# Economic analysis of private investor participation in long-term distribution network planning

ALI ASHOORNEZHAD[1], HAMID FALAGHI[1,*], AMIN HAJIZADEH[2], AND MARYAM RAMEZANI[1]

[1] Faculty of Electrical and Computer Engineering, University of Birjand, Birjand, Iran.
[2] Department of Energy Technology, Aalborg University, Esbjerg, Denmark.
[*] Corresponding author email: falaghi@birjand.ac.ir

*Manuscript received 22 October, 2021; revised 02 June, 2022; accepted 06 June, 2022. Paper no. JEMT-2110-1337.*

**Recently, distribution network planners have enacted some facilities and policies to utilize the potential of private investor participation. Network planners should propose an attractive scheme to persuade the investor to take part in the long-term planning. In this paper, a distribution network planning approach with the cooperation of the private investor is proposed. In the proposed approach, the network planner optimizes the battery energy storage systems (BESS) installed by the investor to satisfactorily shave the peak load of the system. Through this optimization, the planner provides a financial resource to support the investor during the planning horizon. The benefits of both participants are considered and evaluated through economic indices such as payback period years (PPY), profit investment ratio (PIR), internal rate of return (IRR), and net present value (NPV). Due to the presence of photovoltaic (PV) in the system, and the inherent intermittency of load, a K-means data clustering algorithm is employed to catch the uncertainty of the problem. The obtained mixed-integer nonlinear model is solved via particle swarm optimization (PSO) and the proposed approach is tested and implemented on a 16-bus distribution test system. A sensitivity analysis on the incentive price and investment cost is also performed. Finally, the obtained results are compared with the incentive price of several countries, and it is shown that the proposed approach leads to an acceptable result and reasonable incentive price, while the planner's targets are considered as well.** 

***keywords:*** *Distribution network planning, private investor participation, battery energy storage system, photovoltaic economic analysis.*

http://dx.doi.org/10.22109/jemt.2022.310342.1337

## NOMENCLATURE

| | |
|---|---|
| $k$ | number of clusters |
| $n$ | number of objects |
| $j$ | index for clusters |
| $i$ | index for objects |
| $x_i^{(j)}$ | object in data clustering |
| $c_j$ | centroid for cluster (j) |
| $NCF_y$ | yearly net cash flow |
| $BE_{h,cl}^{stn}$ | sent energy from battery to network |
| $BE_{h,cl}^{stn}$ | sent energy from battery to network |
| $BE_{h,cl}^{rfn}$ | received energy from network to battery |
| $IP$ | offered incentive price |
| $MP_h$ | Efficiency |
| $BE^{pr}$ | battery BESS power rate |
| $C^{OM}$ | operation and maintenance cost |
| $y$ | index for the year of planning |
| $h$ | index for hour |
| $\rho_{cl}$ | probability of cluster |
| $cl$ | index for cluster |
| $c-num$ | number of clusters |
| $p-horizon$ | planning horizon years |
| $dr$ | discount rate |
| $\alpha_y$ | binary variable related to installing a new substation |
| $\beta_y$ | investment cost of substation |
| $C_y^{Isub}$ | investment cost of substation |
| $C_y^{Usub}$ | upgrading cost of substation |
| $P_{h,cl}^{loss}$ | total power loss of the system |
| $P_{h,cl}^{sub}$ | total power of substation |
| $t-load$ | number of load in the system |

| | |
|---|---|
| $b$ | index for bus |
| $V_{min}$ | minimum permitted voltage of buses |
| $V_{max}$ | maximum permitted voltage of buses |
| $S^{sub}_{max}$ | maximum apparent power of the substation |
| $BE^{se}_{h+1}$ | stored energy at BESS |
| $\chi^{ch}_{h}$ | binary variable for charging battery |
| $\chi^{dis}_{h}$ | binary variable for discharging battery |
| $\eta$ | charge/discharge efficiency |
| $BE^{pr}_{max}$ | maximum permitted power rate of battery |
| $C^{pr}_{inv}$ | investment cost of BESS power rate |
| $C^{cap}_{inv}$ | investment cost of BESS energy capacity |
| $BE^{pr}$ | BESS energy capacity |
| $C^{cap}_{rep}$ | replacement cost of BESS |

## 1. INTRODUCTION

From a distribution network planner's point of view, load growing is a challenging issue that should be well addressed in long-term planning. In such conditions, upgrading and installing HV/MV substations is a primary solution that is very common in planning strategies [1]. However, in recent years, the integration of renewable energy resources into the distribution network has been increased as an alternative to supply load demands close to the customers. Although these resources can provide a part of demand especially for end-users, they cannot be considered as an absolute replacement tool for system requirements like HV/MV substations [2]. Nonetheless, it can defer the need of the system to install such requirements, and therefore helps the system operator to save planning costs [3].
Battery energy storage systems (BESS) as distributed generation (DG) resources have recently attracted significant attention, especially in combination with renewable energy resources (RER). BESS can help the system's operator to overcome RERs intermittencies [4]. Moreover, BESS is a useful instrument to reduce reverse power flow, more specific in photovoltaic (PV) equipped systems. They can absorb energy either during off-peak hours or whenever produced power is higher than consumption, and then inject energy into the system during peak hours [5]. This procedure modifies the load profile and brings a flatter profile which is entirely valuable for both network planners and network operators [6].
Distribution network expansion planning problems in the presence of RER and BESS have been investigated in numerous studies. These research can be classified based on different categories, including terms of planning, type of resources, solving methodology, and type of RERs [7]. Additionally, some papers have studied the status of HV/MV substations and feeder routing during the planning horizon. In [8] a multi-objective mixed-integer nonlinear planning framework for long-term planning is proposed. In [9] two-layer network planning with the aim of total peak shaving is considered, where PV plants have participated in the problem. The impact of PV-BESS in peak shaving and therefore in the planning problem has been considered in [10]. Similarly, the effect of joint implementation of BESS with RER in network planning has been presented in [11]–[13].
In most of the considered papers, Distribution Companies or governmental sectors are responsible for installing RERs, while it imposes a considerable initial cost at the first year of planning problem [14]. In order to appropriately dealing with this problem, many countries have enacted encouraging policies to persuade private investors to participate in long-term projects [15]–[18]. To reach this aim, various policies have been proposed by the planners including, feed-in-tariff, net metering, and net billing policies [19]. Furthermore, different economic indices such as levelized cost of electricity (LCOE), net present value (NPV), internal rate of return (IRR), and payback period year (PPY) have been introduced and evaluated to assess a project from the investor's point of view [20].
The simultaneous implementation of RERs and long-term network planning problem with the cooperation of private investors have been assessed in several studies [21]–[23]. In [21] a network planning framework from an investor's point of view was proposed, where the system targets were considered as problem constraints. An incentive-based multistage network planning was proposed in [22]. In the study, the incentive prices for private investors were evaluated regarding different buses and several economic criteria. The cooperation of the Distribution Company and private investors with respect to the system of system architecture was presented in the [23]. In this framework, the Distribution Company was looking for the optimal system structure, whereas the profit of private investors was also regarded.
Although the participation of private investors in the distribution network planning problem has been addressed in several studies, the joint implementation of BESS to PV-connected network in a long-term problem regarding private investors has not been considered yet. Therefore, in this paper, a distribution network planning approach with the aim of the maximum benefit of the private investor is presented, while the network planer's targets are also investigated. The main contributions of the paper are as follows:

- The participation of the private investor in the long-term distribution network planning is proposed, where, unlike many studies, the source of incentive prices is clarified.
- Different economic indices are considered to evaluate the planning problem from the investor's point of view. Meanwhile, the economic and technical targets of the Distribution Company are also considered.
- A sensitivity analysis on the economic indices and investment cost is performed. Furthermore, a comparison of the incentive prices of several countries with the obtained results is also presented to validate the obtained results.

The rest of the paper is organized as follows:
In section 2, the methodology of the proposed approach and uncertainty modeling are presented. The formulation of the planning problem, the economic reformulation, the system constraints, and also the solution method are introduced in section 3. In section 4 the test system is demonstrated and the numerical results of the problem are presented. The Sensitivity analysis is also presented in this section. Finally, the conclusion of the paper is summarized in section 5.

## 2. MODELING OF THE PROPOSED PLANNING APPROACH REGARDING THE COOPERATION OF PRIVATE INVESTOR

In the proposed approach, the planner is seeking an optimal network structure which is the most profitable project from the private investor's point of view. To reach this goal, the network planner should provide a financial resource to buy energy from the investor. This resource is mainly provided by saving the total cost of the planning problem over horizon years. In this paper, two different cases are introduced and investigated to evaluate the maximum financial resource. Firstly, the basic case is considered as an ordinary plan, while there is no private investor and no BESS in the problem. Afterward, the proposed case which is a problem in the presence of BESS and the private investor is assessed. In the proposed plan, the BESS is obliged to supply an important part of the system load, which eventually leads to system peak shaving. This shaved load profile would defer the requirement of the system to install or upgrade HV/MV substations, which results in a lower planning cost. Finally, by comparing the basic case and the proposed case, the maximum payable cost to the investor is obtained. The conceptual model of the proposed approach for the distribution network planning problem with the cooperation of the private investor is illustrated in Fig. 1. As this figure shows, the first part of the problem is assigned to catch the uncertainty treatment of the system. Then, the basic planning problem is implemented to evaluate the basic cost. Afterward, the proposed approach is applied and the financial resources are evaluated by comparing these two cases. The difference between these plans determines the maximum incentive price that the planner can offer to the investor. By computing the incentive price, the total paid cost to the investor and the total planning cost of the proposed approach is calculated. Finally, the optimum solution is determined while it not only does not impose any additional costs on the planner but also leads to the minimum payback period years.

### A. Uncertainty modeling

The presence of RERs in the planning problem increases the complexity of the problem since they show an intermittency treatment due to time-varying, geographical and climatological nature. Moreover, the distribution system has an inherent uncertainty that comes from load variation. As a consequence, in this paper, the planner is facing a couple of uncertain resources associated with PV and the load of the system. Therefore, it is very important to utilize uncertainty modeling to enhance the precision of results.
There is a wide range of methods to model the uncertainty of the system, including the analytical method, approximation method, and numerical and sampling method. Monte Carlo simulation and the point estimate method are well-known methods that are frequently used in such problems [24]. But in this paper, the presence of battery in the problem entails the modeling to utilize time-series data to implement charge/discharge strategies. Therefore, a group of 24-hours data is required to capture the uncertainty and performing load flow. To achieve this goal, a data clustering algorithm is employed in this paper.
Among several clustering algorithms, K-means is a practical and simpler one. This algorithm is used to classify the objects into $K$ disjoint clusters. Objects with the nearest mean which usually show a similar feature are located in the same cluster. K-means is an iterative algorithm that starts with $K$ initial data as cluster center [25]. The membership and cluster centers are updated through each iteration until the objective function is satisfied. In the k-means clustering algorithm, we are looking for the minimum objective function $(J)$ which comprises of squared error as (1):

$$J = \sum_{j=1}^{k} \sum_{i=1}^{n} \left\| x_i^{(j)} - c_j \right\| \quad \textbf{(1)}$$

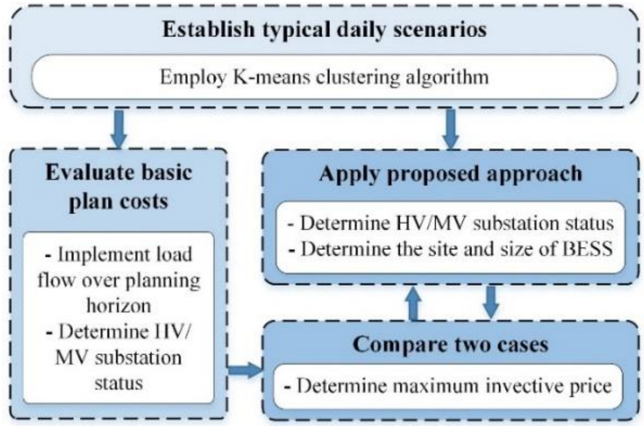


**Fig. 1.** Conceptual model of the proposed planning approach

In the above function, the $\left\| c_i^{(j)} - c_j \right\|$ is the distance function and should be evaluated in every iteration.

### B. Planning problem with and without private investor participation

As mentioned before, the absence and presence of the private investor divide the problem into two cases; the basic case, and the proposed case. The basic case is a routine planning problem without any BESS in the system. In this case, the planner has to appropriately support the horizon load of the system by installing or upgrading HV/MV substations. Therefore the planner has to only optimize the status of the substation in the basic case.
On the other hand, the second case is a planning problem concerning the proposed approach. In this case, the private investor is another participant in the problem which is responsible to install batteries in the system. Therefore, the proposed case should be investigated from both participant's standpoint and all targets should be fully addressed as follows:

- **Planer's point of view:** The network planner is looking for a system structure with a minimum price. Additionally, the best location and capacity of batteries are also determined by the planner to reach a reasonable peak shaving. Reaching a higher percentage of load shaving would cause postponement in upgrading HV/MV substation. Consequently, the planner can save a higher amount of money, which leads to offer a higher incentive price to the investor. The planner can increase the amount of supportive price until the total cost of the proposed case does not exceed the cost of the basic case. Any planning result which encroaches on this constraint is considered a non-profitable plan.

- **Investor's point of view:** Investors are usually looking for the most profitable plan, regardless technical operation of the distribution system. Thus in the inventor's modeling, just economic metrics are assessed. A project is considered a profitable plan when economic criteria such as PIR or PPY show a reasonable value. In this paper, the Feed-in Tariff policy is considered as an incentive strategy.

# 3. MATHEMATICAL FORMULATION AND SOLUTION METHOD

## A. Objective function

In the proposed approach, the planner should convince private investors to participate in the planning. Therefore, the planner is looking for the maximum incentive price that could offer to the investor, without enduring any additional cost to the system. Thus, the objective function is defined based on the profit of the investor. In this condition, system planning costs are considered as equality constraints which is explained in the next subsection. Moreover, some technical constraints should be assessed in the problem. It should be noticed that peak shaving is an innate target of the problem, whereas if the network the planner reaches a plan with a smoother load, the requirement cost of upgrading and/or installing HV/MV substations will be declined. This leads to higher saved costs and consequently, the maximum paid cost to the investor is increased, which finally leads to a lower PPY. The objective function of the proposed distribution network planning is as follows:

$$\min\ PPY = Y_{lng} + \frac{\left|NCF_{lny}\right|}{\left|NCF_{lny}\right| + NCF_{lny+1}} \tag{2}$$

Where $Y_{lng}$ is the year of planning with the last negative amount of net cash flow, $CNF_{lny}$ is the last negative amount of net cash flow among planning years, and $CNF_{lny+1}$ is the first positive amount of net cash flow among planning years [22].

Yearly net cash flow can be calculated by evaluating the cash inflow and cash outflow of the investor. Cash inflow depends on the sold energy to the system which is proportional to the incentive price. On the other hand, cash outflow depends on two parameters; operation and maintenance cost, and buying energy from the network to charge batteries, as shown in (3):

$$NCF_y = \sum_{cl=1}^{c-num}\sum_{j=1}^{24}\left\{\begin{array}{l}\left(BE_{h,cl}^{stn} \times IP \times \rho_{cl}\right)\\ -\left(BE_{h,cl}^{rfn} \times MP_h \times \rho_{cl}\right)\\ +\left(BE^{pr} \times C^{OM}\right)\end{array}\right\} \tag{3}$$

As mentioned before, this paper proposed a plan to provide the source of incentive prices by saving costs during the planning horizon. This saved cost is calculated by subtracting the cost of the basic plan $(C_{basic})$ and proposed plan $\left(C_{p-plan}\right)$.

$$IP = \frac{C_{basic} - C_{p-plan}}{\sum_{y=1}^{p-horizon}\left\{\left(\sum_{cl=1}^{c-num}\sum_{h=1}^{24} BE_{h,cl}^{stn}\right)\Big/(1+dr)^y\right\}} \tag{4}$$

Each of the plan costs is composed of three main parts, including investing and/or upgrading cost of substation $\left(IU^{sub}\right)$, cost of losses $\left(C^{loss}\right)$, and bought energy from the market $\left(C^{up-m}\right)$. However, the proposed plan consists of sold energy to the BESS $(CB^{ctb})$ as well. The relations of these plans are presented in (5) to (10).

$$C_{basic} = \sum_{y=1}^{p-horizon}\left\{\frac{IU_y^{sub} + C_y^{loss} + CM_y^{up-m}}{(1+dr)^y}\right\} \tag{5}$$

$$IU_y^{sub} = \alpha_y \times C_y^{Isub} + \beta_y \times C_y^{Usub} \tag{6}$$

$$C_y^{loss} = \sum_{cl=1}^{c-num}\sum_{h=1}^{24}\left(P_{h,cl}^{loss} \times MP_h \times \rho_{cl}\right) \tag{7}$$

$$CM_y^{up-m} = \sum_{cl=1}^{c-num}\sum_{h=1}^{24}\left(P_{h,cl}^{sub} \times MP_h \times \rho_{cl}\right) \tag{8}$$

$$C_{p-plan} = \sum_{y=1}^{p-horizon}\left\{\frac{IU_y^{sub} + C_y^{loss} + CM_y^{up-m} - CB_y^{ctb}}{(1+dr)^y}\right\} \tag{9}$$

$$CB_y^{ctb} = \sum_{cl=1}^{c-num}\sum_{h=1}^{24}\left(BE_{h,cl}^{rfn} \times MP_h \times \rho_{cl}\right) \tag{10}$$

## B. Economic formulation

In order to evaluate the planning problem from the investor's standpoint, it is needed to assess the results through some economic metrics. Hence, four economic criteria are computed in this study. One of the most important economic indices that may effectively influence the investor's decision is PPY, which in this paper is considered as the objective function. Net present value $(NPV)$ is presented as the second index as presented in (11).

$$NPV = \sum_{y=1}^{p-horizon}\frac{NCF_y - C_y^{rep}}{(1+dr)^y} - C_0 \tag{11}$$

$$C_0 = C_{inv}^{pr} \times BE^{pr} + C_{inv}^{cap} \times BE^{pr} \tag{12}$$

$$C_y^{rep} = C_{rep}^{cap} \times BE^{pr} \tag{13}$$

In the above equations, $C_0$ is the initial investment cost of BESS as represented in (12), and $C^{rep}$ is the replacement cost of BESS that based on the calculation of this paper, it will happen in the eleventh year of the planning.

$$NPV = \sum_{y=1}^{p-horizon}\frac{NCF_y - C_y^{rep}}{(1+dr)^y} - C_0 \tag{14}$$

The next economic index is the profit investment ratio $(PIR)$ which is used to calculate the ratio between the present value of the total benefit obtained by the investor and the present value of investment cost. This economic index is calculated according to (15).

$$PIR = \frac{\sum_{y=1}^{p-horizon}\frac{NCF_y - C_y^{rep}}{(1+dr)^y}}{C_0} \tag{15}$$

Finally, the internal rate of return $(IRR)$ is considered to assess the attractiveness of planning from the investor's point of view. IRR is an interest rate in which the net present value of the planning problem is becoming zero. A project is considered a profitable plan if the IRR is being greater than the discount rate. This factor is evaluated as follow:

$$\sum_{y=1}^{p-horizon}\frac{NCF_y - C_y^{rep}}{(1+IRR)^y} - C_0 = 0 \tag{16}$$

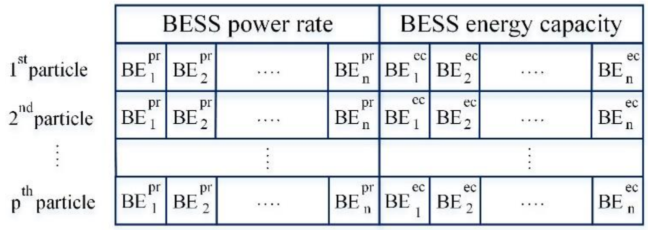


**Fig. 2.** Proposed structure of particle in PSO

### C. Problem constraints

Due to the requirement of the solution method to perform load flow during each hour of clusters, one of the first and foremost constraints of the system is the energy balance in the system. This constraint should be satisfied for both active and reactive power as presented in (17) and (18).

$$BE^{rfn}_{h,cl} = P^{loss}_{h,cl} + BE^{stn}_{h,cl} + \sum_{b=1}^{t-load} P^{load}_{h,cl,b} \tag{17}$$

$$Q^{sub}_{h,cl} = Q^{loss}_{h,cl} + \sum_{b=1}^{t-load} Q^{load}_{h,cl,b} \tag{18}$$

The voltage of every bus in every load flow and every year of the planning horizon should follow the permitted interval as (19). Moreover, the total apparent power of the substation should not exceed its maximum value, as shown in (20).

$$V_{min} \leq V_{b,h} \leq V_{\max} \qquad \forall b \in t - load \tag{19}$$

$$Q^{loss\,2}_{h,cl} + P^{loss\,2}_{h,cl} \leq S^{sub\,2}_{max} \qquad \forall h \in [1, 24], cl \in c - num \tag{20}$$

There are some constraints regarding BESS condition, including the relevancy of stored energy in the battery to stored energy in the last hour (21), the limitation in the maximum power rate at every hour (22), and selecting just one of the charging or discharging status at the same time as (23).

$$BE^{se}_{h+1} = BE^{se}_{h} + \chi^{ch}_{h} \times BE^{pr}_{h} \times \eta - \chi^{dis}_{h} \times \frac{BE^{pr}_{h}}{\eta} \tag{21}$$

$$BE^{pr}_{h} \leq BE^{pr}_{max} \tag{22}$$

$$\chi^{ch}_{h} + \chi^{dis}_{h} \leq 1 \tag{23}$$

### D. Solution method and flowchart of the proposed approach

The main problem of this paper is a mixed-integer nonlinear programming problem, with an interior linear calculation. So far, various methods have been introduced to solve such problems like branch and reduce algorithm, branch and bound technique, and evolutionary algorithm. In this paper, particle swarm optimization (PSO) as a powerful and well-known evolutionary algorithm are employed to reach optimum results.

The proposed structure of a system with p particle is depicted in Fig. 2. According to the figure, each particle is comprised of two main parts, where the first part is related to the BESS power rate, and the second part is dedicated to BESS energy capacity. In this paper, some candidate busses are supposed to occupy batteries, and n denoted the number of candidate busses. The Optimization procedure of the proposed planning approach is shown in Fig. 3. According to the proposed approach and as explained before, the procedure starts with data clustering algorithms to make daily clusters. These arrays of daily data and their probability are then used to load flow evaluation. Afterward, the basic plan costs are computed, as this step is necessary to determine the maximum payable cost to the investor. The next step is creating random particles which is the first step of the PSO algorithm. After that, the load flow for different clusters and hours over daily information is executed through an iterative loop. By performing the mentioned steps, components of planning cost and total received energy from batteries are evaluated. Then, by comparing the basic costs and the proposed costs, the maximum payable cost that the planner can offer to buy energy from the investor is calculated. Finally, the maximum incentive price and economic metrics are evaluated for each particle. This procedure is repeated until the stopping criteria of the program are fully satisfied.

**Table 1.** Simulation parameters

| parameter | unit | value |
|---|---|---|
| Planning horizon | year | 15 |
| Annual load growth | % | 5 |
| Discount rate | % | 10 |
| Off-peak market price | $/MWh | 35 |
| Middle-peak market price | $/MWh | 49 |
| Peak market price | $/MWh | 75 |
| Upper voltage limitation | % | 1.05 |
| Lower Voltage limitation | % | 0.95 |
| PV plant capacity (bus 12 and 16) | MV | 8 |
| BESS power rate | $/KW | 200 [29] |
| BESS energy capacity | $/KWh | 150 [29] |
| Charge/discharge efficiency | % | 0.85 [29] |

## 4. NUMERICAL RESULTS

### A. System description

The proposed approach is programmed and implemented via MATLAB software. The program is tested on a 16-bus radial distribution test system, which consists of 3 feeders as shown in Fig. 4. More information about the buses and load of the test system can be found in [26]. Since the proposed planning is based on the cooperation of the investor and the PV-connected system, it is supposed that a couple of PV plants with the capacity of 8 MW are connected to buses number 12 and 16. The planning period is assumed 15 years and all economic indices are also evaluated over this period. Moreover, the load growing and emerging new load are supposed to be integrated with the existing busses. The data relative to upgrade and install HV/MV substations are taken from [27]. Throughout the simulation, the total load of the system is evaluated, and whenever the maximum load of the system exceeds the substation capacity, either an upgrade or installing a new one is carried out. The voltage of the system is set to 12.66 kV and the power factor is assumed to be 0.9 lag. Historical information about solar irradiance data are also obtained from [28]. Other useful information for the simulation are listed in Table 1.

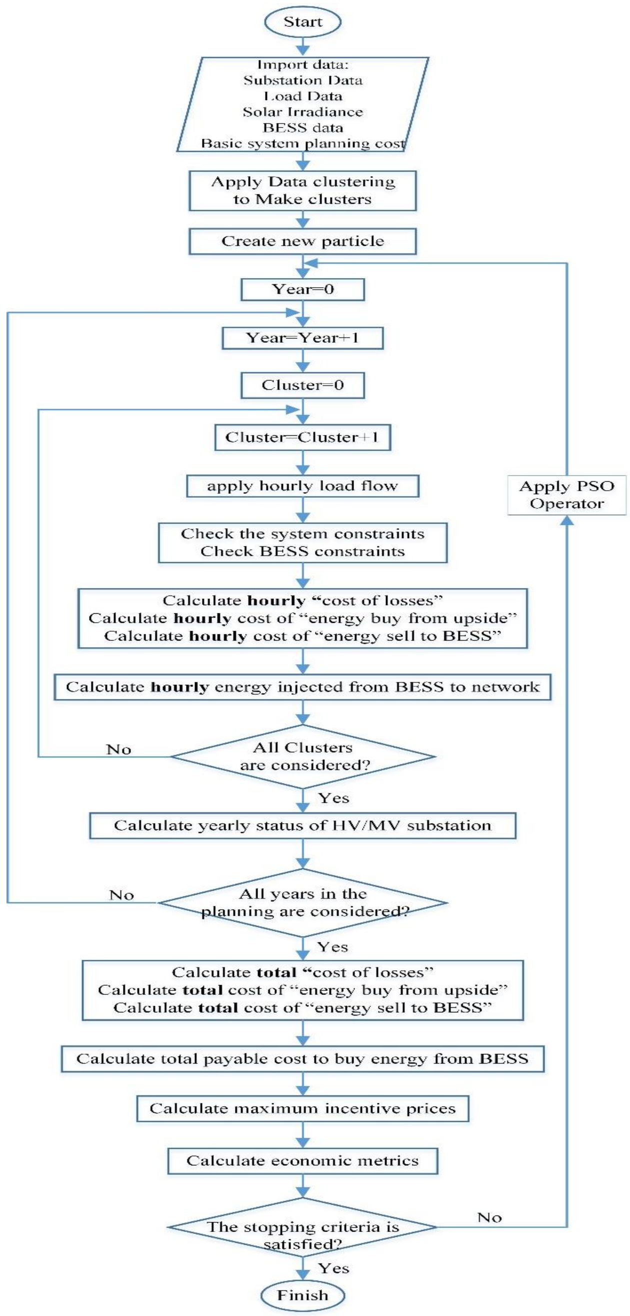


**Fig. 3.** Optimization procedure of the proposed planning approach

### B. Simulation results

According to the proposed flowchart presented in section 3, before executing the main program, the data clustering method is programmed and run to obtain the daily clusters. By implementing the K-means clustering method, yearly data of solar irradiance and load of the system are declined to limited data. In this paper, the number of clusters is set to ten groups. Therefore, to evaluate the operation cost of the problem over each year, an array of 240 load flow calculations is required. A sample of the result of the clustering algorithm is displayed in Fig. 5. As this figure shows, a series of the data with almost similar values is located in the sample cluster. Each of the obtained clusters shows

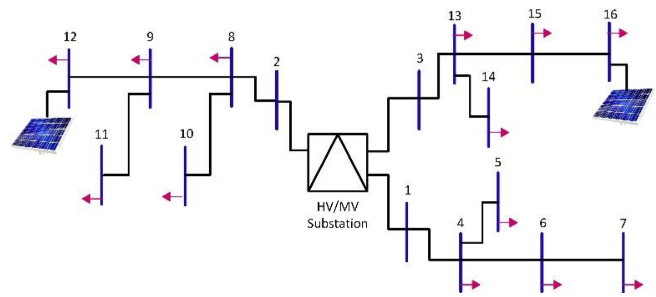


**Fig. 4.** 16-bus distribution test system (basic plan)

a probability that should be considered in the evaluation. The number of members in each cluster and the relevant probability are listed in Table 2.

After implementing the data clustering method, the simulation program has been executed for the basic and proposed cases, and the results are summarized in Table 3. The basic result shows that the system operator has to pay about 107.6 M$ to buy energy from the market over 15 years. Through employing batteries, however, this price is decreased to about 104.7 M$ in the proposed case. The reason is that in the proposed plan, the operator provides a part of the energy from stored energy in the batteries, especially during peak hours which has higher energy costs. Similarly, the cost of losses in the proposed case is decreased slightly and reaches about 1.1 M$. This is due to the installation of BESS in some busses, where they provide a part of energy close to the consumption places. Therefore, lower energy is transmitted through the MV network which causes lower losses. Another item that creates the major difference between the two cases is the cost of "investing and/or upgrading substation". In the basic case, the amount of this parameter is about 6.7 M$, while in the proposed case this value is reduced to about 1.3 M$. Fig. 6 illustrates the reason for this meaningful difference. This figure is depicted for the worst cluster over in the horizon year of planning. As this figure shows, the maximum load of the system in the basic case exceeds 60 MW and reaches about 64 MW, which means a new HV/MV substation should be installed in the system. Moreover, the figure shows that PV equipped system can fully shave the noon peak of the system, but it could not be helpful for the evening peak of the system. On the other hand, in the proposed case the operator can fully shave both peaks of the system, while stored energy in the batteries is injected into the system whenever the operator needs to catch it. In this situation, the planner just requires to update the capacity of the HV/MV substation over planning periods; this is why the cost of this item is significantly reduced. It should be mentioned that the total planning cost of both cases is the same, in order to have a better comparison.

Fig. 7 shows the state of charge (SOC) of batteries, output power of PV plants, and the exchange energy between the RERs and network during the worst cluster. As this figure represents, batteries are charged in the early morning when the price of energy is of the least value. These batteries remain in full charge status until the evening peak and then inject the power into the system. On the other hand, PVs produce energy whenever the sun lights are available. With this cooperation, the network planner is able to fully shave the peak of the system and reaches the mentioned results. The exchanged energy is shown in this picture as well, where it reveals that during some hours, the system sends energy to the RERs, and in some other hours, the system receives energy from RERs. This exchanged energy is utilized to reach the planner's target.

The test system with the presence of BSSS is depicted in Fig. 8. Detailed information about batteries and economic results are listed in Table 4. As the results show, it is needed to install 5 battery units in busses 4, 6, 9, 14, and 15. The total required capacity is about 20.8 MWh, while the total power rate is about 6 MW. According to the table, the incentive price that the network planner should offer to the investor is 170 $ per MWh. Although this price is about four times higher than the off-peak price and two times higher than the peak price, it is still worthwhile from a network planner's point of view. This is because the proposed case does not impose any additional cost on the network and both cases show the same total cost. By selling energy at the offered price, the PPY of the problem will reach less than five and a half years, which is an acceptable project from the investor's standpoint. The profit investment ratio of this project is about 1.2881 and the total paid cost to buy energy from the investor is about 11 M$. Moreover, the IRR of this project is about 15.05, which is greater than the supposed discount rate. Therefore, as mentioned before, this planning problem is regarded as a profitable project from the investor's standpoint.

Net cash flow as another economic criterion is evaluated and shown in Fig. 9. As the figure shows, the income of investors faces a sudden descent after the eleventh year. At this time, the investor has to replace the devices since their life is over. It should be noticed that after replacing BESS, it can work for another similar period, and therefore the investor can enact another contract with the Distribution Company and earn more money even after the planning period. Consequently, if a longer-term is supposed for the planning period, the investor net cash flow would increase, and the PIR will reach a value higher than 1.2881. In many studies, the contract period is supposed about 20 years, which causes to sell a higher amount of energy to the system, and therefore the investor benefits reach a higher amount.

To be sure about the proper meeting of voltage constraints on the system, the voltage of the system over four of the worst clusters is depicted in Fig. 10. As this figure shows, the voltage of all buses is located within the permitted interval over the planning horizon. However, an overvoltage is occurred in the last feeder which is due to the presence of the photovoltaic system.

In order to have a better understanding of the impact of PV plant's capacity on the planning results, lower size of plants are assessed and the results are summarized in Table 5. Results of this table demonstrate that by decreasing the size of PV plants up to 6 MW, the maximum load shedding of the system shows a similar value. This means the system planner can employ a lower capacity of PV plants to reach the same load shedding. However, the total planning cost of the system is increased due to the lower supplied energy by PV plants. But if the planner wants to attain proper load shedding which causes to postpone of installation HV/MV substation, the capacity of PV plants should not be determined lower than 5 MW. A lower value than this capacity cannot appropriately shave the noon peak of the system and therefore the maximum load of the existing substation exceeds its permitted values. As a consequence, a new substation would be required which leads a higher total planning costs.

### C. Sensitivity analysis

In this subsection, a sensitivity analysis on economic indices for incentive price and investment cost is performed. Moreover, a

**Table 2.** Data clustering result and probability of clusters

| Cluster number | Members in the cluster | Probability of the cluster |
|---|---|---|
| 1 | 30 | 0.09 |
| 2 | 22 | 0.06 |
| 3 | 48 | 0.13 |
| 4 | 41 | 0.11 |
| 5 | 22 | 0.06 |
| 6 | 21 | 0.06 |
| 7 | 63 | 0.17 |
| 8 | 52 | 0.14 |
| 9 | 51 | 0.14 |
| 10 | 15 | 0.04 |

**Table 3.** NPV of planning cost for the basic and proposed cases

| Cost (M$) | Basic case | Proposed case |
|---|---|---|
| investing and/or upgrading substation | 6.7 | 1.3 |
| Energy losses | 1.2 | 1.1 |
| Buy energy from Market | 107.6 | 104.7 |
| Buy energy from BESS Investor | - | 11 |
| sell energy to BESS investor | - | 2.6 |
| Total planning costs | 115.5 | 115.5 |

**Table 4.** Private investor results

| | |
|---|---|
| BESS placement | Bus 4: 2.1 (MWh) - 0.8 (MW) |
| | Bus 6: 5.6 (MWh) - 1.8 (MW) |
| | Bus 9: 7.2 (MWh) - 2.3 (MW) |
| | Bus 14: 4.3 (MWh) - 1.3 (MW) |
| | Bus 15: 1.6 (MWh) - 0.4 (MW) |
| Incentive price | 170 ($/MWh) |
| PPY | 5.45 (years) |
| Profit investment ratio | 1.2881 |
| Total paid cost to investor | 11 (M$) |
| IRR | 15.05 (%) |

**Table 5.** Planning results considering different values of PV plants capacity

| PV plant capacity (MW) | Maximum load shedding (%) | Total planning cost (M$) |
|---|---|---|
| 8 | 0.907 | 115.5 |
| 7 | 0.907 | 117.3 |
| 6 | 0.907 | 119 |
| 5 | 0.908 | 120.3 |
| 4 | 0.915 | 122.2 |
| 3 | 0.924 | 124.2 |

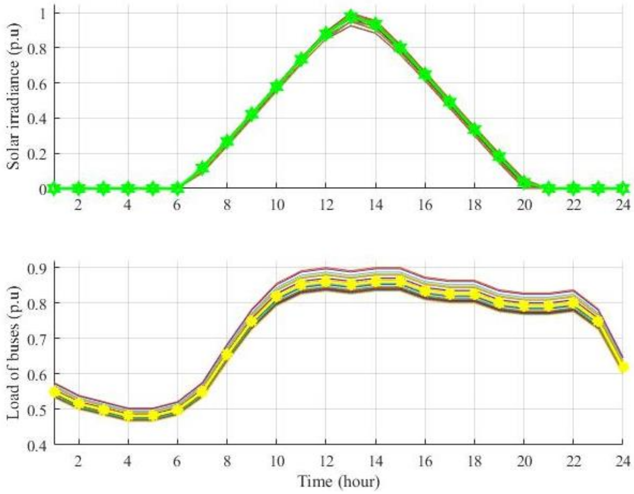


**Fig. 5.** Sample result of data clustering algorithm

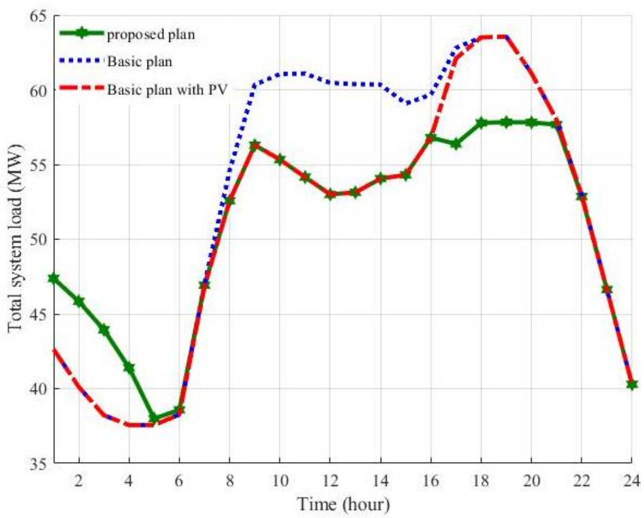


**Fig. 6.** Total system load in different cases

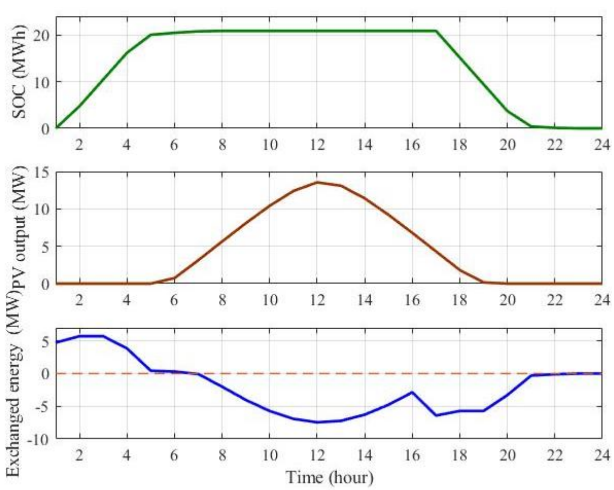


**Fig. 7.** SOC, PV output, and exchanged energy in the worst cluster

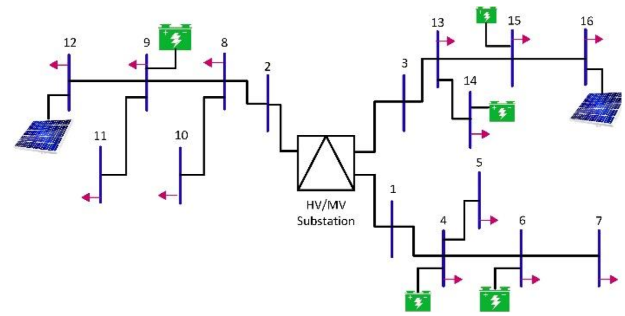


**Fig. 8.** 16-bus distribution test system (proposed case)

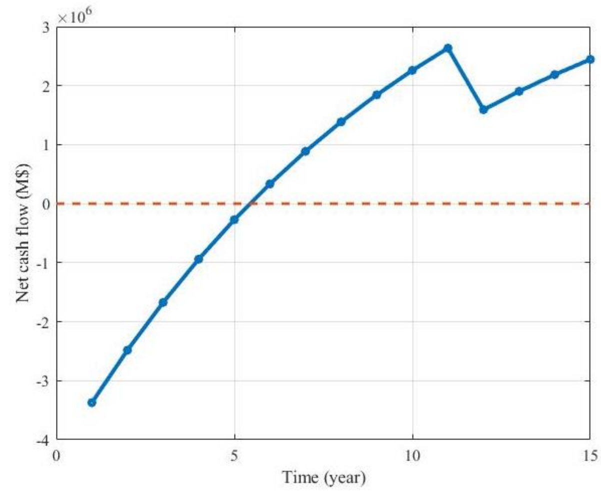


**Fig. 9.** Net cash flow in the proposed case

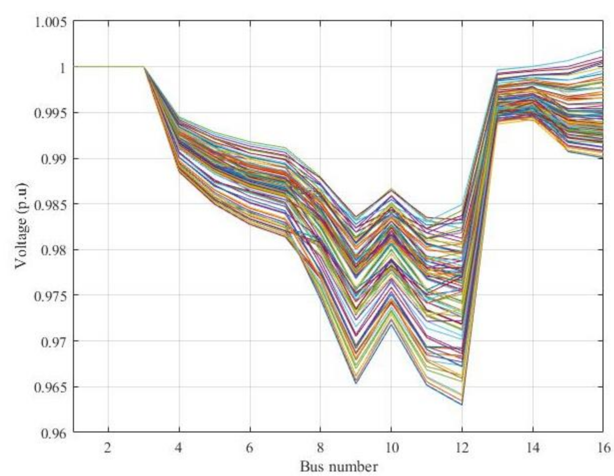


**Fig. 10.** The voltage of different buses over four clusters

comparison between the proposed case and the Feed-in Tariff of different countries is presented. Through sensitivity analysis, each variable is set from -20% to +20% with a step of 10%. Firstly, expected changes in different economic metrics through variation in incentive prices are depicted in Fig. 11 to Fig. 16. The net present value relevant to different incentive prices is depicted in Fig. 11. As this figure shows, by increasing the incentive price, the present value of investors increased as well. But if the planner decreases the incentive price to about 20% of the reference value (170 $/MWh), the investor could not benefit during 15 years and it would not be an affordable plan at all. Fig. 12 illustrates the positive impact of increasing incentive prices on the PIR. This figure demonstrates that there is almost a linear relationship between the incentive prices and PIR. Moreover, with a 20% increase in the offered price, this factor can reach about 1.54. Moreover, the impact of incentive prices on the PPY is shown in Fig. 13. The results show that a 20% reduction in the incentive price will raise the PPY to more than 13 years. On the other hand, the investors can contribute to a project with a PPY of 4 years, if the planner offers an incentive price 20% higher than the proposed case. It should be mentioned, although offering a higher incentive price causes to a lower PPY, it consequently leads to a higher planning cost which is not affordable from the planner's point of view. Therefore, a logical tradeoff between participants should be occurred to include their profit. In this paper, providing incentive prices as 170 $/MWh is the best choice, where the planner is not imposed any additional cost.

BESS is considered as new technology and it is expected that the price of this technology is decreased in the near future. On the other hand, there is a wide range of technologies with different investment costs. Thus, a sensitivity analysis regarding investment cost is performed and depicted in Fig. 14. This figure demonstrates that in the current situation if the investment cost of BESS is reduced by 20%, the PYY can even be reached in about 4 years, which is recognized as a quite affordable plan.

Since the IRR is an index to evaluate the attractiveness of a project, the sensitivity analysis on the IRR is also performed. This index is investigated through a variation in the incentive prices and investment cost, and the results are displayed in Fig. 15 and Fig. 16, respectively. In these figures, a horizontal line with the value of 10 percent is also depicted which is related to the discount rate of this paper. Any plan that leads to an IRR higher than this value is regarded as an affordable plan. Therefore, a reduction of either 10 or 20 percent in the incentive price makes the planning problem a costly plan. On the other hand, an increase of 10 percent in the investment cost remains the planning problem as a reasonable project. The variation of the IRR with other values is illustrated in the figures.

Finally, to present a better insight from obtained results a comparison between the proposed case and enacted Feed-in Tariff in several countries is performed. Considered countries consist of some European and Asian ones including France, the United Kingdom, Italy, Germany, China, Japan, Malaysia, and Thailand [30]. The results of PIR and PPY based on the considered countries are evaluated and depicted in Fig. 17. As this figure shows, among considered countries, the UK and China present the least incentive prices. This leads to a PPY of higher than 15 years and the PIR is reached about 0.5. In different circumstances, Japan and France offer the highest incentive prices, while their PPY is less than 3 years and their profit investment ratio is about 2.5. To sum up, in contrast with the proposed case, 5 of 8 considered countries present a higher Feed-in Tariff, which means obtained result of this study is an acceptable value from both planner and investor's point of view.

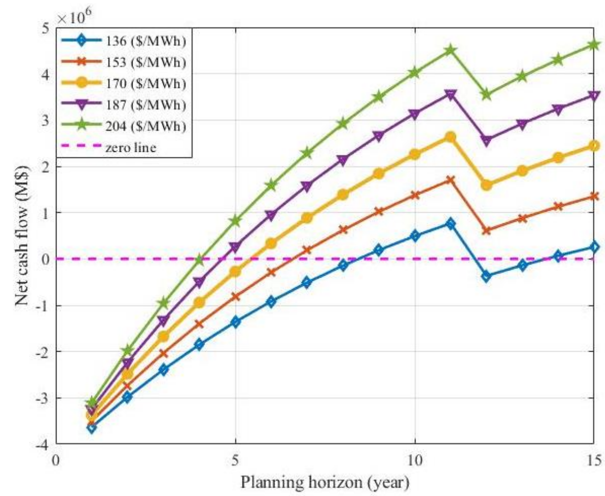


**Fig. 11.** Net cash flow for different incentive prices

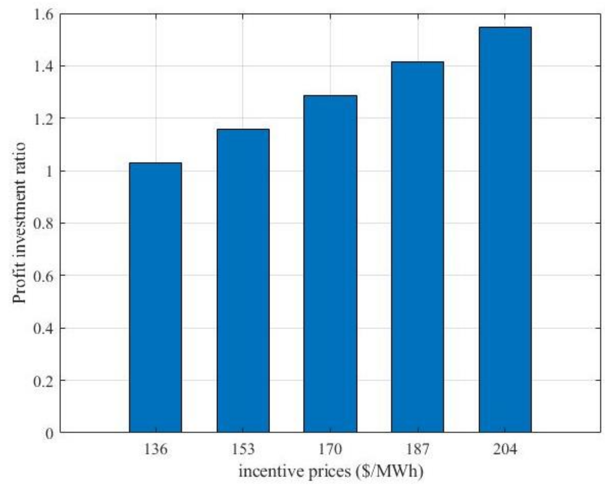


**Fig. 12.** PIR for different incentive prices

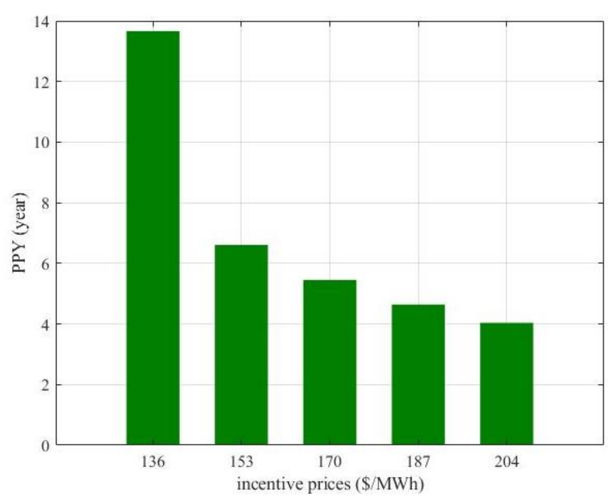


**Fig. 13.** PPY for different incentive prices

## 5. CONCLUSIONS

In this paper, a long-term distribution network planning approach with the cooperation of the private investor and the network planner has been presented. In the proposed approach, the planner utilized the investor potential in installing BESS to shave the peak load of the system at the horizon year. At the same time, the planner provided a source of financial support to buy energy from the investor. This financial resource was mainly

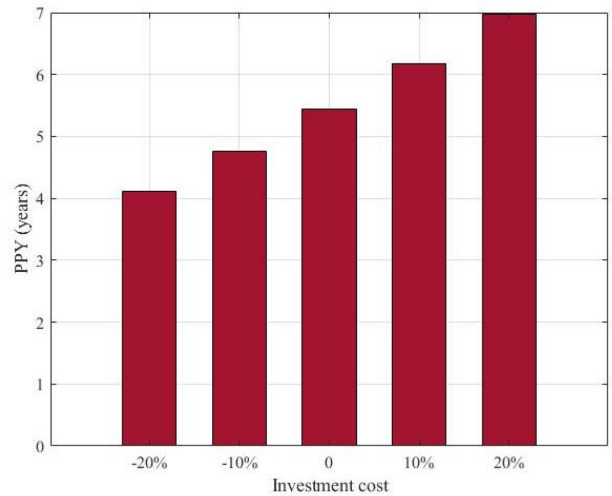


**Fig. 14.** PPY for different investment cost (incentive cost=170$/MWh)

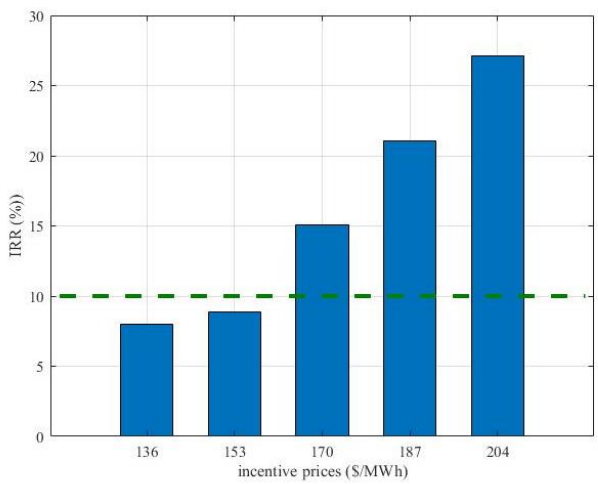


**Fig. 15.** IRR for different incentive prices

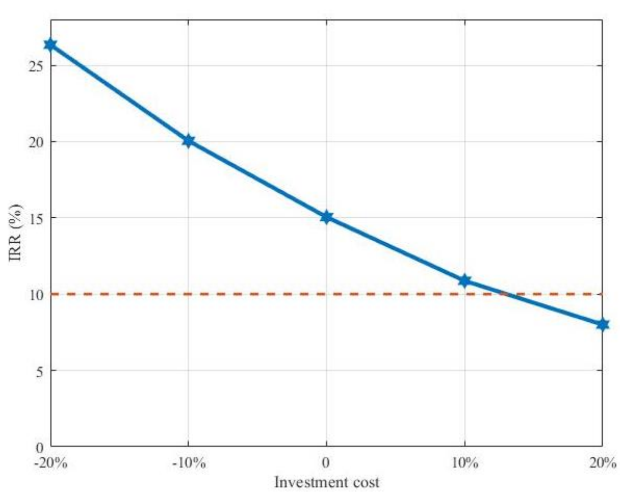


**Fig. 16.** IRR for different investment costs (incentive cost=170$/MWh)

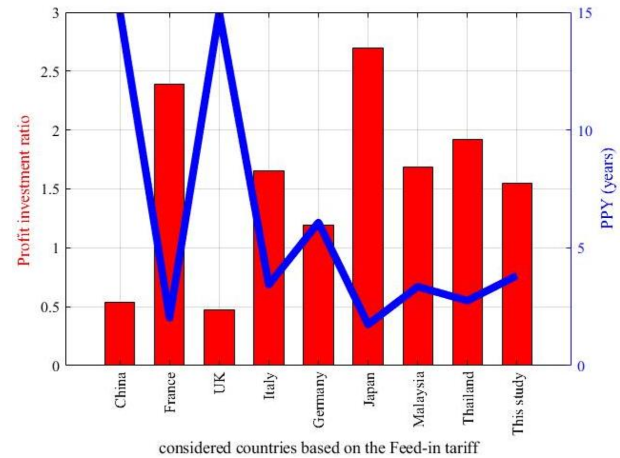


**Fig. 17.** IR and PPY based on the different countries' Feed-in Tariff

provided through saved costs due to a delay in installing and upgrading HV/MV substation in the long term. According to the limited financial resource, the incentive price that the planner can offer to the investors was determined. This incentive price was then evaluated from the investor's point of view via several economic metrics such as PPY, NPV, PIR, and IRR. Meanwhile, a sensitivity analysis for incentive price and investment cost was carried out. Finally, the result of this paper was compared with the incentive prices of several countries. This result revealed that in comparison with different countries, the incentive price of this study represented an acceptable value when it did not impose any additional cost to the system planner, and could be considered as an affordable plan for both participants.

## REFERENCES

1. A. Bosisio, A. Berizzi, E. Amaldi, C. Bovo, and X. A. Sun, "Optimal Feeder Routing in Urban Distribution Networks Planning with Layout Constraints and Losses," J. Mod. Power Syst. Clean Energy, vol. 8, no. 5, pp. 1005–1014, 2020.
2. H. A. S. Abushamah, M. R. Haghifam, and T. G. Bolandi, "A novel approach for distributed generation expansion planning considering its added value compared with centralized generation expansion," Sustain. Energy, Grids Networks, vol. 25, p. 100417, 2021.
3. A. Ashoomezhad, Q. Asadi, H. Falaghi, and A. Hajizadeh, "Private Investors Participation in Long-Term Distribution Network Planning," in 2021 12th Power Electronics, Drive Systems, and Technologies Conference (PEDSTC), 2021, pp. 1–5.
4. L. Luo et al., "Optimal scheduling of a renewable based microgrid considering photovoltaic system and battery energy storage under uncertainty," J. Energy Storage, vol. 28, p. 101306, 2020.
5. S. Kumari, P. Jain, D. Saxena, and R. Bhakar, "Dynamic Distribution Network Expansion Planning Under Energy Storage Integration Using PSO with Controlled Particle Movement," in Advanced Engineering Optimization Through Intelligent Techniques, Springer, 2020, pp. 497–514.
6. M. Uddin, M. F. Romlie, M. F. Abdullah, C. Tan, G. M. Shafiullah, and A. H. A. Bakar, "A novel peak shaving algorithm for islanded microgrid using battery energy storage system," Energy, vol. 196, p. 117084, 2020.
7. V. Vahidinasab et al., "Overview of electric energy distribution networks expansion planning," IEEE Access, vol. 8, pp. 34750–34769, 2020.
8. V. H. Fan, Z. Dong, and K. Meng, "Integrated distribution expansion planning considering stochastic renewable energy resources and electric vehicles," Appl. Energy, vol. 278, p. 115720, 2020.
9. H. Tang, C. Liu, Y. Cao, K. Lv, and Q. Zhang, "Hierarchical scheduling

learning optimisation of two-area active distribution system considering peak shaving demand of power grid," Discret. Event Dyn. Syst., pp. 1–30, 2021.
10. S. Lakshmi and S. Ganguly, "Multi-objective planning for the allocation of PV-BESS integrated open UPQC for peak load shaving of radial distribution networks," J. Energy Storage, vol. 22, pp. 208–218, 2019.
11. H. Mehrjerdi, "Simultaneous load leveling and voltage profile improvement in distribution networks by optimal battery storage planning," Energy, vol. 181, pp. 916–926, 2019.
12. L. Viola, L. C. P. da Silva, and M. J. Rider, "Optimal Operation of Battery and Hydrogen Energy Storage Systems in Electrical Distribution Networks for Peak Shaving," in 2019 IEEE PES Innovative Smart Grid Technologies Conference-Latin America (ISGT Latin America), 2019, pp. 1–6.
13. R. Martins, H. C. Hesse, J. Jungbauer, T. Vorbuchner, and P. Musilek, "Optimal component sizing for peak shaving in battery energy storage system for industrial applications," Energies, vol. 11, no. 8, p. 2048, 2018.
14. A. Ashoornezhad, H. Falaghi, M. Yousefi, and A. Hajizadeh, "Bi-Level Distribution Network Planning Integrated with Energy Storage to PV-Connected Network," in 2020 IEEE 29th International Symposium on Industrial Electronics (ISIE), 2020, pp. 1325–1329.
15. R. P. Praveen, V. Keloth, A. G. Abo-Khalil, A. S. Alghamdi, A. M. Eltamaly, and I. Tlili, "An insight to the energy policy of GCC countries to meet renewable energy targets of 2030," Energy Policy, vol. 147, p. 111864, 2020.
16. G. Gozgor, M. K. Mahalik, E. Demir, and H. Padhan, "The impact of economic globalization on renewable energy in the OECD countries," Energy Policy, vol. 139, p. 111365, 2020.
17. I. J. Scott, A. Botterud, P. M. S. Carvalho, and C. A. S. Silva, "Renewable energy support policy evaluation: The role of long-term uncertainty in market modelling," Appl. Energy, vol. 278, p. 115643, 2020.
18. G. Bersalli, P. Menanteau, and J. El-Methni, "Renewable energy policy effectiveness: A panel data analysis across Europe and Latin America," Renew. Sustain. Energy Rev., vol. 133, p. 110351, 2020.
19. K. D. Pippi, G. C. Kryonidis, and T. A. Papadopoulos, "Methodology for the Techno-Economic Assessment of Medium-Voltage Photovoltaic Prosumers Under Net-Metering Policy," IEEE Access, vol. 9, pp. 60433–60446, 2021.
20. N. H. Umar, B. Bora, C. Banerjee, P. Gupta, and N. Anjum, "Performance and economic viability of the PV system in different climatic zones of Nigeria," Sustain. Energy Technol. Assessments, vol. 43, p. 100987, 2021.
21. F. Barati, S. Jadid, and A. Zangeneh, "Private investor-based distributed generation expansion planning considering uncertainties of renewable generations," Energy, vol. 173, pp. 1078–1091, 2019.
22. M. A. Alotaibi and M. M. A. Salama, "An incentive-based multistage expansion planning model for smart distribution systems," IEEE Trans. Power Syst., vol. 33, no. 5, pp. 5469–5485, 2018.
23. H. Arasteh, V. Vahidinasab, M. S. Sepasian, and J. Aghaei, "Stochastic system of systems architecture for adaptive expansion of smart distribution grids," IEEE Trans. Ind. Informatics, vol. 15, no. 1, pp. 377–389, 2018.
24. B. R. Prusty and D. Jena, "A critical review on probabilistic load flow studies in uncertainty constrained power systems with photovoltaic generation and a new approach," Renew. Sustain. Energy Rev., vol. 69, pp. 1286–1302, 2017.
25. S. Li, H. Ma, and W. Li, "Typical solar radiation year construction using k-means clustering and discrete-time Markov chain," Appl. Energy, vol. 205, pp. 720–731, 2017.
26. Y. Latreche, H. Bouchekara, K. Naidu, H. Mokhlis, and W. M. Dahalan, "Comprehensive Review of Radial Distribution Test Systems," TechRxiv, no. 1, pp. 1–65, 2020.
27. A. Bagheri, H. Monsef, and H. Lesani, "Integrated distribution network expansion planning incorporating distributed generation considering uncertainties, reliability, and operational conditions," Int. J. Electr. Power Energy Syst., vol. 73, pp. 56–70, 2015.
28. "https://www.solarreviews.com/solar-panels/solar-panel-cost/."
29. V. V Thang, "Optimal sizing of distributed energy resources and battery energy storage system in planning of islanded micro-grids based on life cycle cost," Energy Syst., pp. 1–20, 2020.
30. G. Coria, F. Penizzotto, and R. Pringles, "Economic analysis of photovoltaic projects: The Argentinian renewable generation policy for residential sectors," Renew. Energy, vol. 133, pp. 1167–1177, 2019.