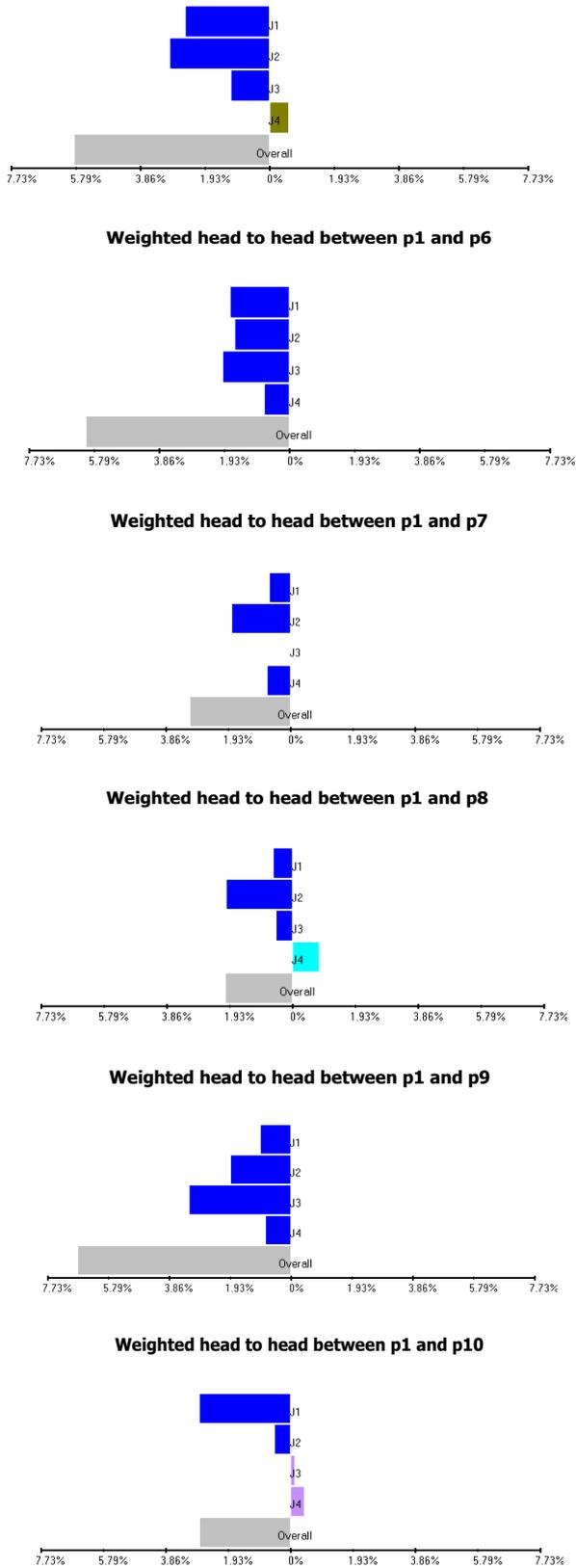


Fig. 16: Prioritization of the Pareto-solution with respect to

$$J_1^{LU} \text{ to } J_4^{LU}$$

Prioritization of Pareto-optimal solutions with respect to J_1^{LU} to J_4^{LU} has been shown in Fig. 16. Also, final

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.

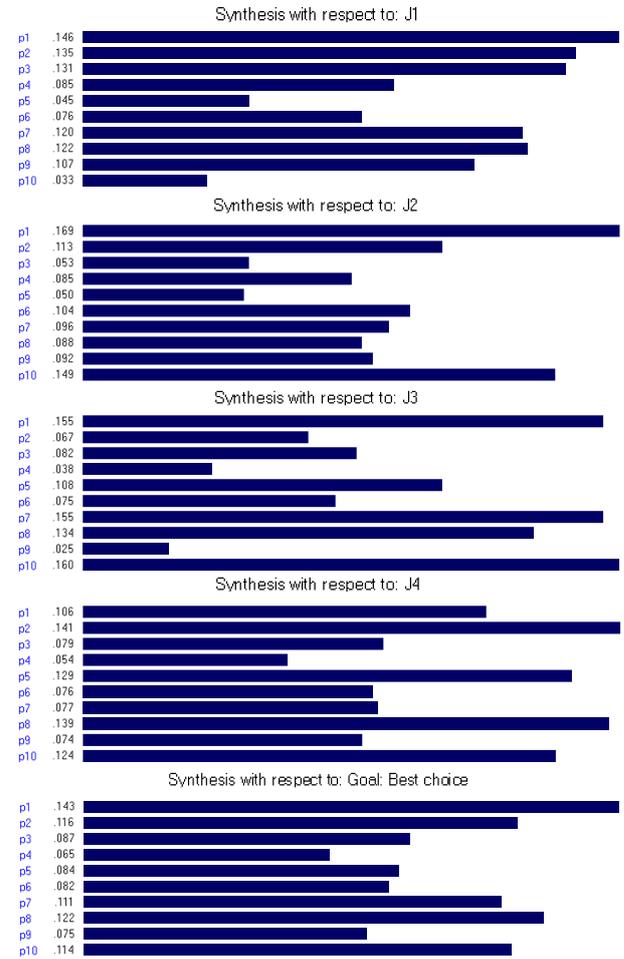


Fig. 17: General prioritization based on relative weight of each solution.

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.

Table 4: lines added to system I.

	n_{1-2}	n_{1-3}	n_{2-4}	n_{3-4}	n_{9-10}	n_{12-13}	n_{9-11}	n_{4-12}	n_{16-18}	n_{19-24}	n_{23-25}
Scenario 1											
Scenario 2											
Scenario 3											
Scenario 4											

Table 5: lines added to system II.

	n_{1-4}	n_{2-7}	n_{7-10}	n_{9-10}	n_{11-15}	n_{11-24}	n_{14-19}	n_{19-21}	n_{20-22}
Scenario 1									
Scenario 2									
Scenario 3									
Scenario 4									

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 , 30.0441×10^6 , 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 , 19.9687×10^6 , 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.

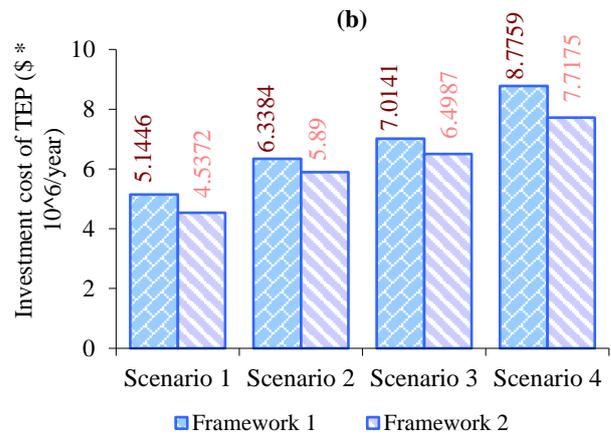


Fig. 18: Comparison of J_1 for (a) test system I and (b) test system II.

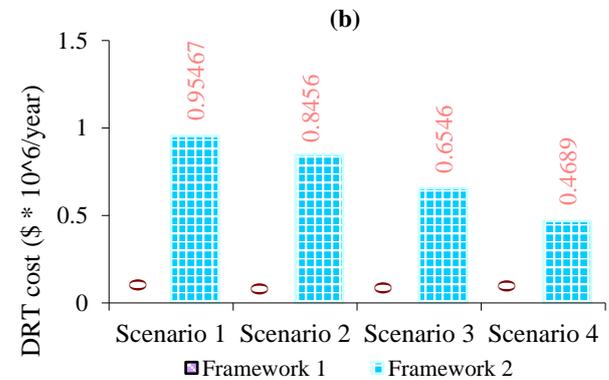
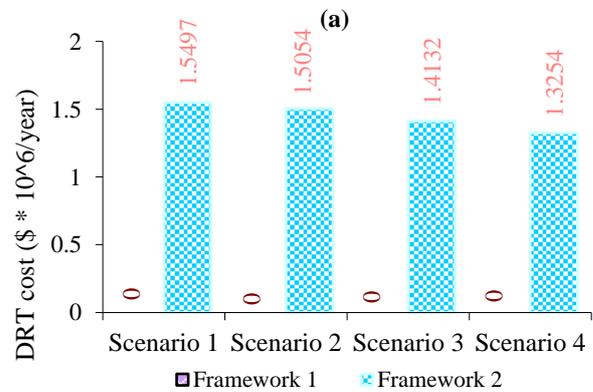
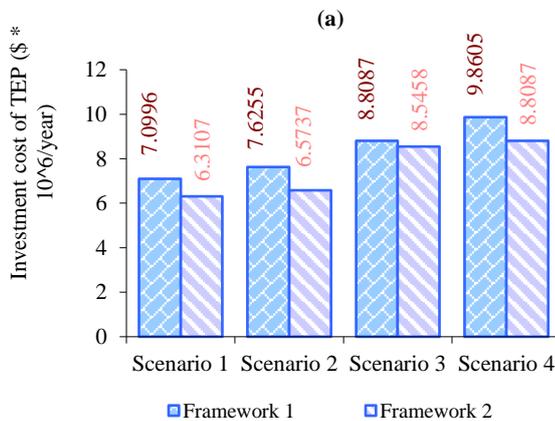


Fig. 19: Comparison of J_2 for (a) test system I and (b) test system II.



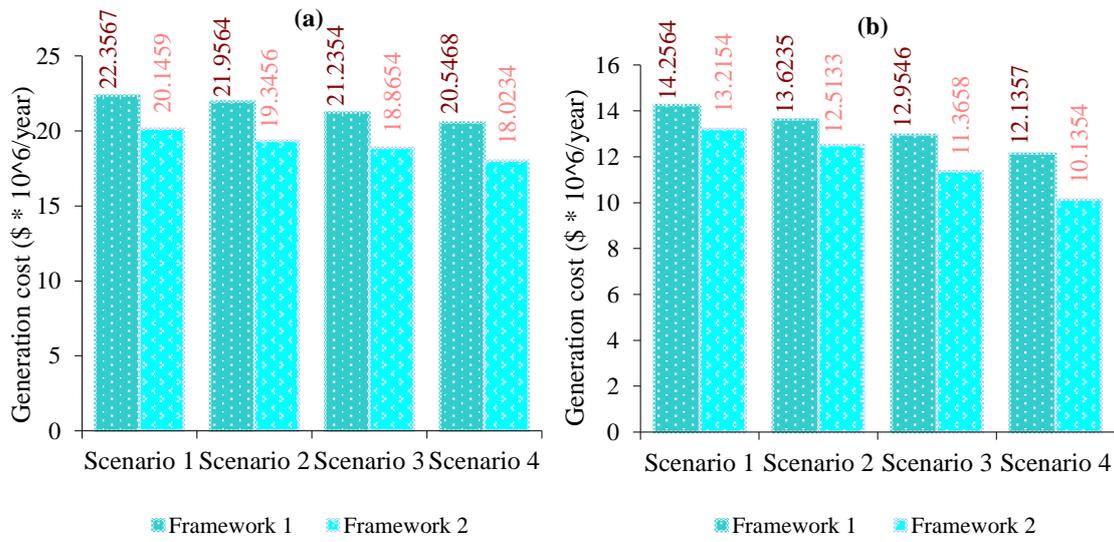


Fig. 20: Comparison of J_3 for (a) test system I and (b) test system II

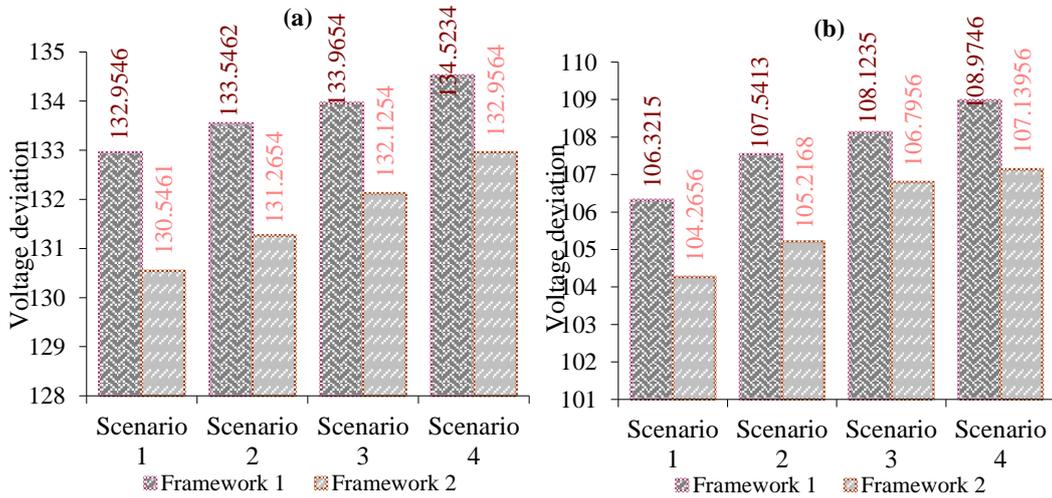


Fig. 21: Comparison of J_4 for (a) test system I and (b) test system II.

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.

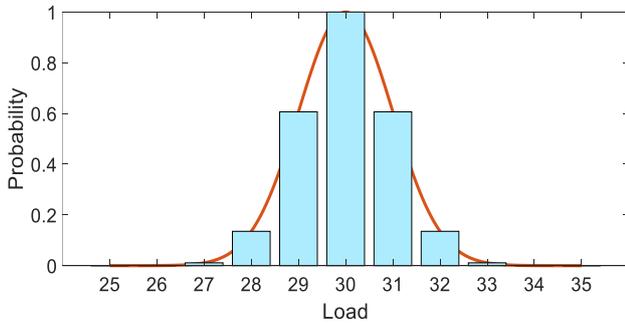


Fig. 22: Probability distribution function for load bus 8 in system I.

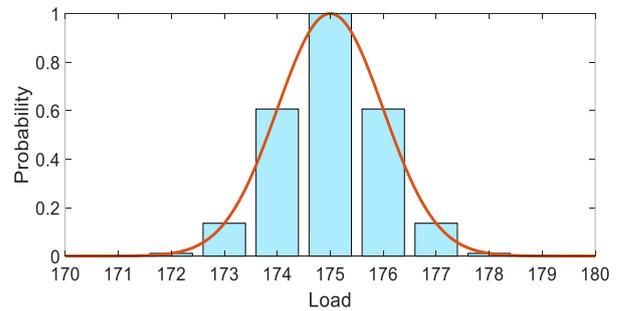


Fig. 23: Probability distribution function for load bus 9 in system II.

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.

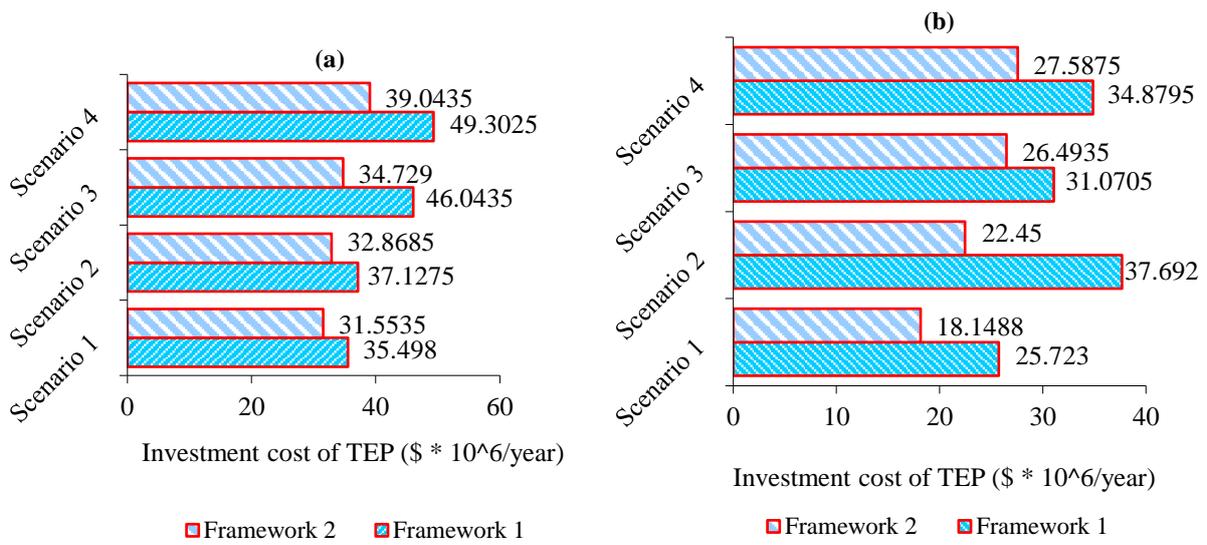


Fig. 24: J_1 value in uncertainty condition, (a) system I, (b) system II.

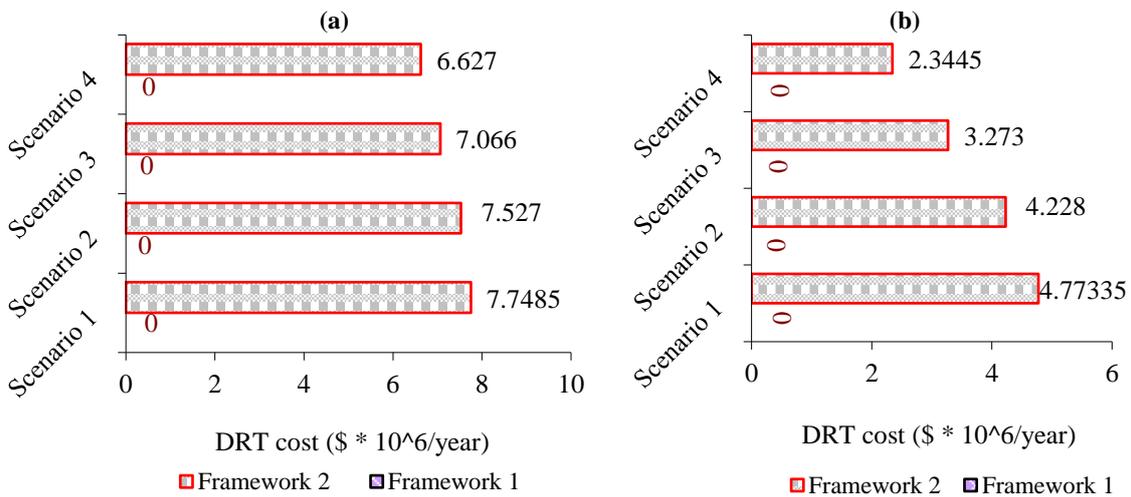


Fig. 25: J_2 value in uncertainty condition, (a) system I, (b) system II.

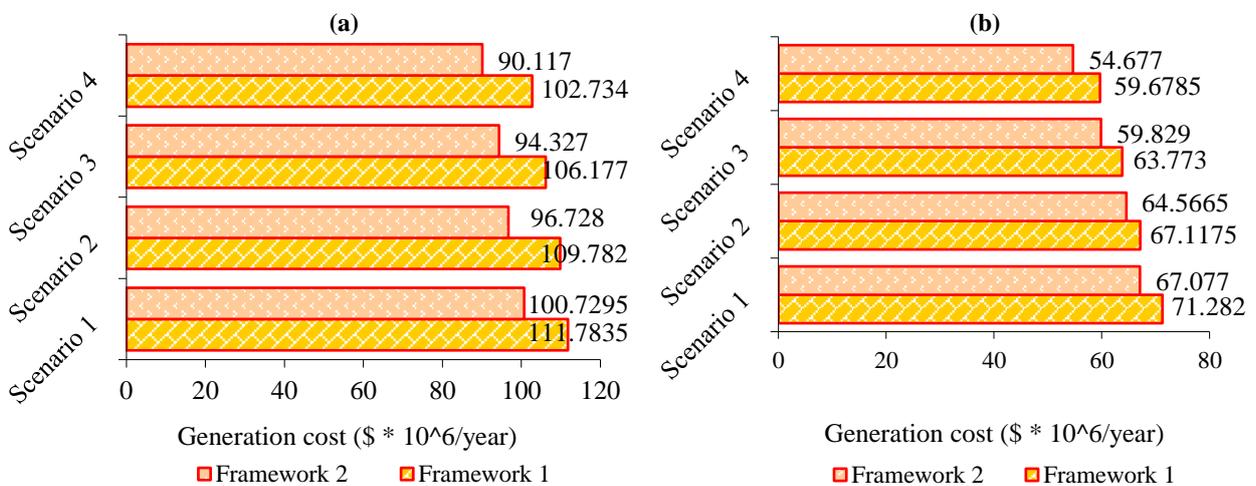


Fig. 26: J_3 value in uncertainty condition, (a) system I, (b) system II.

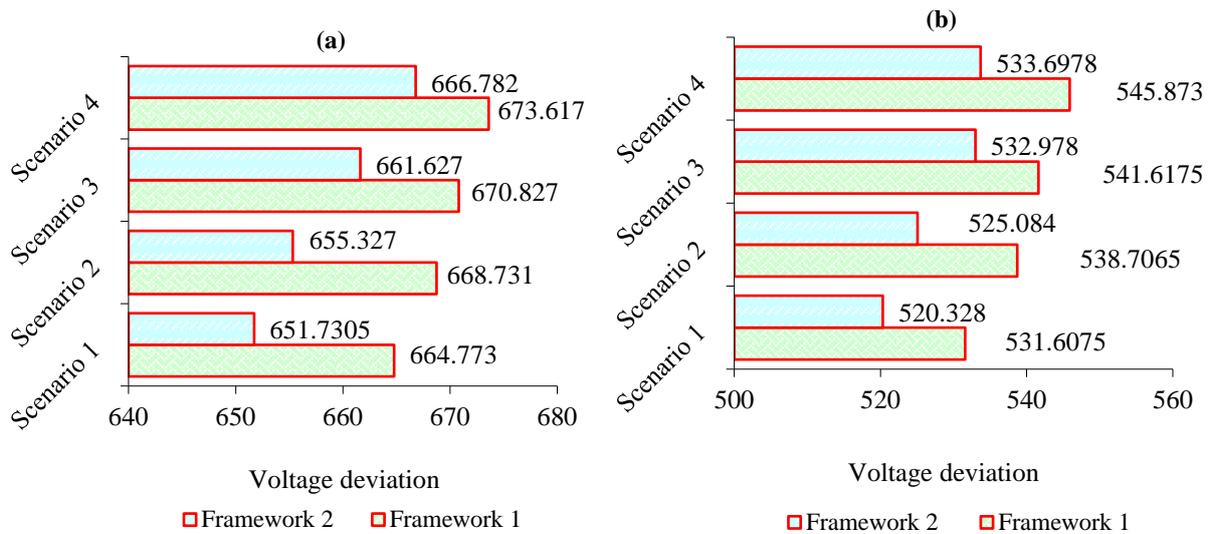


Fig. 27: J_4 value in uncertainty condition, (a) system I, (b) system II.

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.

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