Chapter 7

An economic demand management strategy for passive consumers considering demand-side management schemes and microgrid operation

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7.1 Introduction

In recent years, there are strong incentives to utilize electricity end-users for reducing greenhouse gases, competitive energy policies, and participate in consumption management. The increased penetration of microgrids and the extended strategies of demand-side management have created an excellent opportunity for consumers to acquire these benefits in smart systems. Consequently, in this circumstance, a passive consumer, in addition to purchasing energy from the electricity market directly, can manage to supply its demand economically by choosing the right strategy. To this end, it can utilize the new concept of microgrids and local production to meet the need. Consumres can also participate in load management programs independently or integrated with the microgrid concept.

Nowadays, with the development of smart infrastructures, microgrids can bridge the gaps between electricity market prices and consumer behavior. A microgrid can be considered as a single electrical load from a utility's viewpoint, and from behind the consumer meter, a microgrid can function as a distributed energy resource [1]. Due to seasonal peak loads, increased network reliability, and energy shortages, this controllable load can be an excellent platform for the implementation of demand-side management schemes.

Demand response (DR) programs as a part of demand-side management are powerful tools that facilitate the process of transforming conventional microgrids into green systems by consumption management and efficient utilization renewable sources. These programs involve the modification of customer's demand for energy by various means, such as financial incentives and behavioral change through educational approaches. Accordingly, microgrid and customer reliability will be improved by implementing the DR programs in microgrids. Besides, this benefit can be achieved through the reduction of demand during critical times.

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Recently, due to the propulsion of the smart grid paradigm, numerous efforts have been made to integrate the schemes of DR and microgrid operation. In [2], the impact of the customer participation level in emergency DR for microgrid operation is analyzed in the presence of different uncertainties. In addition, this work examines the effect of different incentives on total costs of operation is examined by a model that is presented based on price elasticity and customer benefit. The scheduling problem based on various incentive rewards and constraints related to microgrid operation is presented in [3]. The authors of [4] propose an optimization function of microgrid operation with the purpose of minimizing operational costs and emissions by considering the DR programs. Due to economic dispatch of a renewable microgrid, the operational costs are investigated in [5] by considering the participation of the consumers in DR schemes. To solve the economic dispatch to minimize the operation cost of microgrid, in [6], the authors proposed the model of different DR programs to prioritize running the plans in the presence of microgrid. In [7], the optimal operation of a microgrid is assessed by the combination of various DR programs. A mathematical model has been developed for microgrid system considering the impact of different DR schemes to minimize the objective function. In order to maximize net income in [8], a cost-benefit analysis is presented to plan the operation of grid-connected microgrid in combination with DR programs. The authors in [9] introduced an incentive payment oriented DR scheme for microgrid operational planning. A stochastic optimization approach is proposed to consider the presence of different types of customers. In [10], a comprehensive DR framework in a microgrid environment proposed to mitigate peak demand and energy saving. Considering DR schemes for a microgrid retailer, an optimal strategy for energy dispatch and pricing is presented in [11]. An economic optimization model is introduced in [12] to manage microgrid and allocate the shiftable loads in the residential sector. The authors in [13] proposed a dynamic optimization model based on DR schemes to minimize the operation cost and maintain the supply-demand balance in microgrids.

Despite the reviewed literature, the question that authors are interested in here is quite different. This work explores which strategy would be best suited for a typical passive load to manage its demand economically; purchasing electricity from the grid and participating in load management plans, or transferring to a microgrid and integrating with DR programs. To this end, developing an integrated procedure that covers both microgrid establishment and DR strategy effects from the economic viewpoint, can be vital. The proposed methodology here is concentrated to find a tradeoff point between the costs of microgrid and the DR.

The scope of this work is to propose a procedure that can address this economic problem as much as possible. Accordingly, the intended method is aiming to consider microgrid costs and DR scheme cost regardless the market mechanisms to manage the network load economically. On this base, first, the corresponding cost model for installation and operation of microgrid is formulated. For simplicity, in the formation of the microgrid, renewable energy-based units are not considered. Then, the output is evaluated alongside DR cost with the viewpoint of reaching the compromise point. Finally, the proper DR program related to the best performance is selected as the final strategy. Two DR programs including price-based DR (PDR) and incentive-based DR (IDR) are considered in the studies. The introduced procedure is implemented on several real loads and is investigated under different case studies. The detailed results are presented in the analysis of significant contributions and benefits of the proposed method.

This chapter covers a summary of DR programs in Section 2. Classification of microgrid applications is provided in Section 3. The cost model for installation and operation of microgrid, the cost function related to the run of the various DR programs, and the proposed decision-making method are presented in Section 4. Finally, to investigate and analyze the proposed algorithm, three case studies are presented in Section 5.

7.2 Types of DR programs

DR can be defined as changes in electricity usage by end-use customers from their usual consumption patterns in response to changes in prices. DR programs may be classified either according to how the enrolled consumers respond or by their type (motivation procedure and trigger criteria) regarding the characterization of their load. The U.S. Department of Energy (DOE) categorizes these programs into PDR and IDR [14]. PDR offers collaboration in time-varying rates that reflect the value and cost of electricity for different periods. However, in IDR consumers voluntarily provide load reductions by responding to economic signals. Indeed, the PDR includes the actual cost for the electricity, while the IDR provides customers with peak shaving incentives [15]. This section includes detailed discussions on some of the DR strategies for both categories. In the end, the overall impact of these strategies on microgrid operation is investigated.

7.2.1 PDR strategies

In different articles, various strategies have been studied for PDR. However, here, only three schemes are considered. These include time of use (TOU), critical peak pricing (CPP) and real-time pricing (RTP) [16]. These methods are used for cost modeling and economic evaluation in the proposed model.

- *Time of Use (TOU) pricing*. Electricity consumers that are charged with flat prices are not aware of the varying cost of electricity. One way in which consumers will be incentivized to change their consumption patterns is through price signals delivered via TOU tariffs, in which the price of electricity varies depending on factors such as electricity network constraints and the wholesale price of electricity [17]. These tariffs are designed to more closely reflect the investment and the production cost structure, so key issues such as the duration of individual periods and related price levels are involved in the design of TOU rates. Many countries divide a year into peak periods and valley periods according to summer or non-summer months to charge differently. This pricing is easy to be implemented and has a great effect on load shifting, although it cannot be strictly called a dynamic pricing strategy for its high consistency [18]. Static TOU tariffs are the stepped rate structure, which varies into several periods (usually less than five periods) during the day fixedly and regularly. The pricing scheme of TOU tariff can be introduced as follows:

$$P_{TOU-i} = \begin{cases} F_1, & i \in (h_1, h_2) \\ F_2, & i \in (h_2, h_3) \\ \vdots \\ F_k, & i \in (h_{k-1}, h_k) \end{cases} \tag{7.1}$$

In (7.1), a day is separated into *k* periods (*h* stands for hour) and a certain price level is provided for each period known as F_i.

- *Critical Peak Pricing (CPP)*. The long-term electricity supply costs associated with using electricity during a specific period of the day are reflected by TOU tariffs. In order to capture the short-term costs of considered critical periods for the power system, CPP tariffs may be employed [19]. This strategy, also called peak load pricing, has both characteristics of TOU tariffs and emergency load control, therefore, it can be a supplement to TOU pricing which has some mandatory restrictions for electricity demand in critical peak periods. A CPP period is announced ahead of time, typically day-ahead, and customers on the CPP rate can reduce their bill by shifting or reducing their loads during these peak times. In this way, the higher rates on emergency or critical peak periods (e.g. unavailability of reserves, extreme outages, etc.) are charged by CPP tariffs, while the prices in other times remain the same [20]. The power utility may sign contracts with consumers to specify the maximum number of days per year that may be considered critical and the number of periods for which the CPP rate is applied otherwise; they will get some punishments. Equation (7.2) provides the pricing scheme of CPP tariff:

$$P_{CPP-i} = \begin{cases} R_{N1}, & i \in (h_1, h_2) \\ \vdots & \text{If not Critical Periods} \\ R_{Nk}, & i \in (h_{k-1}, h_k) \\ R_{C1}, & i \in (h_{C-1}, h_{C-2}) \\ \vdots & \text{Otherwise} \\ R_{Cm}, & i \in (h_{C-(m-1)}, h_{C-m}) \end{cases} \tag{7.2}$$

where R_{Nk} and R_{Cm} are the separated price levels for normal and critical tariffs, respectively. A day is split into *k* periods and also *m* part is introduced for critical times.

- *Real-time pricing (RTP)*. This strategy separates a day into several short time slots similar to TOU tariff. Generally, RTP is an electricity pricing strategy that directly according to the real-time supply and demand situation, reflects the marginal value of electricity [21]. Therefore, prices vary in real-time (e.g. an hour or a half-hour) depending on the current wholesale cost of electricity so it can be said that the scheme is theoretically most reasonable. Furthermore, RTP and real-time power load have a positive correlation for general operating state. A typical relationship of the pricing scheme is obtained as follows [22]:

$$P_{RTP-i} = \alpha \times A\_Load_i \tag{7.3}$$

In (7.3), α is the rate between load and price, and A_Load_i is the overall consumed load of a certain end-user. This correlation depends on different factors such as real-time status of the operation, line losses, wholesale price and so on. Besides, electricity regulations and the policy of governments and other organizations, e.g. ISOs, limit the setting of electricity prices in practice

7.2.2 IDR strategies

In dynamic pricing, the load control scheme is defined without a third-party operator that manages load-shedding. However, IDR programs are employed by the power utility to control the load of the consumer directly or based on the response of the incentive measures by consumers. Here, three schemes of IDR include direct load control (DLC), emergency DR (EDR) and interruptible load program (ILP), are discussed.

- *Direct Load Control (DLC)*. Ordinarily, DLC programs involve a utility or system operator that allows them to switch on and off specific customers' appliances for a short time during peak periods and critical events. In return for participating, consumers are usually rewarded by way of a financial incentive such as a one-off sign-up payment, recurring annual payment, and ongoing electricity bill discounts [23]. This type of program is mostly applied to residential or small commercial customers. PDR schemes could be supplemented by DLC to reinforce gains of these schemes. This service of contract-based reliability enhancing can be planned to control loads in 10-14 hours.

- *Interruptible load program (ILP)*. This program considers curtailment options to a predefined level. In order to turn off specific loads by participants in these services, customers receive a discount or bill credit in exchange to reduce load during system contingencies. Besides, participants may face penalties in case they fail to respond to a DR event [24]. These are offered for typical customer size from 200 kW up to 3 MW so that customers on these tariffs must curtail within 30 to 60 minutes when being notified by the utility. Also, the total amount of period that a utility can call interruption often is not more than 200 hours per year [25].

- *Emergency DR (EDR) program*. The incentive payments are considered to consumers due to the reducing power consumption during reliability triggered events. These programs can be also known as a combination of DLC and ILP programs. In contrast to ILP, since there is no contractual obligation, this scheme does not impose any penalties if consumers cannot participate [26]. However, these programs have a narrow application, and they are called a very limited number of times per year (less than 5).

7.2.3 DR programs and microgrid operation

As mentioned before, DR programs are divided into two categories. PDR programs depend on the behavior and response of electricity consumers to the suggested prices. Therefore, from the viewpoint of participants, the utilization of microgrids by the consumers is related to the associated cost-benefit. Due to the type of PDR programs, the operation of microgrid will be relatively long-term (at least monthly). On this way, if the microgrid costs involved are higher than the cost of PDR implementation, the participant's preference will be to use the DR scheme into the desired period. Assuming a variety of PDR schemes, the participation priority can be a criterion to choose the economic microgrid operation.

Since the period and times of participation in IDR programs are predefined, it is possible to combine them with PDR programs. Generally, if the microgrid costs involved are lower than the cost of PDR implementation, then these costs can equilibrate with IDR program cost. With each IDR scheme implemented, the microgrid can be run for the customer's electricity availability. Accordingly, when the IDR contract is signed, the microgrid is engaged if needed. In this case, the microgrid is run at the specific periods then turns off.

7.3 Classification of microgrid applications

In the literature, conventional micro-generators, renewable energy resources and energy storage systems are often described as distributed energy resources (DERs) that are on-site generation sources in distribution system [27]. Generally, a microgrid is well-known for integration of DERs into the power grid, as well as its ability to operate in an islanded mode during certain cases. Therefore, the microgrid is described as a low-voltage distribution network of interconnected DERs, controllable loads and critical loads that can operate in either grid-connected or islanded mode [28]. Besides, the microgrid may be used as remote/off-grid case that is not considered in this article.

In general, the microgrid may comprise several distributed generation systems, renewable (such as wind power, photovoltaic, hydro and fuel-cell devices) or conventional generation (such as micro-turbines, diesel generators and internal combustion engines) and a cluster of loads [29]. In this way, the customers can utilize from on-site generators, with the intent of adding additional resources over time, such as energy storage or other renewable sources [30]. However, due to the specific conditions of use of renewable technologies (availability of wind or solar radiation in the time of load demand), in this study it is assumed that conventional generation is used only as a microgrid.

Therefore, customers can deploy this solution to manage their electric load consumption. Whereas DR is primarily focused on loads of consumer side, features analysis of various loads in the presence of microgrid can facilitate to operate microgrid integrated with DR.

The consumption pattern of loads may be indicated as urban, semi-urban, and rural or island. However, the practical application of microgrid for various loads can be mostly classified into eight sectors: Industrial, military, campus/institutional, commercial, healthcare, residential, remote or rural, and others (such as data centers and cell-phone towers). These applications are explained from the viewpoint of DR as follows.

7.3.1 Industrial sector

Industrial facilities, which are increasingly being established in remote locations, may not have continuous access to the main electricity grid. Therefore, this sector may be dependent on fuel and tend to use microgrid. Suppose an industrial consumer can manage electrical demand by utilizing distributed generation, energy storage, and load shifting [31]. Furthermore, the motivation of microgrid operation is the increased security and reliability needs in a grid-connected industrial site.

On the other hand, the industrial sector is suitable for developing DR programs; however, adopting DR programs may be challenging for industrial firms. For instance, temporarily interrupting one or more processes may result in significant load reductions [32]. On this base, certain industrial sectors are only suitable for load management due to their technical restricts. By deploying microgrids in place, the industrial customer may solve this problem to integrate microgrid and DR strategies. Therefore, to provide flexible load solutions, a smart microgrid scheme can establish continuity of the industrial performance by implementing DR strategies.

7.3.2 Military sector

Military sector bases require reliable and resilient power to accommodate a variety of missions. Microgrids are easy to communicate on a community level but have more specific benefits when installed in military applications. Indeed, the military sector can enhance the security of critical electrical loads against the threat of grid outages by microgrids and this can be useful for DR schemes implementation. In order to develop a better DR management system, smart technologies can be used to communicate critical loads performance in real-time. This can help make decision and participate in DR programs, using microgrid without military sector interruption. Besides, cost-effective energy security is a driver to use the other military microgrids such as renewable resources [33]. It should be noted if these technologies are implemented in a secure procedure and well protected from cyber threats, it can be an opportunity for the military sector [34].

7.3.3 Campus/institutional sector

So far, deploying on-site generation on a campus with multiple loads has been a successful procedure. Typically, the operation of microgrids with capacities ranging from 4 to over 40 MW has been common in this sector [35]. Furthermore, various abilities and numerous advantages to management of net load shape during grid needs driven development of smart microgrids in the institutional sector. Generally, campus systems may include university and government campuses, and corporate parks. These are geographically large systems covering many buildings (residential, commercial, and/or industrial) but within a single ownership boundary that does not cross public rights of way [36]. Therefore, the potential for automated demand response is one of the key benefits of this sector along with the use of microgrids.

7.3.4 Commercial sector

Nowadays, microgrids have gained popularity to provide for economic requirements and demand management of commercial building installations, thereby supplementing the conventional grid. Practical applications of microgrids in smart commercial buildings are to increase renewable generation contribution and provide a high level of reliability and resiliency in response to grid outages [37]. One of the most direct ways a commercial microgrid can be used to cut costs is as a means to hedge power prices, so that the system controls can be programmed to optimize for price. The usage peaks in commercial buildings typically align with an electric utility's overall demand peaks. This means that utilities are particularly incentivized to participate with commercial customers to reduce or shift load through DR. Accordingly, a microgrid could use utility power until prices rise and then switch to its own, lower-cost power by participating in DR schemes [38].

7.3.5 Healthcare sector

A healthcare facility or medical center requires reliable electricity, heating, and cooling for running high-tech equipment and keeping patients healthy and comfortable. The microgrids system provides significant economic and environmental benefits to the most advanced healthcare sectors, ensuring the medical center's sustainability and reducing its carbon footprint [39]. These sectors must care for patients 24/7, which creates greater demand for lights, heat and cooling so that their consumption is much more than a commercial building of the same size. Due to the special energy requirements of this sector, huge opportunities can be offered in healthcare facilities by new technologies and procedures. These may be constituted to adopt new enablers and install advanced systems such as smart microgrids, which can empower them to participate in DR programs.

7.3.6 Residential sector

The main challenges in this sector are in making decisions for integrating individual home residential customers into large microgrids, and the deployment of microgrid technology at the level of individual homes. In the first case, it is possible to serve anywhere from a few up to thousands of customers, and to support the penetration of local energy sources (electricity, heating, and cooling). In this situation, some houses may have some renewable sources that can supply their demand as well as that of their neighbors within the same community. In addition, this microgrid may have centralized or several distributed energy storage [40]. However, a decentralized building-integrated microgrid approach has the advantages of control over energy resources by customers. Besides, by adding microgrid capabilities, any changes performed behind the utility meter will likely not introduce significant legal or regulatory complications beyond because individual homes are already connected to the electrical distribution network [41]. Accordingly, using a variety of DR strategies, an appropriate framework for management of energy can be developed for a residential microgrid [42].

7.3.7 Remote or rural microgrids

These microgrids never connect to the utility grid and instead operate in an island mode at all times because of economic issues or geographical position. To incorporate renewable energy sources as an add-on to diesel generator-based systems that so-called hybrid microgrids, provide great potential to diversify generation and lower microgrid operating costs in rural areas [43]. The careful resource assessment and understanding of demand profiles based on local conditions should be employed for the selection of remote microgrids. On this basis, effective and economic operation of microgrid is vital for sustained development; therefore, some DR strategies may be used as an appropriate method to operate rural microgrids [44].

7.3.8 Other microgrids

In addition to the above sectors, microgrids can also be used in other cases. For example, today's data centers are trying to make their operations more resilient and efficient, and this is creating the perfect environment for new technologies like advanced microgrids to flourish. Because of data center investments in backup power equipment such as battery storage, a participant between a data center and its local microgrid may improve the situation for all parties. In this way, the DR schemes can be employed by interacting with data center facilities and microgrids [45].

Furthermore, the electric vehicle (EV) is to be viewed as a distributed resource and is becoming an enabling technology for microgrids. The integration EV-based microgrid, and operation planning strategies can be created under different vehicle behaviors with the minimum total cost goal [46]. Accordingly, the EV-based microgrid, as well as renewable resources, can present new opportunities for DR strategies so that can be employed to store energy when electricity consumption is low and discharge it in times of peak demands [47].

Microgrids connected to cell phone towers could help nearby communities gain access to electricity. In this way, energy service utilities can provide cell phone tower owners and operators with electricity at a competitive price while also providing electricity to nearby communities, with everyone being connected via the microgrid. These towers typically rely on expensive diesel generators, but now, renewable microgrids can offer the less expensive electricity prices, reliable and clean alternative [48].

7.4 The decision procedure for operating of a microgrid integrated with demand response

In this section, details of the proposed decision procedure are provided to select DR schemes. For this purpose, the main concepts involved in this procedure are initially discussed. Therefore, this section begins with the cost model of investment and operation corresponding to the typical microgrid. Then, impact of DR programs on microgrid costs is investigated by modeling the cost of these programs. Finally, the detailed descriptions about the decision procedure are presented.

7.4.1 Microgrid cost modeling

This section presents the costs related to installation, maintenance, operation, and start-up of a microgrid. In order to compare these to the annual DR costs, microgrid costs are expressed annually.

7.4.1.1 Microgrid installation cost

The cost of microgrid installation is included in the purchased cost of distributed generation (DG) with the specified capacity and distribution infrastructure costs. The first cost element can be formulated as the following equation [49]:

$$C_{DG-I} = C_I^{DG} \times P^{DG} \tag{7.4}$$

where C_{DG-I} is the total installation cost of the microgrid. Also C_I^{DG} and P^{DG} are installation cost of DG ($/kW) and capacity of DG unit (kW), respectively. Moreover, the distribution infrastructure costs are comprised of the network costs and likely transformer cost. These can be calculated as follows:

$$C_{NT-I} = C_I^{NT} \times L^{NT} \tag{7.5}$$

$$C_{TR-I} = C_I^{TR} \times P^{TR} \tag{7.6}$$

where C_{NT-I} , C_I^{NT} and L^{NT} indicate the overall installation cost of a private network, the installation cost of a private network ($/m) and length of the network unit (m), respectively. Furthermore, C_{TR-I} ,C_I^{TR} and P^{TR} show the total installation cost of private transformer, installation cost of a private transformer ($/kVA) and capacity of transformer unit (kVA), respectively.

These costs should be converted to the annualized cost (C_I^{Ann}) for a payback period of n years and interest rate r, using the following equation:

$$C_I^{Ann} = \frac{r\left(r+1\right)^n}{\left(r+1\right)^n - 1} \times \left(C_{DG-I} + C_{NT-I} + C_{TR-I}\right) \tag{7.7}$$

7.4.1.2 Microgrid maintenance cost

This cost includes the annual mechanical and electrical reformation costs. Generally, this term is presented as a percentage of installation cost that can be calculated as [50]:

$$C_M = C_I \times \rho \tag{7.8}$$

where ρ is a constant value in terms of percentage and C_M is the maintenance cost per year.

7.4.1.3 Microgrid operation cost

The cost of microgrid operation can consist of fuel cost, work force and so on. This cost depends on duration of microgrid operation; therefore, this equation can be written as [49]:

$$C_O = P_{Av}^{DG} \times C_O^{DG} \times T^{DG} \ / \ 24 \quad (7.9)$$

where P_{Av}^{DG} is average generated power by DG. C_O^{DG} and T^{DG} are the operation cost of DG source and duration of operating hours in a year, respectively.

7.4.1.4 Microgrid start-up cost

Generally, this cost is considered only for fuel-consuming DG units. By definition, the start-up cost can be shown as a function of two parts, i.e., the hot and cold start-up cost. This function is expressed as follows [51]:

$$C_S = \left[C_{SH} + C_{SC} \left(1 - e^{(T_{off} / T_C)} \right) \right] \times N \quad (7.10)$$

where C_{SH} and C_{SC} are hot and cold start-up costs ($), respectively. In addition, T_{off} is the shutdown time of DG unit, T_C is the time constant of DG cooling and N indicates the number of start-ups.

Finally, the overall cost of microgrid deployment can be calculated as:

$$C_{MG}^{i} = C_I^{Ann} + C_M + C_O + C_S \quad (7.11)$$

7.4.2 DR cost modeling

The costs of participating in DR schemes are considered as DR costs. In practice, the customers will participate in these programs according to comparison of the cost of microgrid utilization and DR strategies. As mentioned previously, these programs are categorized into PDR and IDR. In order to make proper decisions about the use of microgrid or the participant in DR schemes, the cost model should be developed for each scheme.

7.4.2.1 PDR-based cost

In PDR programs, electricity tariffs are defined based on different hours of consumption in various sectors. The typical curves of power load and TOU prices in each period are shown in Fig. 7.1. The load curve may be divided into three parts: Peak, mid-peak, and off-peak. On this base, TOU prices are selected as a fixed tariff for each part. By predicting consumption of each part, the participant can calculate the related cost using different tariffs as follows:

$$C_{TOU}^{i} = \sum_{m=1}^{3} pr_{TOU-m} \times W_{TOU-m} \quad (7.12)$$

where W_{TOU-1}, W_{TOU-2} and W_{TOU-3} are the forecasted consumptions in total periods of the peak, mid-peak and off-peak, respectively. Also, pr_{TOU-1}, pr_{TOU-2} and pr_{TOU-3} are the tariffs corresponding in TOU scheme.

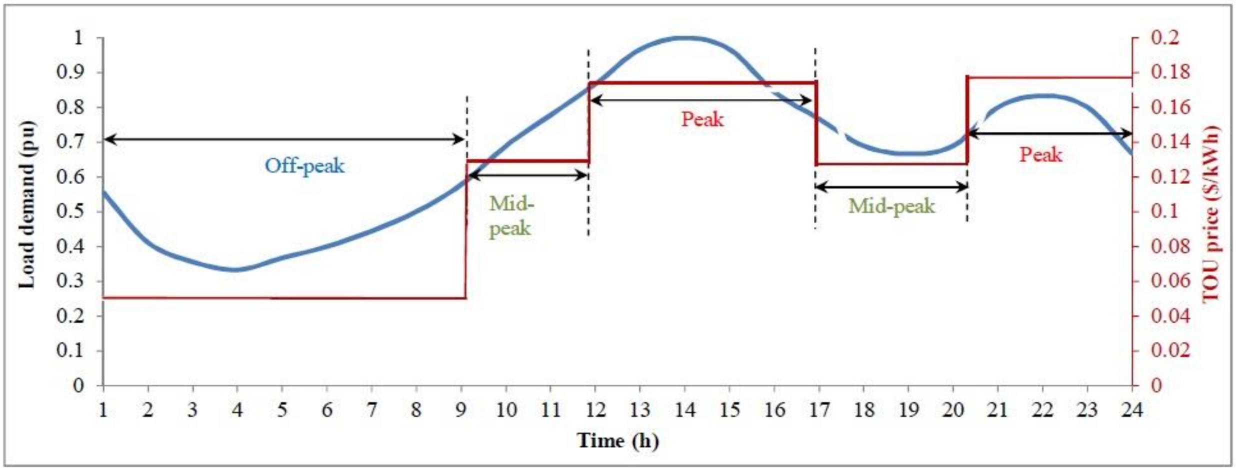


Fig. 7.1. The typical curves of load and TOU price

CPP pricing is similar to TOU strategy. In this scheme, the price level of different periods is slightly lower than TOU scheme. However, if an event happens, the price is suddenly raised. Therefore, in this case, two values of electricity consumption, i.e., the normal and the event period, should be estimated to calculate total cost. A typical CPP scheme is illustrated in Fig. 7.2.

As mentioned before, if participants in this scheme fail to abide by their mandate, they have to pay the penalty. Assuming all obligations are met, the estimated cost of participating in the scheme is calculated as follows:

$$C^{i}_{CPP} = \sum_{m=1}^{3} pr_{CPP-m} \times W_{CPP-m} + \sum_{m=1}^{3} pr'_{CPP-m} \times W'_{CPP-m} \tag{7.13}$$

where pr_{CPP-m} and pr'_{CPP-m} are related to the normal and event tariffs in each period, respectively. Also W_{CPP-m} and W'_{CPP-m} indicate the estimated consumptions in the normal and the event periods, respectively.

Since RTP pricing expresses better flexibility than TOU and CPP schemes, this tariff is indicated usually based on the consumption of the electric load. In this study, the common RTP is described in relation to the load of microgrid, given as [13]:

$$pr_{RTP-k} = a_k W^{2}_{RTP-k} + b_k W_{RTP-k} + c_k \tag{7.14}$$

where pr_{RTP-k} and W_{RTP-k} indicate the RTP price and the general consumption of microgrid at time step k, respectively. Besides, the different values for a_k, b_k, and c_k can be selected based on the actual demand at various time steps. Therefore, the cost of this scheme can be calculated to estimate the consumption at K periods as follows:

$$C^{i}_{RTP} = \sum_{k=1}^{K} pr_{RTP-k} \times W_{RTP-k} \tag{7.15}$$

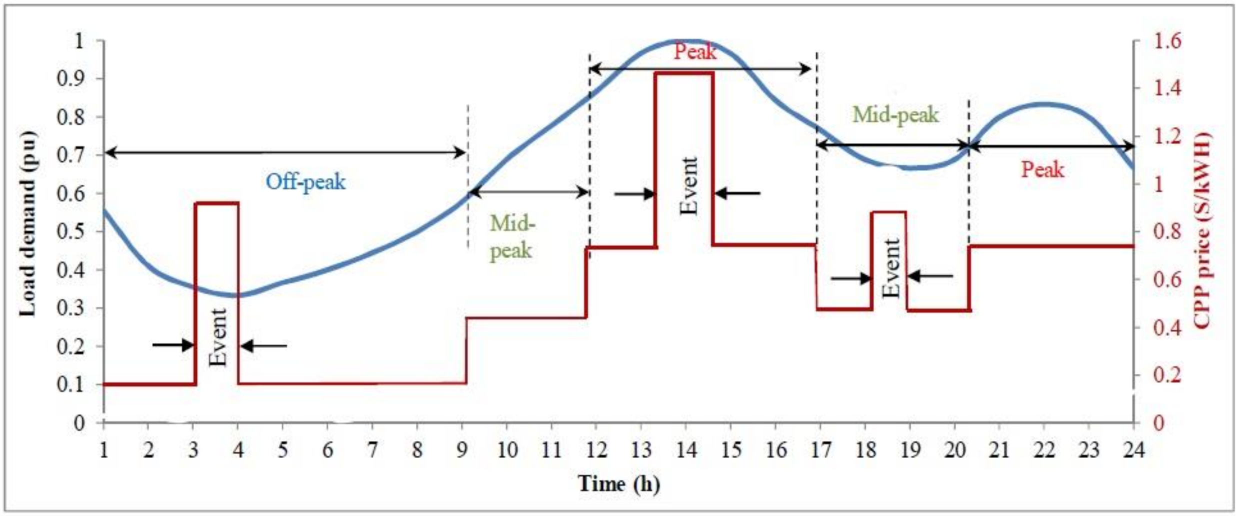


Fig. 7.2. The typical curves of load and CPP price

7.4.2.2 IDR-based cost

Despite the popularity of these programs, the determination of the incentive amount is often arbitrary. Generally, these schemes are bilateral contracts in which the participants can attend at certain periods and specific tariffs. Depending on the type of scheme, there may be occasional penalties if the program does not run. In fact, if IDR contract seems profitable, the customers will be eager to participate in the scheme. As a result, the costs of these programs are seen from the viewpoint of electricity utility.

In order to increase the motivation to participate in the scheme, the related incentives are often constituted from two terms: readiness charge and participation incentive. The readiness charge is related to the fee of capability for the predefined demand interrupt or curtailment that is specified in the contract. But after participating in the scheme, the incentive quantity is calculated based on the content of the reduction in demand. Considering these points, by assuming the participation in the total contract, the cost function is expressed as follows:

$$C_{IDR_k} = \left(\sum_{i=1}^{N} P_{IDR_k - i} \times T_{IDR_k - i} \right) pr_{IDR_k} + P'_{IDR_k} \times pr'_{IDR_k} \tag{7.16}$$

where C_{IDR_k} can be related to *k*th scheme, i.e., DLC, ILP and EDR. Also $P_{IDR_k - i}$ and $T_{IDR_k - i}$ are *i*th demand amount and *i*th period participating in *k*th scheme. Besides, pr_{IDR_k} indicates the price of participating in *k*th scheme per $/kWh. The second element is introduced for readiness charge. Therefore, P'_{IDR_k} is associated with the agreed interrupted/curtailment power and pr'_{IDR_k} is related to power price per $/kW, in *k*th scheme.

7.4.3 The decision algorithm

In order to provide flexible load side services, there are various options, such as the use of microgrids and DR schemes, namely PDR and IDR. Because of the economic savings resulting from the use of these options, customers have to consider one of these choices. This is particularly visible and palpable to large consumers.

Generally, demand side plans are implemented according to the overall policies of each distribution company. The PDR program, usually defined as a one- or several-month (almost long-term) period, seeks to modify or reduce subscriber consumption at different times. By saving and managing consumption at different time slots, consumers can control their costs at PDR prices. However, in practice, an electricity consumer may not be willing to cooperate in reducing or disrupting electricity due to the sensitivity of production lines or activities, specific requirements for a high level of service, or the effort required on the consumer's part to participate. Therefore, the consumer should either pay the costs in full by participating in the PDR program or cover its entire load through the microgrid. The IDR program, which is often offered to subscribers in critical condition of the network, results in short interruptions (1 to 4 hours). Contracts for these programs usually offer attractive tariffs to entice more consumer participation. Despite these attractions, in practice, these plans may also cause problems for some subscribers to reduce or disconnect, which may prevent them from fully cooperating. In these cases, too, the microgrid can be used as a backup to prevent subscribers from being interrupted at a given time. Therefore, comparing the rewards of this program with the cost of microgrids will be crucial for selecting the appropriate IDR program and the related interval. Thus, a combination of IDR and microgrid can be an economic option for consumers.

Therefore, the integration of microgrid technology and demand-side management plans can increase customer satisfaction. Here, to plan the economic demanding strategy of passive load considering DR programs and operating in the form of microgrid, a procedure based on different cost evaluation is proposed. In fact, in this approach, the cost of DR plans is examined along with the costs of microgrid technology for a typical load. The flow chart of this procedure is illustrated in Fig. 7.3. As observed, investigation of two DR schemes is carried out separately in the presence of microgrids. To this end, the PDR scheme is first evaluated alongside the microgrid. Given the cost of the types of PDR programs, the consumer can decide on whether or not to cooperate, in other words, to use microgrid or not. However, by participating in IDR programs, the consumer can utilize the microgrid to eliminate the problems of cutting or reducing the load due to participate in these programs.

Regarding the proposed tariffs, this algorithm assumes that the cost of a DR scheme is comparable to the microgrid operation costs. As it is observed, this flowchart is divided into two steps, and each step consists of three levels (L-I, L-II and L-III), which are described as follows:

Step I: Microgrid operation and PDR programs

At this step, the cost of PDR schemes is compared to the costs of microgrids. For this purpose, first, one of the plans is selected, and the cost of one-day collaboration in that PDR scheme is calculated. Then, the cost of one-day performance in the form of microgrid is obtained (L-I). These two costs are compared and if the cost of cooperating in the PDR were less than the cost of the microgrid, the day's counter would increase. This increase will continue to a threshold value, *M1*, defined by the operating company unless the cost of cooperating in the PDR exceeds the cost of the imaginary microgrid for a day. From that day on, consumer performance in the form of a microgrid would be economical. This is the point of decision and discrimination between choice of transferring into the form of microgrid or participating merely in DR programs (L-2). These calculations are performed for other PDR schemes in the same manner and compared with the cost of microgrids, and a discrimination point is specified for all schemes. Becoming a microgrid for the number of days beyond this point will be the economical choice of the passive load (L-3). It should be mentioned that there may be no discrimination point for any of the PDR schemes, which means that becoming a microgrid versus PDR plans is not economical.

Step II: Microgrid operation and IDR programs

At this stage, similar to the previous step, computation is executed at the first level, and at the second level, comparisons are completed, and finally, at the third level, the selection is made. The only difference is the nature of the IDR scheme. Thus, for each time of execution of a particular IDR program in a defined interval (one hour or more per interval), the value of the reward to the plan is calculated. Accordingly, the rewards for IDR should be greater than the cost of transferring the consumer into the microgrid at each stage to benefit subscribers. Therefore, the counter increases to the threshold value, *M2*, specified by the company, and the discrimination points are specified for all the schemes. It is ultimately up to the user to decide on the best strategy. Ultimately, the consumer makes the best choice by comparing costs.

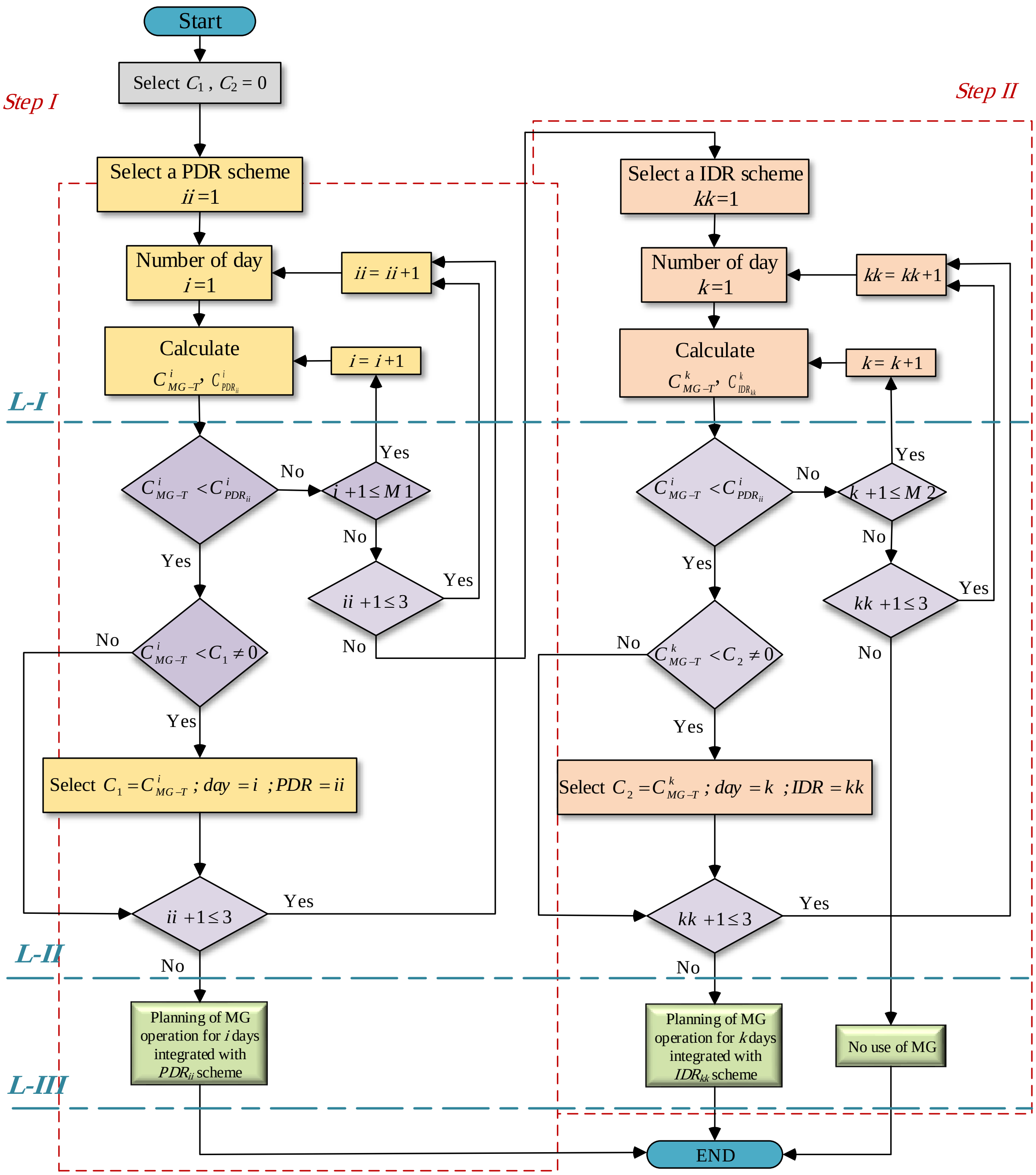


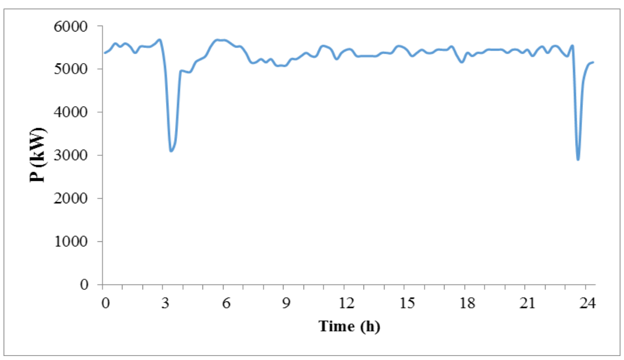
Fig. 7.3. The flowchart of the proposed framework to decide about economic demanding strategy for a passive consumer

7.5 Numerical studies

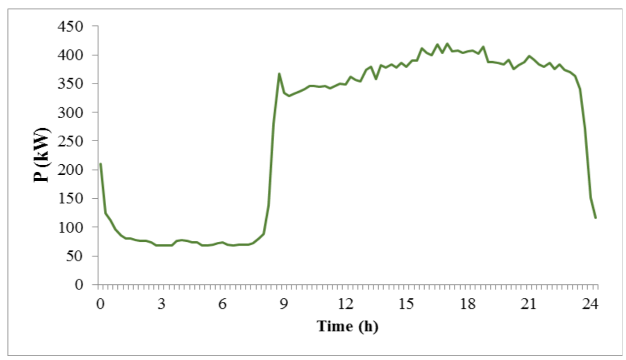
To assess the efficiency of the proposed procedure, three case studies of industrial, commercial, and hospital customers are evaluated while they can be operated as a microgrid and numerical results for DR strategies are analyzed thoroughly. Customer data from the Guilan electrical distribution company are used in this study. This company is responsible for providing distribution services for an approximate of 1.5 million customers to the south of the Caspian Sea. The load curves of selected customers are illustrated in Fig. 7.4. Also the cost parameters of a typical microgrid are presented in Table 7.1.

Furthermore, in all cases, it is assumed that seven events in peak, two events in mid-peak and one event in off-peak have been considered in CPP scheme. In addition, the penalties in the schemes are ignored.

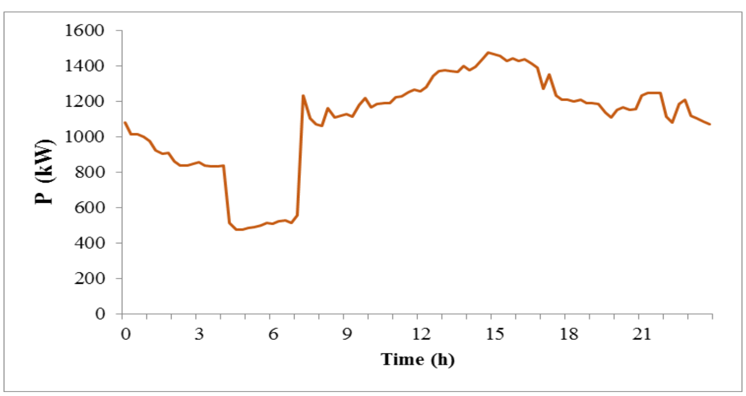
For each load, the microgrid is connected to the external grid with 5800, 450, and 1600 kVA capacity, respectively, which can be operated at 90% of its capacity due to operational constraints. In this study, considering centralized-style consumption of case studies, the cost terms related to the private distribution network and transformer are ignored. First, the effect of running PDR schemes on microgrid cost is investigated. Then an economic assessment of IDR programs implementation is provided. All the schemes compared with the state that the load can act as a microgrid. In the end, the best option of DR program is selected to operate the microgrid.



(A)



(B)



(C)

Fig. 7.4. The typical load curves (A) industrial, (B) commercial, and (C) hospital

Table 7.1. Typical information of microgrid

Parameter	Unit	Value
Installation cost	$/MW	320
Operation cost	$/MWh	29
Maintenance cost	$/MWh	7
Startup cost	$	0.15
Interest rate	%	12.5
Planning period	Year	15

7.5.1 Case I – Industrial load

The peak load curve of a typical industrial firm is illustrated in Fig. 7.4(A). This large electrical load has various industrial production lines and a connected microgrid to medium voltage (MV) with 5.8 MVA capacity. The different tariffs of TOU and CPP schemes are shown in Table 7.2, whereas the proposed prices for IDR programs are introduced in Table 7.3. The RTP rates are calculated using (7.14) by constant coefficients 5×10^{-9}, 2×10^{-5} and 0.01 for a_k, b_k and c_k respectively.

It is assumed that the participation occurs during the summer season, and the overall electric load is charged by microgrid when the customer participates in DR scheme. Accordingly, the costs of different DR schemes should be calculated and compared with the deploying microgrid cost. In order to estimate the industrial load consumption, historical data are used.

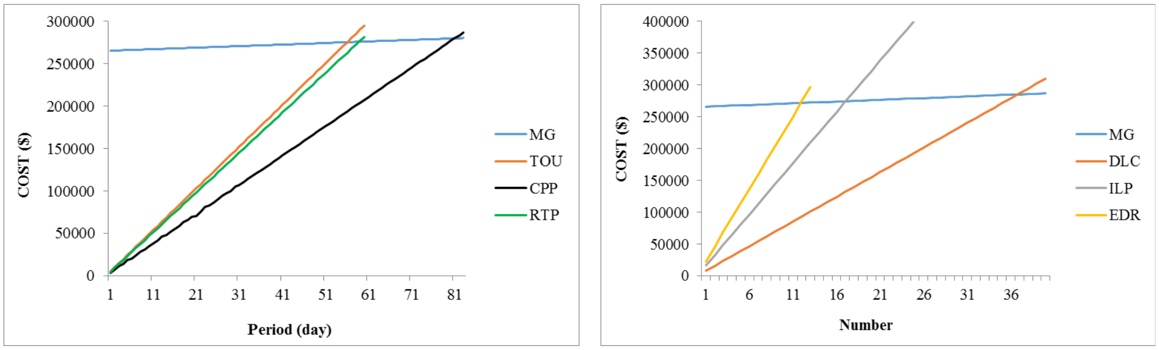
In this way, firstly, the cost of various PDR programs for different days are calculated and depicted as Fig. 7.5(A) in comparison with microgrid utilization cost. As it is observed, if TOU program is planned for less than 55 days, the participation in this program is economical compared to microgrid running; whereas, the use of microgrid can be more economical for more days. Besides, this number of days for CPP program is equal to 75 days, while in RTP program is roughly same as TOU scheme.

Table 7.2. Tariffs of TOU and CPP schemes in case I

Period	Hours	TOU price ($/kWh)	CPP price ($/kWh) Non-event day	Event day
Peak (8 h)	12-17 20-24	0.14	0.096	0.46
Mid-peak (6h)	9-12 17-20	0.09	0.065	0.15
Off-peak (10 h)	00-9	0.055	0.039	0.039

Table 7.3. Tariffs of IDR schemes in case I

Scheme	Hour	For load reduction ($/kW)	For readiness ($/kW)	For consumption reduction ($/kWh)
DLC	4 h	1.52	-	-
ILP	2 h	-	3.04	0.09
EDR	1 h	4.56	-	-



(A) (B)

Fig. 7.5. The various costs for (A) PDR and (B) IDR, compared with microgrid cost in case I

In this way, the similar results of IDR program running are shown in Fig. 7.5(B). Generally, if DLC contract is conducted 36 times a year, this contract may be economical for this industrial consumer. Obviously, the contract is more economical with more times a year. Furthermore, this value is for ILP scheme equal to 17 times yearly, whereas, EDR contract can be economical annually for more 11 times.

7.5.2 Case II – Commercial load

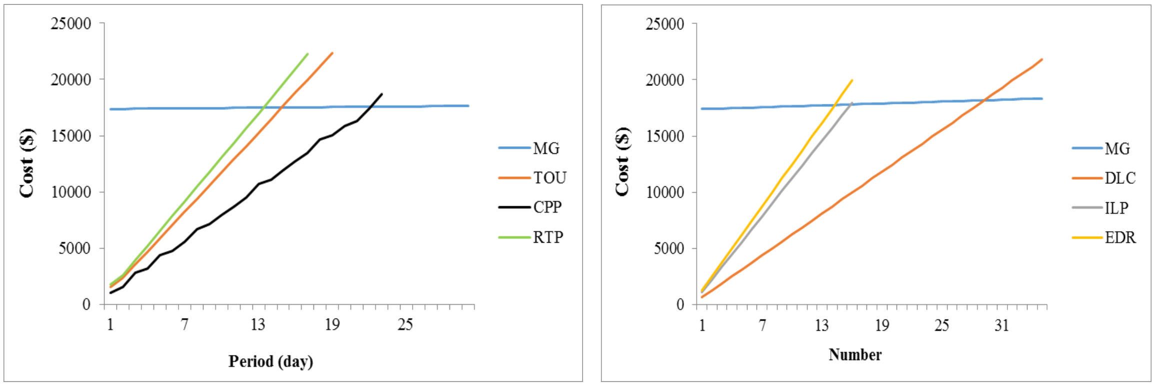
In this section, the impact of DR programs in the presence of microgrid for a hypermarket with the peak load curve shown in Fig. 7.4(B) is investigated. The microgrid is also connected to MV grid at 450 kVA capacity. The tariffs of different PDR and IDR schemes are shown in Table 7.4 and Table 7.5, respectively. Besides, the constant coefficients 8×10^{-7}, 4×10^{-4}, and 0.05 for a_k, b_k and c_k, respectively, are used to calculate RTP rates. Cost calculations are considered by assuming the participation of total electric load in the summer and the use of microgrid.

Table 7.4. Tariffs of TOU and CPP schemes in case II

Period	Hours	TOU price ($/kWh)	CPP price ($/kWh) Non-event day	Event day
Peak (7 h)	17-24	0.3	0.2	0.94
Mid-peak (7h)	9-17	0.22	0.15	0.7
Off-peak (10 h)	00-9	0.13	0.09	0.09

Table 7.5. Tariffs of IDR schemes in case II

Scheme	Hour	For load reduction ($/kW)	For readiness ($/kW)	For consumption reduction ($/kWh)
DLC	4 h	1.73	-	-
ILP	2 h	-	3.00	0.057
EDR	1 h	3.46	-	-



(A) (B)

Fig. 7.6. The various costs for (A) PDR and (B) IDR, compared with microgrid cost in case II

Similar to case I, the costs of DR programs implementation are compared to microgrid cost. The results are shown in Fig. 7.6. As can be seen in Fig. 7.6(A), the TOU, CPP, and RTP schemes are economical for 14, 21 and 11 days in a year, respectively, compared with microgrid cost. Indeed, microgrid can be used instead of participating in the above schemes with longer intervals.

Accordingly, the results of IDR programs running are shown in Fig. 7.6(B). In this way, the contract of DLC, ILP and EDR schemes are economical for more 29, 16, and 14 times per year, respectively. Therefore, for a commercial consumer is economical to use microgrid if periods of IDR contract are greater than the mentioned values.

7.5.3 Case III – Hospital load

In this case, the deployment cost of the microgrid in a hospital integrated with DR programs that has the peak load curve in Fig. 7.4(C), is assessed. The microgrid is connected to MV grid at 1.6 MVA capacity. The TOU and CPP tariffs in Table 7.6 and the IDR tariffs in Table 7.7 are shown. The RTP rates are calculated by the constant coefficients 8×10^{-7}, 5×10^{-5} and 0.022 for a_k, b_k and c_k, respectively. In the presence of microgrid, if the overall electric load in the summer can contribute to DR schemes, different costs are calculated.

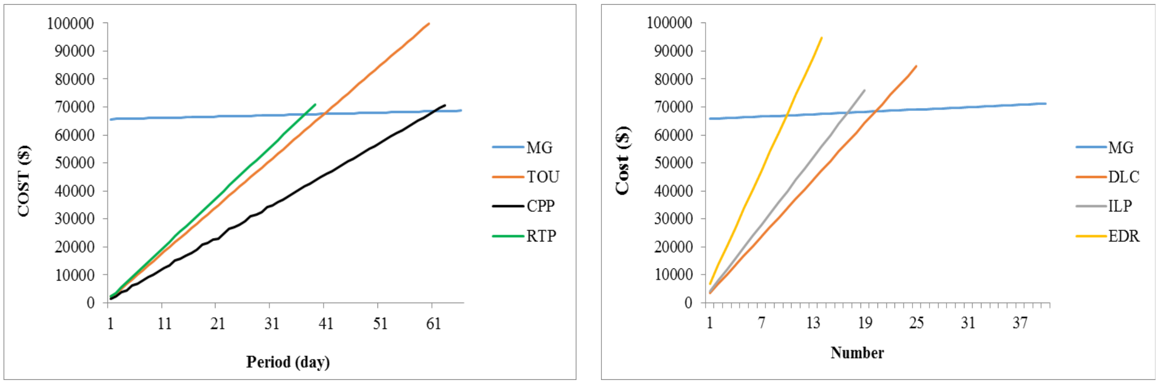
Table 7.6. Tariffs of TOU and CPP schemes in case III

Period	Hours	TOU price ($/kWh)	CPP price ($/kWh) Non-event day	Event day
Peak (8 h)	12-17 20-23	0.14	0.096	0.46
Mid-peak (13h)	7-12 17-20 23-4	0.09	0.065	0.15
Off-peak (3 h)	4-7	0.055	0.039	0.039

Table 7.7. Tariffs of IDR schemes in case III

Scheme	Hour	For load reduction	For readiness	For consumption reduction

		($/kW)	($/kW)	($/kWh)
DLC	4 h	2.6	-	-
ILP	2 h	-	3.04	0.0176
EDR	1 h	5.2	-	-



(A) (B)

Fig. 7.7. The various costs for (A) PDR and (B) IDR, compared with microgrid cost in case III

The calculation results for PDR and IDR schemes are depicted in Fig. 7.7. The CPP program for less than 58 days is economical compared to microgrid utilization, whereas TOU scheme is more suitable for less than 36 days. Similarly, for less than 32 days, the RTP program is an economic scheme. These results are shown in Fig. 7.7(A). Obviously, the use of microgrid may be cost-effective if there are more days in the proposed schemes.

Fig. 7.7(B) illustrates the cost of IDR schemes compared to microgrid cost. Accordingly, the contract of DLC, ILP, and EDR schemes are economical for more 19, 16 and 9 times per year, respectively. As a result, in order to be economical for microgrid utilization, this consumer should conclude a contract with more than the mentioned values for each scheme.

7.5.4 Final deduction

The results presented in the previous sections are analyzed here. Table 7.8 summarizes these results. By comparing the cost of microgrid and PDR schemes, it is economical to use these schemes for the maximum number of days specified in Table 7.8. Since PDR schemes should be deployed for the summer season (90 days), the operation of microgrid for commercial load is entirely economical instead of PDR tariffs. For hospital load, microgrid operation is more suitable compared to TOU and RTP schemes; however, with these tariffs, the least economic benefit of microgrid utilization is for industrial load.

An IDR scheme alongside with microgrid operation is economical when the number of times running the program in contract exceeds the mentioned values in Table 7.8. Although the microgrid is operated when a load is interrupted, an important limitation of these schemes is the execution number; the load may be disconnected or connected time after time which can cause problems for some customers. On the whole, the participation of all consumers in ILP scheme can be economical for values greater than those presented in the table below.

Table 7.8. A summary of results to use different schemes integrated with microgrid

Load	PDR scheme (days)			IDR scheme (hours)		
	TOU	CPP	RTP	DLC	ILP	EDR
Industrial	55	75	52	36	17	11
Commercial	14	21	11	29	16	14
Hospital	36	58	32	19	16	9

7.6 Conclusions

In this chapter, an economic demand management strategy for a passive consumer considering demand-side management schemes and microgrid operation was proposed. The main categories of DR programs, including PDR and IDR schemes were examined. Microgrid utilization for different type of loads was investigated in detail. To this end, the cost models for microgrid and DR schemes were extended. Based on these models, a decision criterion for determining the best choice for supplying the consumer demand was developed. In this regard, the cost of microgrid utilization alongside DR schemes were analyzed and compared. A number of practical examples were provided and the results of the proposed method in the real case studies were presented.

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