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CASE STUDY

Feasibility study on the integration of residential PV-battery systems in system peak load shaving: A case study in Iran

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Abstract

This paper investigates the impact of residential photovoltaic (PV) battery systems in a real test system with the goal of system peak load shaving. In order to encourage residential investors, a levelised feed-in tariff (LFiT) scheme is introduced. Accordingly, two proposed cases and relevant suggestions are presented to reach a better performance. The profitability of the project is apprised via several economic criteria such as net present value, simple and discount payback period years (PBY and DPBY), internal rate of return (IRR), benefit to cost ratio, net cash flow, and levelised cost of energy. Moreover, different levels of peak shaving subject to customers' participation and the size of the PV-battery system are also obtained. An actual test system regarding 1-year recorded data is employed to elevate the precision of results. Obtained results demonstrate that in the current situation in Iran, the PBY is about 5.83 years and the IRR is about 0.43. Meanwhile, the ratio of the LFiT should be about 3.5 to reach the same result as the current circumstances. Finally, a sensitivity analysis on systems' parameters is performed to identify the impact of these parameters on economic indices.

1 | INTRODUCTION

1.1 | Background, motivation, and approach

Among different challenges that a power network operator is facing, load growth may be from the prominent ones, since networks should be continuously updated to meet this demand. This procedure imposes a high initial cost on the power networks owing to the requirement of new power plants, substations, and lines [1]. However, installing distributed generation (DG), particularly renewable ones, has attracted huge attention in the last decades. Alongside this, many governments enacted supporting policies to encourage private investors in installing DGs due to their numerous advantages, like reliability, reducing greenhouse gas emissions, and decreeing power losses [2].

The Iranian government, like many countries such as Brazil, India, Egypt, and Nigeria has enacted incentive policies in 2016 to persuade investors to contribute to projects [3]. Although these supporting policies incorporate various renewable resources like wind, photovoltaic (PV), hydropower, and thermal, PV systems have attracted remarkable attention in contrast to the other ones. This is due to two main reasons; first, almost all provinces of Iran have a great potential in generating solar energy as depicted in Figure 1. This situation is much better in the central, eastern, and southern areas of Iran. Second, PV systems range in assorted sizes, including from some kW to several hundred MW. Therefore, PV can either directly connect to low-voltage or high-voltage systems. The outcome of this decision in an eastern province of Iran is shown in Figure 2. In addition, four different sample days regarding four seasons, and the load growth in the past 4 years are also drawn in this figure. As this figure indicates, the system is facing two major peaks named the noon peak and the evening peak. Despite the coincidence of generated energy with the noon peak, no energy is injected into the system during the evening peak by DGs.

Although the system operator can count on PV systems to support the noon peak of the system, they are not helpful for the whole system peak. Moreover, the high penetration of PV systems, the intermittent treatment, and the non-dispatchable nature of these resources may cause some problems such as reverse power flow and voltage raising [4]. One of the solutions

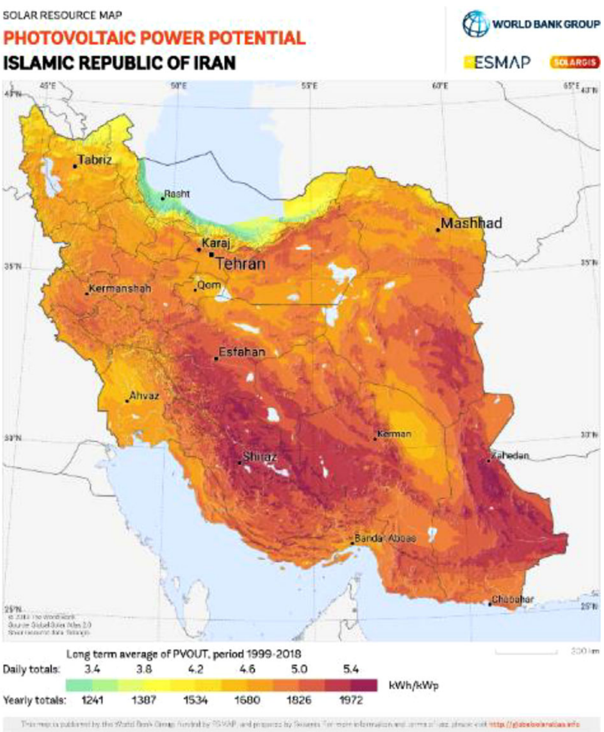

FIGURE 1 Photovoltaic electricity potential for Iran based on [7].

to overcome such problems is engaging a battery bank in PV systems to store and shift the produced energy from daytime to evening peak [5]. Thus by installing and appropriately managing PV units and battery banks, the system operator would be able to reach a better load profile [6]. Here, the implementation of battery and PV systems with the aim of peak shaving in a real network in Iran is considered.

1.2 | Literature review

Despite the numerous benefits of DGs and renewable resources, the significant initial cost of such resources is still a notable obstacle to growing them. Therefore, many countries have legislated supporting policies to convince private investors in installing renewable resources, which has been considered in numerous studies. Economic analysis for a 100 kW PV plant under the feed-in tariff (FiT) and net-metering (NM) policy in the Philippines was considered in [9]. PBY and BCR as two substantial economic criteria are investigated, and it was shown that the FiT scheme can lead to lower PBY and higher BCR for this case. A similar analysis in Poland was performed in [10], where the size of PV panels, tilts of the modules, and size inverters were perused to determine the optimal size of these instruments. Simultaneous consideration of NM and environmental performance for Slovenia was carried out in [11]. The suggested method evaluates the best size of the battery and the minimum price per kWh of the system. Analogous researches for countries like Malaysia [12], Peru [13], Kuwait [14], Croatia [15], Kenia [16], Netherlands [17], Turkey [18], Argentina [19], and Indonesia [20] were presented to assess the supporting policies and economic evaluation. Furthermore, a similar study for Italy was presented in [21], where the Italian government introduced a subsidized tax deduction over a period of 5 years. This instruction leads to realization of usage of battery storage systems into PV systems in residential sectors. A comprehensive review on recent advances in energy storage systems for renewable resources such as PV system and wind turbines was also presented in [22]. In the study, different technologies as well as strategies to integrate the storages in renewable resources were also investigated.

In Iran, however, the government has enacted a FiT scheme to support on-grid resources that instigates an outstanding tendency to install renewable resources, PV ones in particular. Hence, many articles assessed this policy and its impact on investors' decisions. In [23], a dynamic FiT scheme enacted in Iran has been introduced and the economic assessment for residential and commercial customers was investigated. The effect of several parameters like geographical and climatic conditions in the optimization of PV systems in Iran was assessed in [24]. The economic evaluation for a real commercial PV system in Iran was considered in [25], where the actual data of an installed case was employed to validate the results. In [26], besides economic evaluation, the environmental evaluation of grid-connected silicon solar panels with respect to Iranian policies was presented. The Iranian rules on supporting residential PV systems were investigated in [27] and a new FiT system regarding different areas of Iran was supposed in the study.

In most of the mentioned studies, the analysis of PV and renewable energy resources was focused on the investors' standpoint; however, the system operator can conduct these resources to mutually profit from installing such resources. In [28], the performance of on-grid PV and battery systems in peak shaving was investigated through the evaluation of self-consumption levels. Employing batteries with the aim of peak shaving in the system equipped with PV systems was performed in [29]. In the study, a commercial building was assessed and Monte-Carlo simulation is employed to evaluate the price arbitrage. In [30], the impact of decentralized residential batteries on peak shaving was introduced, where increasing the penetration of uncertain resources and deferring expensive network equipment were considered as well. An optimal peak shaving strategy concerning dynamic FiT and demand was proposed in [31], where a day-ahead prediction was developed to determine the best values of elements. In our previous studies [32–34], the cooperation of private investors and distribution companies in long-term planning was considered. In these studies, a framework was introduced to conduct residential investors with respect to the distribution companies' targets. The private investors are responsible to install PV and batteries and the distribution company is in charge of offering an affordable plan.

1.3 | Contributions of this study

Here, a techno-economic analysis of residential PV-battery systems with the aim of total system peak shaving is presented. The

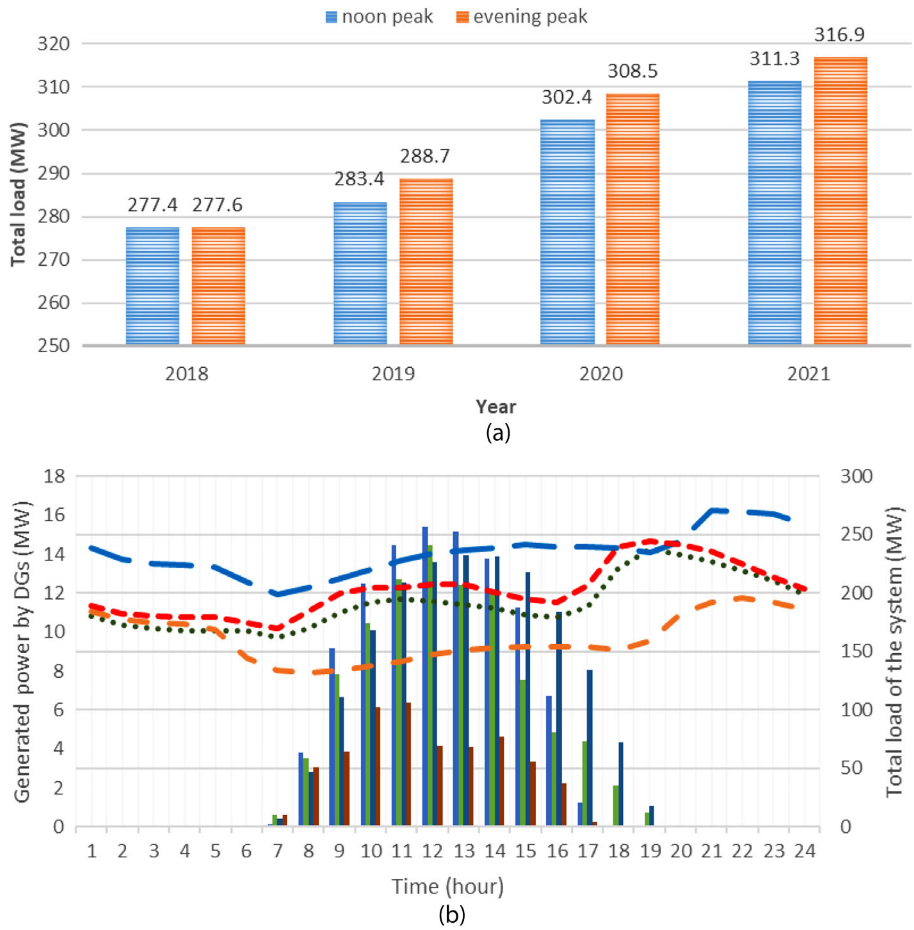

FIGURE 2 Statistics of a distribution network for South-Khorasan in Iran: (a) load growth; (b) four sample days relevant to four seasons. Based on the information offered in [8].

proposed method, in particular, considers the incentive policies in Iran, where residential customers play an important role in the project subject to this project. A real test system concerning actual data including system load, generated power, and real recorded data of meters is employed to reach a more precise and reliable result. The main contribution of this paper is summarized as follows:

a. A new FiT scheme named levelised FiT (LFiT) is introduced to persuade investors in installing both PV and battery systems. Compared with the conventional FiT, the proposed scheme makes the project more attractive from the investors' standpoint, while the target of system operators is considered as well.
b. Unlike many studies that considered the project from either investor or distribution companies' attitude, the cooperation of residential private investors and network operators in total system peak shaving as a main target of the paper is considered. In order to evaluate the performance of the proposed framework, some economic indices such as PBY, DPBY, BCR, and IRR are computed.
c. Iranian's new instruction related to the guarantee purchase agreement, revised in 2021, is considered since there are some remarkable changes in the new rule and previous studies have mostly considered the expired version of the instruction. For instance, the yearly coefficient is distributed over the project period which can highly affect the profit of new investors.
d. The real data concerning recorded information of a whole providence in Iran are analysed to reach accurate and trustworthy results. Meanwhile, the PV degradation factor which is mostly neglected in the previous studies is also considered to show more accurate outcomes. Moreover, a sensitivity analysis on the system parameter such as the FiT, investment cost, and battery degradation is performed.

2 | POLICY FRAMEWORK: COUNTRY BACKGROUND AND SYSTEM SPECIFICATION

Iran, a country located in the Middle East, is considered as one of the main fossil-fuels resources in the world. Therefore, it is predictable that various sections including industry, transportation, economy, and so on are dependent on these costly and pollutant resources. The power system is another notable part that is rigorously relied on natural gas and oils [8]. Thus, for a system operator, it is a challenging issue to appropriately meet annual load growth. Furthermore, installing such power plants requires a high investment cost and usually takes several years, especially in developing countries. Meanwhile, producing energy through fossil fuels power plants emits a huge amount of carbon dioxide and makes the atmosphere more polluted [35].

The aforementioned issues instigate several troubles for either power systems or customers. The scheduled outage is one of the substantial problems that the Iranian power system had to apply in the last years, to overcome the lack of proper capacity. Through this program, almost all customers have experienced unsupplied energy during the last summer. As a consequence, the government has to persuade a superseded policy to compensate for unsupplied demands. DGs are desirable solutions to mitigate the gap between the maximum load of the system and the production capacity [36].

Starting in 2014, the Iranian Ministry of Energy enacted an instruction to engage private investors' participation in constructing renewable power plants. According to this instruction, investors can export and sell the whole produced energy to the system based on a guaranteed purchase price. This guaranteed agreement takes 20 years, and the renewable energy and energy efficiency organization of Iran (SATBA) is responsible to manage contracts. SATBA presents various FiT schemes with respect to the nominal capacity of the renewable power plants so that by increasing the capacity, the amount of incentive price would decrease. Therefore, residential investors can receive the highest incentive price which could lead to more economic investment. It should be mentioned that the incentive prices that SATBA offers the investors were adjusted by a 0.7 factor after the tenth year of the contract.

By promoting this instruction, the tendency of installing renewable resources by private investors has increasingly grown. This procedure increased the capacity of installed renewable resources to about 920 MW at the beginning of 2021. In addition, about 3.2 GW of resources are waiting for admission to connect their units to the network. It is worth mentioning that about 49% of total installed resources are assigned to PV systems, as shown in Figure 3 [37].

Although the Iranian Ministry of Energy has employed a supporting scheme to persuade investors, this instruction has been reviewed in 2021. Therefore, the new investigation and assessment should be performed based on the new rule and prices, and the former instruction is no longer utilizable for new investors. Consequently, here, the new regulation of SATBA is employed to investigate the economic assessment of investors. Meanwhile, integration of the battery into the PV system is supposed to encounter the system operator's aim in shaving the peak of the system. The diagram of the residential on-grid PV-battery system in the considered case study is depicted in Figure 4. As this figure shows, the whole generated energy by PV and discharged energy from the battery are directly injected into the low-voltage distribution network and no energy is consumed by the customer. This is due to the huge gap between buying and selling energy in Iran, where it is not affordable for a customer to consume produced energy by its resources. Moreover, the battery is charged from PV in order to prevent technical problems such as reverse power flow and overvoltage.

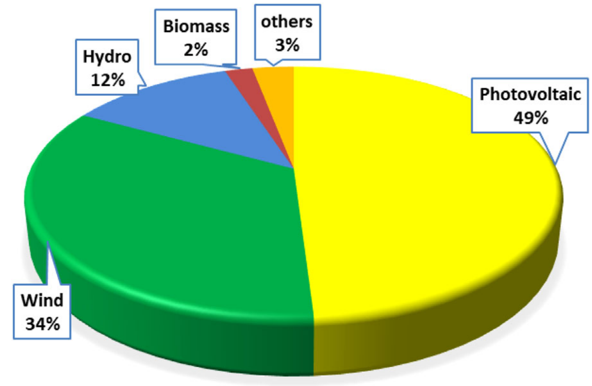

FIGURE 3 The share of renewable resources in Iran renewable production, at the beginning of 2022 [37].

In order to have a better comparison between the real data and the simulation results, recorded data by smart meters of eight customers are shown in Figure 5. All these customers are located in South-Khorasan, where the case study is relevant to this area. Since these meters are working offline mode, the energies produced by PVs are presented for six periods, every other month. The monthly average generated energy by customers is shown in the last bar as well. As this bar illustrates, on average a 5 kW PV plant, which is the restricted capacity by SATBA for a residential customer can produce almost more than 1500 kWh energy per month, which is approximately more than 9 MWh over a year.

3 | METHODOLOGY: PROBLEM FORMULATION AND INPUT DATA

The mathematical modelling of this paper is divided into two main parts: technical modelling and economic formulation. First, technical modelling of on-grid PV battery systems is presented, where the produced energy by PV panels and the charging/discharging status of battery banks are modelled. Then, the economic formulations to evaluate different indices are explained.

3.1 | Technical modelling

Total generated power of a PV system ($P_{PV}(h)$) can be evaluated by aggregating the output power of all panels, as shown in (1):

$$P_{PV}(h) = N_{PV} \times p_{PV}(h). \tag{1}$$

However, the generated power of each PV is influenced by received solar irradiance and output temperature. Therefore,

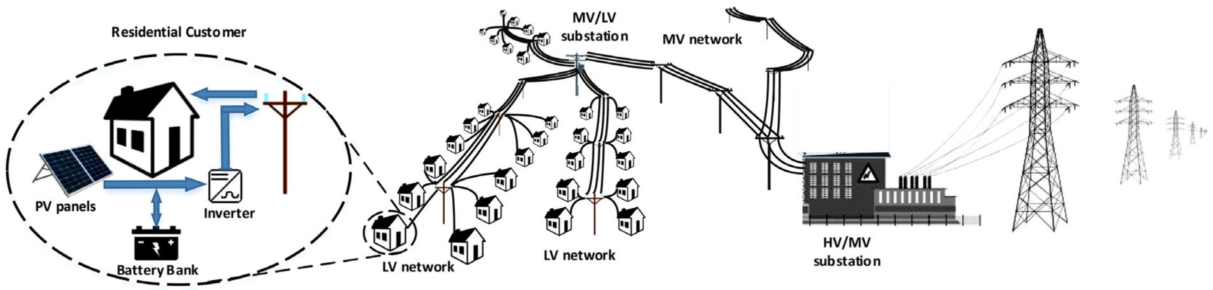

FIGURE 4 Diagram of the residential on-grid photovoltaic (PV)-battery system.

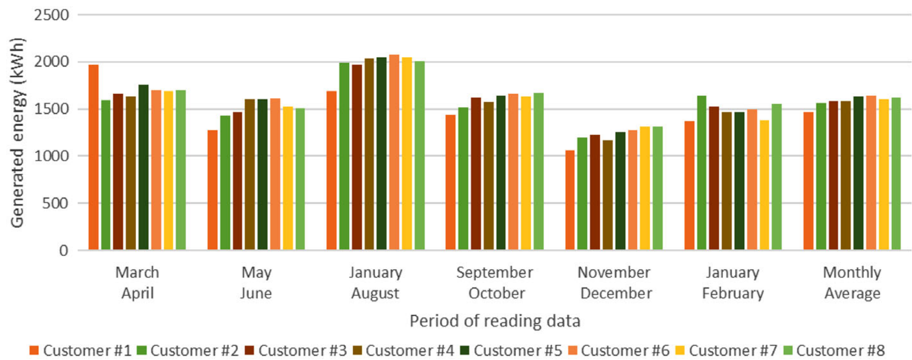

FIGURE 5 Generated energy by 5 kW photovoltaic (PV) panels installed via various customers (based on the real data recorded by smart meters).

generated power by panels can be written as follows [38]:

$$p_{PV}(h) = P_{ref.PV} \times \left(1 + C_T \times \left(T_{PV} - T_{ref}\right)\right) \times \left(\frac{I_{PV}}{I_{ref}}\right). \tag{2}$$

Meanwhile, the temperature of the panel depends on the air temperature and normal operating temperature as shown in (3):

$$T_{PV} = T_{air} + \left(\left(\frac{T_{no} - 20}{800}\right) \times I_{PV}\right). \tag{3}$$

In this study, the main purpose of installing battery banks is to supply a part of the evening load of the system with the aim of evening peak shaving. Therefore, battery banks should reach their full charge state, before the evening hours. Moreover, batteries should be charged from PV panels to alleviate the negative result of over generating. Consequently, once the produced power of PV panels is becoming available, batteries are starting to charge. Afterward, the stored energy in batteries is discharged into the system through peak hours. The stored energy in batteries in the charging and discharging state is computed via Equations (4) and (5), respectively.

$$E_{bat}(h) = E_{bat}(h-1) \times \psi_{cha} \times (1-\omega) + \left(E_{pr} \times \eta_{bat}\right), \tag{4}$$

$$E_{bat}(h) = E_{bat}(h-1) \times \psi_{dis} \times (1-\omega) - \left(\frac{E_{pr}}{\eta_{inv}} \times \eta_{bat}\right). \tag{5}$$

In the proposed structure, an inverter should be installed to convert the direct current of PV and battery to alternating current. The relation between the input and output power of the inverter can be modelled as (6), where P_{net} is the power injected into the network which is affected by the PV output and battery's status:

$$P_{inv}(h) = \frac{P_{net}}{\eta_{inv}}. \tag{6}$$

3.2 | Economic modelling

Since residential customers are one of the prominent parts of this project, their benefits should be well satisfied. Thus, several economic indices including, net present value (NPV), simple and discount payback period years (PBY and DPBY), internal rate of return (IRR), benefit to cost ratio (BCR), and levelised cost of energy (LCOE) are assessed to evaluate the effectiveness of project from the investor's standpoint, but first the FiT price that SATBA offers to buy energy from residential customers should be formulated. According to the SATBA's new rule which is revised in 2021, yearly FiT is computed by (7):

$$FiT_{PV}(y) = FiT_{PV}(1) \times \left(AC(y) \times C(y) \times \left(1 + C_{np}\right)\right). \tag{7}$$

As this relation shows, the FiT is not constant over the project period and is regulated by three factors. The first and foremost factor is the adjustment coefficient, which is raised relevant to the following equation:

$$AC(y) = \left(\frac{RPI(y-1)}{RPI(1)}\right)^{\alpha} \times \left(\frac{EER(y-1)}{EER(1)}\right)^{(1-\alpha)}. \quad (8)$$

According to this equation, the adjustment coefficient is elevated by two factors; retail price index and Euro exchange rate. α is also a factor with a value between 0.2 and 0.3, but it should be mentioned that since Iran is a developing country, these factors do not follow a regular value and may change over the project period. Therefore, here, the $AC(y)$ factor is supposed to be 1.35, which is obtained by assessing the variation of FiT in the last years. The second one is the yearly coefficient which is considered as the outstanding change between the new instruction and the former one. In the former instruction, after the tenth year of the project, the FiT decreased by 0.7; however, in the new instruction, the yearly coefficient is applied three times, in the eighth, twelfth, and sixteenth years. Meanwhile, the reduction factor is 0.6 which brings a lower benefit to the investor. Finally, a national production factor is also considered in FiT to support the national companies. Nonetheless, in practical calculation this factor is not considered yet, so we ignored this factor as well.

Although battery technologies have faced substantial progress in the last years, still they are considered costly instruments. Moreover, the network's operator requires receiving energy in the evening hours to shave the evening peak of the system. As a result, network planners have to follow a policy that tempts customers to install battery banks. Therefore, here, an LFiT scheme is proposed to make the PV battery system a profitable plan. FiT_{bat} is the incentive price that is suggested to buy energy during peak hours. By determining the FiT_{PV} and FiT_{bat} over the project years, the net present value (NPV) and net present benefit (NPB) of every customer are defined via (9) and (10), respectively:

$$NPV = NPB - NPC \quad (9)$$

$$NPB = \sum_{y=1}^{pp}\left(\sum_{h=1}^{8760}\left\{\begin{pmatrix} P_{PV}(h)\times(1-(y-1)\times d) - \\ \psi_{cha}\times(E_{bat}(h)-E_{bat}(h-1)) \end{pmatrix}\times FiT_{PV}(y) + \atop (\psi_{dis}\times(E_{bat}(h)-E_{bat}(h-1)))\times FiT_{bat}(y)\right\}\right)/(1+dr)^{(y-1)} \quad (10)$$

Similarly, the net present cost (NPC) of each customer is evaluated by (11). According to this equation, NPC depends on the investment cost (IC), net present of the replacement cost of battery and inverter (NPR), and net present of operation and maintenance cost of systems' equipment ($NPOM$). The formulation of each of these components is presented in (12) to (14). This paper assumes that the battery bank should be replaced every 5 years since practical experience affirms this supposition. Meanwhile, the inverter should be substituted after ten years, while the PV panel does not need replacing over the project horizon. This is due to the fact that PV panels are mostly used for more than twenty years. But the generated power by PV is gradually decreased, which is considered here by a degradation factor.

$$NPC = IC + NPR + NPOM, \quad (11)$$

$$IC = N_{PV}\times IC_{PV} + N_{bat}\times IC_{bat} + IC_{inv}, \quad (12)$$

$$NPR = \sum_{y=1}^{pp}\left(N_{bat}\times IC_{bat}\times\vartheta_y\times\left(\frac{(1+i)^{(y-1)}}{(1+dr)^{(y-1)}}\right) + IC_{inv}\times\xi_y\times\left(\frac{(1+i)^{(y-1)}}{(1+dr)^{(y-1)}}\right)\right), \quad (13)$$

$$NPOM = \sum_{y=1}^{pp}\left(N_{PV}\times OM_{PV}\times\left(\frac{(1+i)^{(y-1)}}{(1+dr)^{(y-1)}}\right) + N_{bat}\times OM_{bat}\times\left(\frac{(1+i)^{(y-1)}}{(1+dr)^{(y-1)}}\right)\right). \quad (14)$$

For residential customers, especially in Iran, PBY is a tangible criterion that may highly affect customers' decisions on whether contribute to a project or not. The $DPBY$ is a modified version of the PBY that accounts for the time value of money. Both metrics are used to calculate the amount of time that it will take for a project to "break even" or to get the point where the net cash flows generated cover the initial cost of the project. These indices are evaluated based on the (15) and (16), respectively [39].

$$PBY = Y_{ln} + \frac{|CCF_{ln}|}{CCF_{ln+1} + |CCF_{ln}|}, \quad (15)$$

$$NPBY = Y_{ln} + \frac{|CDCF_{ln}|}{CDCF_{ln+1} + |CDCF_{ln}|}, \quad (16)$$

where Y_{ln} is the year of the project with the last negative amount, CCF_{ln} is the cumulative cash flow for that year, and $CDCF_{ln}$ is the cumulative discounted cash flow for that year. The next economic index is IRR which is interpreted as an interest rate in which the total NPV of the project equals zero. A project is considered a fruitful plan if the IRR becomes greater than the real discount rate [40].

$$\sum_{y=1}^{PP}\frac{CCF(y)}{(1+IRR)^{(y-1)}} - IC = 0 \quad (17)$$

BCR is another economic index that is obtained from (18). If this factor reaches a value higher than one, the project is recognized as a profitable plan.

$$BCR = \frac{NPB}{NPC} \quad (18)$$

The last index is $LCOE$ which means the cost of producing a kWh of energy over the project period. This value could give a better insight to the system operator, where reaching a LCOE value lower than the market price means a cost-effective project.

$$LCOE = \frac{NPB}{\sum_{y=1}^{pp}\left(\sum_{h=1}^{8760}\left\{\begin{pmatrix} P_{PV}(h)\times(1-(y-1)\times d)- \\ \psi_{cha}\times(E_{bat}(h)-E_{bat}(h-1)) \end{pmatrix}+ \atop (\psi_{dis}\times(E_{bat}(h)-E_{bat}(h-1)))\right\}\right)/(1+dr)^{(y-1)}} \tag{19}$$

The presence of PV and battery imposes some technical constraints on the system. First, due to problems concerning the reverse power flow, the total generated power by residential investors should not exceed the maximum load of the system as shown (20). The number of PV and batteries are also restricted as (21) and (22), respectively. Finally, the state of the charge of batteries should be located in a permitted interval as presented in (23).

$$N_c \times N_{PV} \times p_{PV}(h) \le L_{max}(h) \;\; \forall h \in [1-8760], \tag{20}$$

$$0 \le N_{PV} \le N_{PV.max}, \tag{21}$$

$$0 \le N_{bat} \le N_{bat.max}, \tag{22}$$

$$E_{bat.max} \times (1-DOD) \le E_{bat}(h) \le E_{bat.max} \;\; \forall h \in [1-8760]. \tag{23}$$

3.3 | Input data and test system specification

Here, a large-scale real distribution test system with respect to its LV customers is considered to evaluate the proposed strategy for installing PV battery systems. The case system is located in the east of Iran and consists of about 390,000 residential customers, and each of them looks like a potential investor. In order to have an hourly load profile over 1 year, the output power of HV/MV substations is gathered and the whole system load profile is obtained. This actual information is utilized to evaluate the performance of the system in peak shaving targets. Meanwhile, solar irradiance and ambient temperature of the test system are obtained from [41]; however, the generated power by simulation results are compared with real data depicted in Figure 5, to show the precision of the generated power by customers. Since a 5 kW PV panel is permitted by the Iranian Ministry of Energy and it is more common in the practical system, the PV system capacity is first set to this value. Other systems' specifications are listed in Table 1. All prices shown in this table are the actual costs at the beginning of 2022 in Iran. These values are transferred to the US dollar based on the exchange rate obtained from the central bank of Iran [42]. It should be noted that economic parameters like discount rate and inflation rate are also acquired from [42]. Since Iran is a developing country, these parameters have shown unstable treatment in the past years, so instead of the data of the current year, an average of 20 years of these data is employed.

TABLE 1 Parameters of the real test system in Iran (exchange rate: 1$ = 4200T̄).

System	Parameter	Unit	Value
PV panel	Investment cost	$/kW	3574.1
	Operation and maintenance cost	$/kW/year	2% investment cost
	Module degradation	%/year	0.7
Battery bank	Investment cost	$/kWh	952.4
	Operation and maintenance cost	$/kW/year	2% investment cost
	Life span	year	5
	Efficiency	%	95
	Depth of discharge	%	80
	Self-discharge rate	%	0.02
Inverter	Rated power	kW	5
	Investment cost	$/kW	1190.5
	Efficiency	%	95
	Life span	year	10
Other parameters	Project period	Year	20
	Base FiT	$/kWh	0.346
	Discount rate	%	19
	Inflation rate	%	16

Abbreviations: FiT, feed-in tariff; PV, photovoltaic.

4 | CASE STUDY RESULTS

In this section, the simulation result for three different cases is presented; first, the current situation in Iran is explained and considered. Then, regarding the current system, a proposed situation is evaluated. Finally, to enhance the proposed system, a modified proposed system is suggested and the results are obtained and compared with the proposed case. Afterward, a sensitivity analysis on the system parameters is presented.

4.1 | Economic evaluation for the current system (installing just PV panels)

According to the last Iranian instruction, every residential customer can install a 5 kW PV system, which causes significant demand for installing PV in the last years. Therefore, the former simulation is dedicated to a system without any batteries; what the Iranian distribution network is experiencing right now. The result for the current situation is shown in Table 2, where the economic and technical results are listed. As it is revealed, the PBY for a residential customer who just install PV panels is less than 6 years. Meanwhile, the IRR is 0.4307, which is greater than the system discount rate, and the BCR reaches about 3. This means installing a PV plant for residential customers in the considered system is beneficial, owing to the proper economic indices. Although this investment seems like a fruitful project from investors' standpoint, the operator is unable to reduce the

TABLE 2 Simulation results for the current system (installing just photovoltaic [PV] panels).

Considered system	PBY	IRR	BCR	LCOE	Total system peak shaving
Current system (installing just PV panels)	5.83	0.4307	3.01	0.5867	0

Abbreviations: BCR, benefit to cost ratio; IRR, internal rate of return; LCOE, levelised cost of energy; PBY, payback period years.

peak of the system, due to the incapability of generating energy during the evening peak of the system. Consequently, the joint implementation of PV and battery in residential sectors are considered in the following subsections. In order to be sure about customers' participation in installing both PV and battery, the proposed system should be as profitable as the current system. Accordingly, the result of table, in particular PBY, is investigated as reference economic indices in the upcoming simulations.

4.2 | Economic evaluation for the proposed system (installing PV panels and battery bank)

The main purpose of the joint implementation of PV and battery is to reach a system with decreased maximum load. To reach this aim, the battery bank should be characterized so that the maximum peak shaving would be achievable. Meanwhile, the capacity of the battery bank must be ascertained from available sizes in the market. Moreover, since the battery is considered as a new and costly technology, the PBY of the project will be remarkably increased if the FiT would be the same as the current system. Therefore, the LFiT is introduced here to encourage customers to install the battery with reasonable PBY. Through it, the FiT is divided into two parts; FiT_{PV} and $FiT_{bat,}$ where the injected power from customers into the system is purchased via different incentive prices. FiT_{PV} is assigned to the daytime hours when the PV can produce energy. In a similar way, FiT_{bat} is devoted to peak hours and whenever the battery can inject power into the system with the aim of peak shaving. Considering all of the factors mentioned above, an analysis of the capacity of batteries and the number of customers who should participate in the project subject to different percentages of peak shaving is performed and results are summarized in Table 3 . This procedure is repeated for different levels of load shaving so that the PBY of the proposed system does not exceed the current system (5.83 years). For instance, if the planner wants to reach a 10 percent total peak shaving, about 20,300 residential customers should install a 5 kW PV system plus a 12 kWh battery bank. This is equal to 5.2% of total residential customers that need to spend 3916 M$ over the project period. It is noticeable that if the Fit_{bat} ratio is being to approximately 3.5 times higher than FiT_{PV}, the PBY of the proposed system would be almost the same as the current system. Furthermore, the operator has to pay costs about 1.5 to 2 times higher than the current system over the project period. Although this brings a higher economic burden to the system operator, it finally leads to total

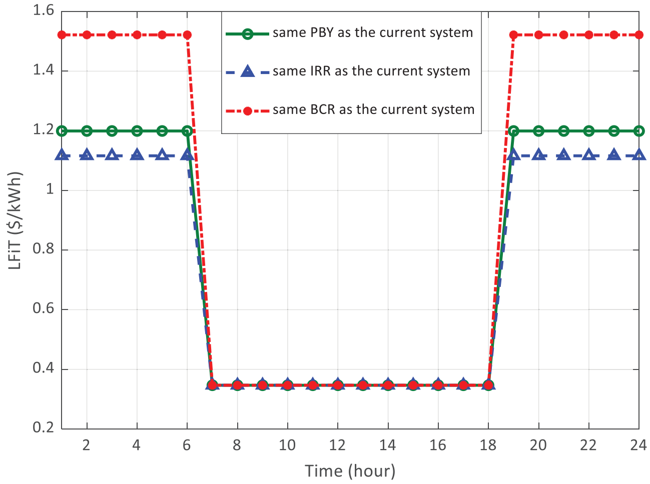

FIGURE 6 Various levelised feed-in tariff (LFiT) to reach the same economic indices as the current system (peak shaving = 10%).

peak shaving while in the current system, no peak shaving is available.

Based on the results illustrated in Table 3, the system operator should offer a Fit_{bat} about 3.5 times higher than FiT_{PV} to present a project with the same PBY. However, this Fit_{bat} to FiT_{PV} ratio does not guarantee similar economic indices in comparison with the current system. Therefore, the Fit_{bat} to FiT_{PV} ratio should be revised to catch a similar index (Figure 6). Various LFiT to reach the same economic indices as the current system (peak shaving = 10%) display the LFiT that the system operator should be enacted to show a similar index as the current system. These results are depicted for a system with 10% peak shaving, which needs a 12 kWh battery bank. It is worth noting that the Fit_{bat} to FiT_{PV} ratio for the BCR is higher than the PBY and the IRR. The reason is that in comparison with the current system, the presence of a battery bank in the proposed system imposes a replacement cost to the investor every five years. Consequently, the Fit_{bat} to FiT_{PV} ratio should be higher than others to compensate for these additional costs.

The net cash flow and the annual cash flow of the proposed system are depicted in Figure 7. As can be seen from the figure, the net cash flow of customers is not uniformly grown. The reason can be considered based on the two dissimilar resources; first of all, the investor has to replace the battery bank and the inverter which causes a reduction in annual cash flow. Second, regarding the SATBA rules, a yearly fraction is applied on the FiT at the beginning of the 8th, 12th, and 16th years, which decreases the net cash flow. However, the net cash flow of the proposed system in comparison with the current system is still reasonable.

The impact of PV and battery banks on the system load and their influence on peak shaving for a sample day are illustrated in Figure 8. In Figure 8a, the influence of the proposed system and current system in peak shaving is clearly depicted. The current system can excellently shave the noon peak of the system, while it is not useful for the evening peak of the system and therefore the total peak of the system is not shaved in this case. On

TABLE 3 A comparison between the current system (installing just photovoltaic [PV] panels) and the current system equipped with battery bank concerning total system peak shaving (the same payback period years [PBY] as current system).

Number of customers who participated in the project		**10 100**	**10 200**	**10 600**	**10 200**	**12 200**	**14 200**	**16 200**	**18 300**	**20 300**	**22 300**	**24 200**
Percentage of customers participated in the project (%)		**2.59**	**2.61**	**2.72**	**2.61**	**3.13**	**3.64**	**4.15**	**4.69**	**5.20**	**5.72**	**6.20**
Current system (installing just PV panels)	Total system peak shaving						**0 %**					
	Total paid cost to investors (M$)	1036	1047	1088	1047	1252	1457	1663	1879	2083	2288	2483
Proposed system (installing PV panels and battery bank)	Capacity of battery for each customer	7	7	9	10	10	11	11	11	12	12	12
	Total system peak shaving	**2%**	**3%**	**4%**	**5%**	**6%**	**7%**	**8%**	**9%**	**10%**	**11%**	**12%**
	Fit_{bat} to FiT_{PV} ratio to reach the same PBY	3.47	3.47	3.48	3.45	3.45	3.49	3.49	3.49	3.46	3.46	3.46
	Total paid cost to investors (M$)	1571	1587	1805	1815	2171	2631	3002	3391	3916	4302	4669

Abbreviation: FiT, feed-in tariff.

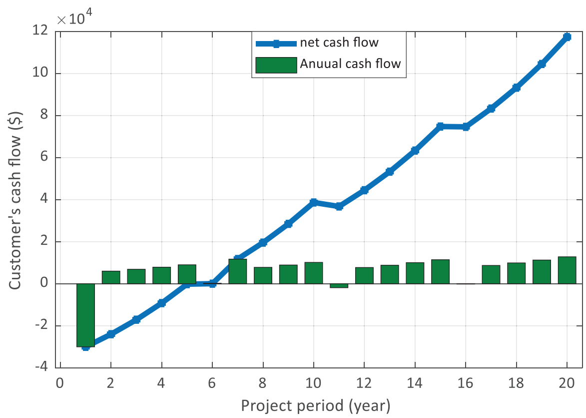

FIGURE 7 Net cash flow of residential investors for the proposed system (peak shaving = 10%).

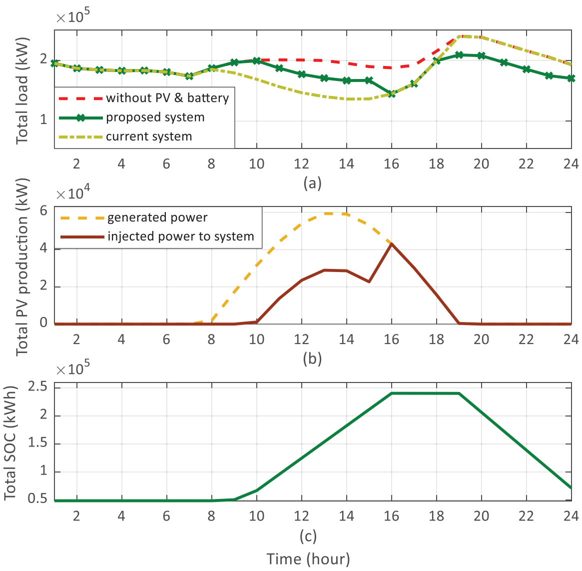

FIGURE 8 (a) Total load of network for different systems, (b) total PV generated and injected power by residential investors, and (c) total SOC of batteries.

the other hand, in the proposed system and by injecting power to the system via PV at noon time and battery in the evening time, as shown in Figure 8b,c, the whole system load is properly shaved and a smoother load profile is obtained.

4.3 | Modified proposed system for installing PV panels and battery bank

In the proposed case introduced in the last section, a considerable initial cost is imposed on the residential customers that can be considered as a barrier to participation in the project. Additionally, the capacity of PV panels is determined as 5 kW based on the Iranian rules which the total power of installed PV by customers may exceed the required value that is needed to shave the noon peak of the system. As a result, the operator has to pay a considerable cost to buy energy from PVs, while the huge amount of production may not be essential. Therefore, in this section, the other capacity of the PV and battery is investigated to determine the minimum amount of these resources with the same peak shaving. Through a sensitivity analysis on the real value of PV and battery, it is figured out that if every residential customer participated in the project reduces the PV capacity to 3 kW; the system operator can reach the same 10% peak reduction as shown in Table 4. As illustrated in the table, the number of customers that should be taking part in the project

TABLE 4 Simulation results for the modified proposed system (installing lower photovoltaic [PV] panels)—the same payback period years [PBY] as the proposed system.

	Number of customers who participated in the project	Total system peak shaving	PV size for each customer	Battery size for each customer	Fit_{bat} to FiT_{PV} ratio to reach the same PBY of the current system	Total paid costs to investors (M$)
Proposed system	20 300	10 %	5	12	3.46	3916
Modified Proposed system	20 300	10 %	3	12	3.67	3165

Abbreviation: FiT, feed-in tariff.

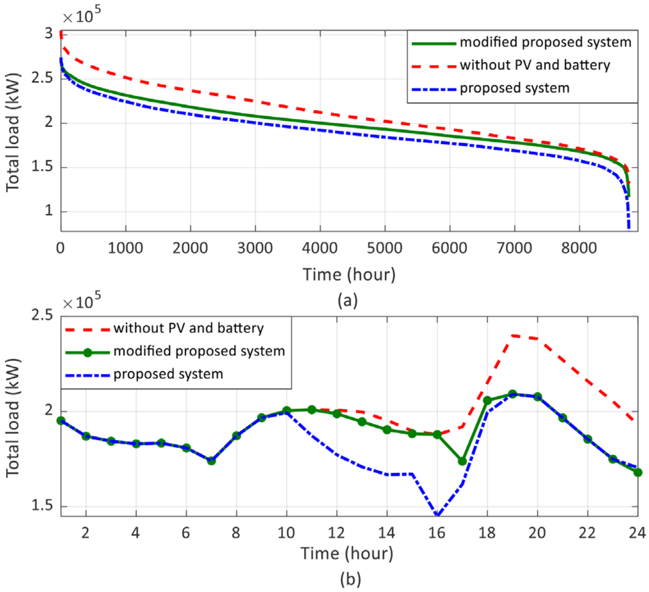

FIGURE 9 (a) Load duration curve; (b) daily load profile for three situations.

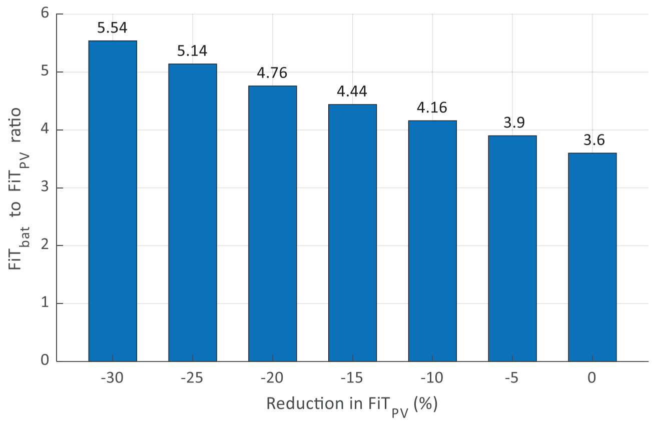

FIGURE 10 FiTbat to FiTPV ratio for the reduction in FiTPV to reach the same payback period years (PBY). PV, photovoltaic; FiT_{PV}, feed-in tariff for PV.

is the same which means the peak of the system can be shaved with lower PV panels. This causes a lower paid cost over the project horizon, where the operator has to pay 3165 M$ instead of 3916 M$, about a 20% reduction in the paid cost. However, by reducing the PV size, the revenue of the residential is decreased due to the lower sold energy to the system. To compensate for this loss, the Fit_{bat} to FiT_{PV} ratio is increased from 3.46 to 3.67, in order to reach the same PBY as the proposed system. Therefore, the system operator can present a more affordable system, while the condition does not change for the investors.

To be more precise about the profitability of the modified proposed case, the load variation curve and a daily load profile are depicted in Figure 9. As Figure 9a shows, in both the proposed system and modified proposed system, the peak of the system are equal together; however, in the remaining hour of a year, the modified proposed system does not rely on investors' production. In other words, in the modified proposed system, the operator mainly engages the residential investors to supply the peak load of the system. Figure 9b makes this more intelligible, where the modified proposed system clearly shows a smoother load profile. The proposed system, however, injected a high power to the system during daytimes that may cause reverse power flow on some hours.

The second suggestion for the proposed case system is related to the variation in FiT_{PV}. If the FiT_{PV} is declined from the current value, the PBY of PV is increased, and consequently, installing just a PV system may not be profitable from investors' point of view and residential investors would no longer be interested in installing a PV system. However, if the FiT_{PV} is decreased and the Fit_{bat} to FiT_{PV} ratio is simultaneously increased to a value that the whole project leads to a similar PBY, more customers might be encouraged to install a joint PV and battery system. Figure 10 shows the Fit_{bat} to FiT_{PV} ratio with respect to the decrement in FiT_{PV} to reach the same PBY of the proposed system. For instance, if the FiT_{PV} is decreased by 30%, the project becomes unprofitable for a PV investor, but if the Fit_{bat} is 5.54 times higher than FiT_{PV}, then the project becomes fruitful for the investors who install both PV and battery.

4.4 | Sensitivity analysis

In this subsection, a sensitivity analysis of system parameters is performed. First, the national production factor which is introduced in Equation (7) is considered. According to the SATBA instruction, a national factor can be inserted in the FiT calculation, while this parameter is currently considered as zero. By

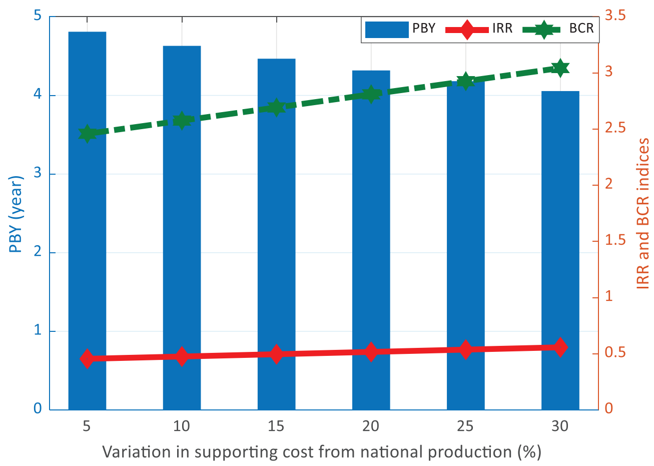

FIGURE 11 Variation of payback period year (PBY) and internal rate of return (IRR) concerning change in the national production factor. BCR, benefit to cost ratio.

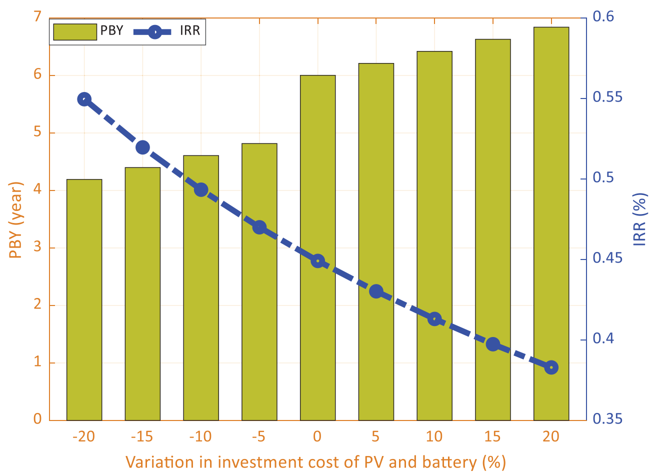

FIGURE 12 The impact of the investment cost of photovoltaic (PV) and battery on economic indices. PBY, payback period years; IRR, internal rate of return.

raising this factor, the residential investors can take a higher benefit as shown in Figure 11. This change not only improves the economic criteria but also persuades local companies to expand their production.

The next parameter that is considered in this section is the investment cost. Since battery technologies have been progressing in the last years, it is predictable that they become cheaper in the future. This situation may happen for PV technologies; however, the reverse situation may also take place. Therefore, the impact of variation on PV and battery costs in the PBY and IRR is evaluated and depicted in Figure 12. As this figure shows, the PBY of the project can be declined to about 4 years if the investment cost of PV and battery face a 20% decrement. Meanwhile, the IRR also reaches about 55% which is an acceptable value from an investor's standpoint.

The impact of PV module degradation factor on PBY and IRR, and yearly generated power by PV panel is illustrated in Figure 13. This factor, however, is ignored in many studies.

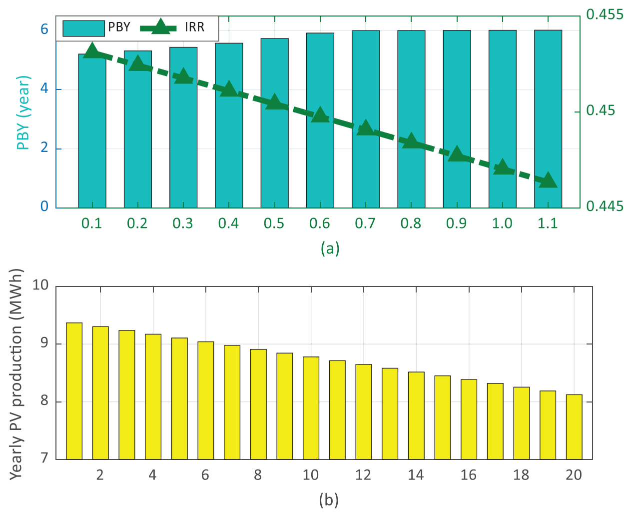

FIGURE 13 The impact of photovoltaic (PV) module degradation on economic indices and PV power production. PBY, payback period years; IRR, internal rate of return.

TABLE 5 Comparison of levelised feed-in tariff (LFiT) of this study with real FiT in selected countries ($/kWh) [18].

This study (Iran)	Germany	Spain	France	Canada	Turkey
0.36 (for PV) 1.2 (for battery)	0.24	0.28	0.39	0.27	0.12

Abbreviation: PV, photovoltaic.

The results show that if this factor is considered as 0.1 (almost ignored) the PBY of the project can be reduced to about 5 years. Moreover, the generated power by a residential customer over the project period is shown in Figure 13b. As can be seen, a residential customer in the first year of planning can produce about 9.7 MWh, which does not deviate from the actual energy predicted in Figure 5. Furthermore, it is illustrated that the generated power can be lowered to about 8 MWh at the end of the project which can affect the net cash flow of the project.

Finally, in order to compare the LFiT of this paper with the real FiT in other countries, the incentive prices offered by different governments are presented in Table 5. This table denotes that the FiT for the PV system in Iran is almost similar to considered countries. The FiT for the battery, however, is higher than the FiT of such countries, but it is noteworthy that this high rate of FiT battery to Fit PV can still be affordable for a system operator if they modified their incentive prices with respect to the modified plans offered here.

5 | CONCLUSION

Similar to many countries, Iran has also enacted FiT policies to support private investors in installing renewable energy resources. However, the tendency to install PV systems has dramatically grown in the last years, which is not suitable to shave the whole peak of the system. Therefore, here, the potential of residential investors in installing renewable resources with the aim of peak shaving was considered. Meanwhile, the revised version of Iranian's instruction published at the beginning of 2021 was engaged to present more precise results. To deal with the both system operator and investors' target, first an analysis of the current system was performed. Following that, the proposed system consisting of battery bank and PV panels was investigated. An LFiT scheme was also introduced to appropriately meet the investors' goals. The different LFiT was then calculated to wisely fulfill the economic criteria. The results well demonstrated that the project can be cost-effective for an investor if the system operator offers LFiT schemes.

Afterward, two suggestions named as modified proposed system were introduced that could lead to better performance. Installing different sizes of PV panels was the first one that caused a smoother load profile and imposed a lower cost on the system operator. In the second suggestion, a variation in FiT was proposed that can rather persuade customers to install both PV and battery since the investors' goals were also well-addressed. Finally, sensitivity analysis on different parameters including national production factor, investment cost, and PV module degradation factor was performed and presented.

The comparison of the current system and proposed systems figured out that both systems could be beneficial from residential customers' viewpoint. Although installing PV panels via residential customers can properly shave the noon peak of the system, they could not be effective for the evening peak. In contrast, by employing the proposed systems, the system operator can satisfactorily shave the whole peak of the system, where the investors' purposes were addressed as well. It should be noted that by taking into account the mutual interaction of residential investors and distribution power systems, the impact of such resources could be more tangible. The investors can even cause to postpone the requirement of the power system in upgrading system instruments which can decrease the total cost of the system. This mutual interaction with respect to the real system structure would be performed in the next study.

NOMENCLATURE

h	index for time (hour)
y	index for time (year)
PV	index for PV panel
bat	index for battery
N_{PV}	number of PV panels
$p_{PV}(t)$	generating power by PV panel
$P_{ref.PV}$	rated power of installed panel
C_T	temperature coefficient ($-3.7*10^{-3}$)
T_{PV}	panel's temperature
T_{ref}	reference temperature (25°C)
I_{PV}	received solar irradiance
I_{ref}	reference solar irradiance (1000 W/m^2)
T_{air}	air temperature
T_{no}	normal operating temperature
$E_{bat}(t)$	state of the charge of battery bank
ω	rate of hourly self-discharge
E_{pr}	energy power rate of battery
η_{bat}	efficiency of the battery
ψ_{cha}	binary variable for charging battery
η_{inv}	efficiency of the inverter
ψ_{dis}	binary variable for discharging battery
$FiT_{PV}(y)$	feed-in tariff for PV
$C(y)$	yearly coefficient
$AC(y)$	yearly adjustment coefficient
C_{np}	coefficient related to the national production
RPI	retail price index
EER	Euro exchange rate
pp	period of project
d	PV module degradation factor
dr	discount rate
N_{PV}	number of PV panels
IC_{PV}	investment cost of PV panels
N_{bat}	number of battery units
IC_{inv}	investment cost of inverter
IC_{bat}	investment cost of battery units
ϑ_y	binary variable for replacing battery
i	inflation rate
ξ_y	binary variable for replacing inverter
OM_{PV}	operation and maintenance cost of PV
OM_{bat}	operation and maintenance cost of battery
N_c	number of customers who contribute to the project
L_{max}	maximum load of the system
$N_{PV.max}$	maximum number of PV panels
$N_{bat.max}$	maximum number of batteries
$E_{bat.max}$	maximum stored energy in battery
DOD	depth of discharge
BCR	benefit to cost ratio
DG	distributed generation
DPBY	discount payback period years

Indices

IRR	internal rate of return
LCOE	Levelised cost of energy
LFiT	Levelised feed-in tariff
NCF	net cash flow
NM	net-metering scheme
NPV	net present value

Parameters and variables

PBY	payback period years
PV	photovoltaic
SATBA	the renewable energy and energy efficiency organization of Iran

AUTHOR CONTRIBUTIONS

Ali Ashoornezhad: conceptualization, methodology, software, validation, formal analysis, writing—original draft, and writing—review and editing. Hamid Falaghi: supervision, investigation, formal analysis, and writing—review and editing.

Amin Hajizadeh: supervision, resources, formal analysis, and writing—review and editing. Maryam Ramezani: formal analysis and supervision.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available in the supplementary material of this article

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REFERENCES

1. Fatima, S., Püvi, V., Arshad, A., Pourakbari-Kasmaei, M., Lehtonen, M.: Comparison of economical and technical photovoltaic hosting capacity limits in distribution networks. Energies. 14(9), 2405 (2021)
2. Ashoornezhad, A., Falaghi, H., Hajizadeh, A., Ramezani, M.: A two-stage multi-period distribution network expansion planning considering the integration of private investors. Int. Trans. Electr. Energy Syst. 311(12), e13226 (2021)
3. Ashoomezhad, A., Asadi, Q., Falaghi, H., Hajizadeh, A.: Private investors participation in long-term distribution network planning. In 2021 12th Power Electronics, Drive Systems, and Technologies Conference (PEDSTC), 1–5. IEEE, Piscataway, NJ (2021)
4. Schleifer, A.H., Murphy, C.A., Cole, W.J., Denholm, P.L.: The evolving energy and capacity values of utility-scale PV-plus-battery hybrid system architectures. Adv. Appl. Energy. 2, 100015 (2021)
5. Xiong, L., Nour, M.: Techno-economic analysis of a residential PV-storage model in a distribution network. Energies. 12(16), 3062 (2019)
6. Li, J.: Optimal sizing of grid-connected photovoltaic battery systems for residential houses in Australia. Renew. energy. 136, 1245–1254 (2019)
7. GIS, S.: No Title. https://solargis.com/maps-and-gis-data/download/iran (2022)
8. IGMC: No Title. https://www.igmc.ir/statistical-center (2022)
9. Farias-Rocha, A.P., Hassan, K.M.K., Malimata, J.R.R., Sánchez-Cubedo, G.A., Rojas-Solórzano, L.R.: Solar photovoltaic policy review and economic analysis for on-grid residential installations in the Philippines. J. Clean. Prod. 223, 45–56 (2019)
10. Górnowicz, R., Castro, R.: Optimal design and economic analysis of a PV system operating under net metering or feed-in-tariff support mechanisms: a case study in Poland. Sustain. Energy Technol. Assessments. 42, 100863 (2020)
11. Virtič, P., Lukman, R.K.: A photovoltaic net metering system and its environmental performance: a case study from Slovenia. J. Clean. Prod. 212, 334–342 (2019)
12. Riyanto, P.W., Hashim, R., Abidin, R.: Solar energy for residential housing: a case study of feed in tariff (FIT) and net metering (NEM) practices in Malaysia. In Symposium on Technology Management and Logistics (STML Go Green) 2019, Universiti Utara Malaysia, issue 6, pp. 52–60 (2019)
13. Mojonero, D.H., Villacorta, A.R., Kuong, J.L., Mojonero, D.H.: Impact assessment of net metering for residential photovoltaic distributed generation in Peru. Int. J. Renew. Energy Res. 8(3), 1–10 (2018)
14. Alajmi, B.N., Ahmed, N.A., Abdelsalam, I., Marei, M.I.: An assessment of net metering and feed-in tariffs for grid-connected PV systems in the Kuwaiti market. Arab. J. Sci. Eng. 47, 3055–3067 (2022)
15. Budin, L., Grdenić, G., Delimar, M.: A quadratically constrained optimization problem for determining the optimal nominal power of a PV system in net-metering model: a case study for Croatia. Energies. 14(6), 1746 (2021)
16. Ndiritu, S.W., Engola, M.K.: The effectiveness of feed-in-tariff policy in promoting power generation from renewable energy in Kenya. Renew. Energy. 161, 593–605 (2020)
17. Londo, M., Matton, R., Usmani, O., van Klaveren, M., Tigchelaar, C., Brunsting, S.: Alternatives for current net metering policy for solar PV in the Netherlands: a comparison of impacts on business case and purchasing behaviour of private homeowners, and on governmental costs. Renew. Energy. 147, 903–915 (2020)
18. Kılıç, U., Kekezoğlu, B.: A review of solar photovoltaic incentives and policy: selected countries and Turkey. Ain Shams Eng. J. 13(5), 101669 (2022)
19. Coria, G., Penizzotto, F., Pringles, R.: Economic analysis of photovoltaic projects: the Argentinian renewable generation policy for residential sectors. Renew. Energy. 133, 1167–1177 (2019)
20. Hidayatno, A., Setiawan, A.D., Supartha, I.M.W., Moeis, A.O., Rahman, I., Widiono, E.: Investigating policies on improving household rooftop photovoltaics adoption in Indonesia. Renew. Energy. 156, 731–742 (2020)
21. D'Adamo, I., Gastaldi, M., Morone, P.: The impact of a subsidized tax deduction on residential solar photovoltaic-battery energy storage systems. Util. Policy. 75, 101358 (2022)
22. Worku, M.Y.: Recent advances in energy storage systems for renewable source grid integration: a comprehensive review. Sustainability. 14(10), 5985 (2022)
23. Bakhshi, R., Sadeh, J.: Economic evaluation of grid–connected photovoltaic systems viability under a new dynamic feed–in tariff scheme: a case study in Iran. Renew. Energy. 119, 354–364 (2018)
24. Firozjaei, H.K., Firozjaei, M.K., Nematollahi, O., Kiavarz, M., Alavipanah, S.K.: On the effect of geographical, topographic and climatic conditions on feed-in tariff optimization for solar photovoltaic electricity generation: a case study in Iran. Renew. Energy. 153, 430–439 (2020)
25. Bakhshi-Jafarabadi, R., Sadeh, J., Dehghan, M.: Economic evaluation of commercial grid-connected photovoltaic systems in the Middle East based on experimental data: a case study in Iran. Sustain. Energy Technol. Assessments. 37, 100581 (2020)
26. Farangi, M., Soleimani, E.A., Zahedifar, M., Amiri, O., Poursafar, J.: The environmental and economic analysis of grid-connected photovoltaic power systems with silicon solar panels, in accord with the new energy policy in Iran. Energy. 202, 117771 (2020)
27. Sheikhhoseini, M., Rashidinejad, M., Ameri, M., Abdollahi, A.: Economic analysis of support policies for residential photovoltaic systems in Iran. Energy. 165, 853–866 (2018)
28. Li, Y., Gao, W., Ruan, Y.: Performance investigation of grid-connected residential PV-battery system focusing on enhancing self-consumption and peak shaving in Kyushu, Japan. Renew. Energy. 127, 514–523 (2018)
29. Campana, P.E., et al.: Li-ion batteries for peak shaving, price arbitrage, photovoltaic self-consumption in commercial buildings: a Monte Carlo Analysis. Energy Convers. Manag. 234, 113889 (2021)
30. Jankowiak, C., Zacharopoulos, A., Brandoni, C., Keatley, P.M.A., Hewitt, N.: Assessing the benefits of decentralised residential batteries for load peak shaving. J. Energy Storage. 32, 101779 (2020)
31. Manojkumar, R., Kumar, C., Ganguly, S., Catalão, J.P.S.: Optimal peak shaving control using dynamic demand and feed-in limits for grid-connected PV sources with batteries. IEEE Syst. J. 15(4), 5560–5570 (2021)
32. Ashoornezhad, A., Falaghi, H., Hajizadeh, A., Ramezani, M.: A bi-level multistage distribution network expansion planning framework with the cooperation of residential private investors (A case study in Iran). IET Renew. Power Gener. 17, 1881–1898, (2023)
33. Ashoornezhad, A., Saberi, R., Asadi, Q., Falaghi, H.: A levelized feed-in tariff to integrate battery into the PV-connected system. In 8th International Conference on Technology and Energy Management. pp. 1–5. IEEE, Piscataway, NJ (2023)
34. Ashoornezhad, A., Falaghi, H., Hajizadeh, A., Ramezani, M.: Economic analysis of private investor participation in long-term distribution network planning. J. Energy Manag. Technol. 6(4), 259–269 (2022)
35. Amin, A., Liu, X.-H., Abbas, Q., Hanif, I., Vo, X.V.: Globalization, sustainable development, and variation in cost of power plant technologies: a perspective of developing economies. Environ. Sci. Pollut. Res. 28(9), 11158–11169 (2021)
36. Zhang, L., Yang, Y., Li, Q., Gao, W., Qian, F., Song, L.: Economic optimization of microgrids based on peak shaving and CO2 reduction effect: A case study in Japan. J. Clean. Prod. 321, 128973 (2021)
37. SATBA. No Title. http://www.satba.gov.ir/en/news/1645/Renewable-Energy-Reports2020

38. Maleki, A., Nazari, M.A., Pourfayaz, F.: Harmony search optimization for optimum sizing of hybrid solar schemes based on battery storage unit. Energy Reports. 6, 102–111 (2020)
39. Alotaibi, M.A., Salama, M.M.A.: An incentive-based multistage expansion planning model for smart distribution systems. IEEE Trans. Power Syst. 33(5), 5469–5485 (2018)
40. Duman, A.C., Güler, Ö.: Economic analysis of grid-connected residential rooftop PV systems in Turkey. Renew. Energy. 148, 697–711 (2020)
41. NASA. No Title. https://power.larc.nasa.gov/data-access-viewer/
42. C. bank of Iran. No Title. https://cbi.ir/default_en.aspx

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