Novel Decision-Based Modeling of Minimizing Usage Cost of Electricity in Smart Grid

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Abstract. The rapid growth of electricity consumption globally defines the need of electronic power conditioning, control of production and distribution of electricity over smart grid from a technical aspect. To reduce the global carbon emission, integrated framework deployments on the smart grid have gain lot of attention from research scientists. Therefore, the present scenario in the field of electricity and power distribution management incorporates the advanced information and communication technology. It can enhance efficiency, reliability and safety standards by conceptualizing distributed renewable energy utilization. This paper aims to represent an efficient and structured power distribution network (i.e. Grid) based framework to optimize the electricity cost of smart appliances. The proposed study conceptualizes the optimal framework by introducing a novel energy buffering methodology which integrates both micro grid controller and distributed energy storage to formulate the network. An analytical modeling has been introduced and tested considering storage capacity, financial cost, and electricity price to ensure the effectiveness of the proposed operational energy measurements using smart meters. The study also depicts ability of proposed method to significantly reduce the long-term term financial cost.

Keywords: Distributed energy storage · Optimal decision process · Micro grid controller · Smart grid

1 Introduction

The enormous power consumption due to the rapid growth of electricity usage in the major cities leads to a critical situation of the electricity crisis. To reduce the amount of carbon emission globally, the current research trends mostly focused into the smart grid technology deployment for efficient electricity and power distribution management. Therefore, research on smart grid has drawn wide attention from researchers. The state of art power distribution frameworks in smart grid is integrated with the information network, in order to efficiently distribute the renewable energy in terms of efficiency, reliability, and safety [1]. The smart grid technology is conceptualized in a way where imposing smart appliance enables self-configurable systems (i.e. commercial and residential electrical appliances) to regulate their power usage patterns automatically.

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The principle mainly follows the optimization of cost metric by reducing the power consumption during peak demand hours [2, 3]. It can be seen that micro-grid infrastructure can fully support the functionalities of smart appliances, which is basically located at the down-stream power distribution networked sub-station. The emerging trends on distributed power generations such as distributed energy resources e.g. windmills, turbines, solar panels and distributed energy storage has gained more and more concern in the recent years. The Fig. 1 shows a power distribution scheme with information network architecture consists of different type of components.

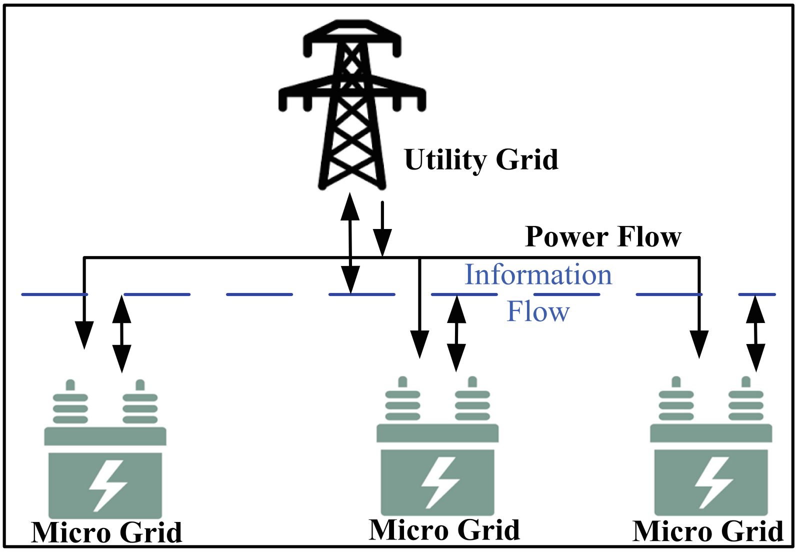

Fig. 1. Power distribution information network with micro grid

It was seen that most of the existing studies with adopted distributed energy storage are found exploiting the deliverable functionalities associated with irregular nature of power generation from the utility grid aspects. The conventional studies pertaining distributed energy storage haven't discussed that how to utilize it for minimizing the usage cost of smart appliances. Moreover, it is very difficult to make the best use of distributed energy storage resources considering optimized electricity price in real-time.

The proposed study discusses about an analytical modeling for minimizing the cost of electricity usage by the consumer using smart appliances running over grid architecture. The novelty of the proposed system can be seen by its feature of allocating the power to the respective smart appliances at the proper time with the lower financial cost [4, 5]. It also incorporates a Markov Optimal Process for incorporating a precise modeling of decision making. The comparative analysis shows the effectiveness of the proposed model. The organization of proposed paper is as follows Sect. 2 highlights the recent studies about the financial cost optimization, whereas Sect. 3 and four discusses the problem description and design methodology of the proposed model respectively, followed by result discussion (Sect. 5), Conclusion and future research direction is discussed in Sect. 6.

2 Related Work

This section discusses about the existing studies towards the power management techniques. The work carried out by Collotta and Pau [5] have presented a power management approximate for smart residences that integrates a wireless-network, stands on Bluetooth Low Energy, for communication among residence employments, with a residence power management plan. The recommended approximate addresses the collision of standby employments and high-power evaluation weights in peak hours to the energy expenditure charges of customers. Sun et al. [6] have presented a cognitive power technique for Communication-based train control schemes with smart-grids are illustrated to improve both train process presentation and cost effectiveness. The author also prepares a cognitive power scheme model for Communication-based train control methods. A review work carried out by Ye et al. [7] has presented a significance of a hierarchical up-link communication power control system for a neighborhood area network utilizing a two-stage “Stackelberg” amusement approximate. An illustrating on linear-receivers, the “Stackelberg” stability for the recommend game is obtained.

The research work carried out by Erol-Kantarci et al. [8] have discussed a complete study on the smart grid-driven approximates in an energy-efficient statements and data interiors and the communication between smart grid and data and announcement infrastructure. Ye et al. [9] have proposed cost-effective, elastic, and feasible neighborhood area network design utilizing wireless equipments such as *“IEEE 802.11 s” and “IEEE 802.16”*. They presented an optimization issue to reduce overall rate. To resolve the issue, they also studied the issue of choosing the best number of access in a neighborhood area network. The review work carried out by Martín-Arias [10] has discussed about a superior idea of lighting method intend for urban surroundings with high-customization abilities with the accumulation of lighting approach directed through wireless methods. Bera et al. [11] have demonstrated an energy competent smart indicating system towards reducing the power expenditure by the smart indicators for green smart network statement.

Wan et al. [12] have presented an unique technique for predicting the energy management system controlled by smart grids. The authors have designed the unique charecteristics of solar power as well as photovoltaic power followed by standardizing the performance values. The design is completely done using statistical mechanism. This work has also elaborated about other form of forecasting models in power management with a special focus on its merits and demits. Pang et al. [13] have illustrated a effective smart metering approximate as an essential piece of building automation and control system for the insist manage of construction examines. It may help customers to observe the energy expenditure and take necessary action to reduce their energy competence at a better granularity. The review study transmitted by Ortiz et al. [14] have presented an easy but yet capable network innovation and tree building protocol that also acts as an smart metric for direction selection in smart surroundings. The author has also emphasized about usage of fuzzy-logic. They also carried out experimental analysis to prove that presented system offer better efficiency in contrast to conventional routing parameters.

Hence, it can be seen that there are quite a good amount of work being carried out towards smart grid system. The next segment discusses about the issues.

3 Problem Description

In the recent times, enormous usage of residential and commercial smart appliances leads to indefinite power consumption. Therefore a situation arises where dealing with financial cost of electricity usage has become more challenging. Most of the state of art power distribution management system does not discusses about the financial cost effectiveness from the technical perspective whereas very fewer studies are found to have significant impacts on reduction of peak demands and lowering risk of grid operations. One of the most significant research problem is that there are lesser amount of work towards exploring effectiveness of the power evaluation system in recent times. It has not been well investigated for the micro-grid that how to utilize the distributed energy storage to decrease the financial price of smart appliances users. It is very challenging to make best use of the valuable distributed energy storage resource with the consideration of real-time electricity price, as well as the characteristics of the distributed energy storage and smart appliances.

4 Design Methodology

This section of the paper introduces the design methodology of the proposed framework namely Optimal Decision Process in smart grids to effectively reduce the electricity cost of smart appliances. The proposed model is conceptualized based on a theoretical modelling of an optimal scheme which incorporates Markov Decision Process for token allocation policy under distributed energy storage scenario.

The following Fig. 2 shows the architecture of the proposed framework. It initiates a set of operations which include Micro-Grid Controller (MCG) operations, Smart Appliances (SA) operations, and Distributed Energy Storage (DES) power pricing and allocation policy. The proposed framework considers a micro-grid controller module which is further integrated with SAs and a distributed information network, which could be possibly a neighborhood area network or building area network. However, the proposed system introduces the frame structure of a micro-grid controller networked model which is primarily composed of a set of decision and action phases. The highlighted Fig. 2 shows that proposed framework imposed different type of operations to reduce the financial costs associated with each smart appliance. It incorporates a principal of bursty energy usage patterns which could possibly minimize the overall monetary cost of smart appliance. The optimal decision problem has been derived using Markov Decision process. The following Fig. 3 highlights the integrated

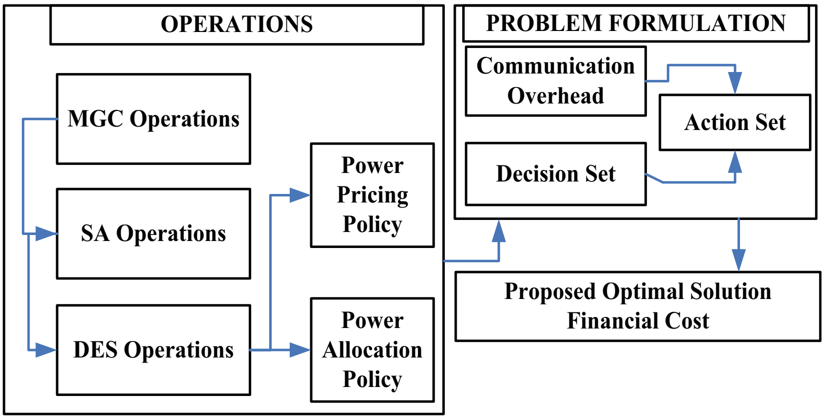

Fig. 2. Proposed system architecture

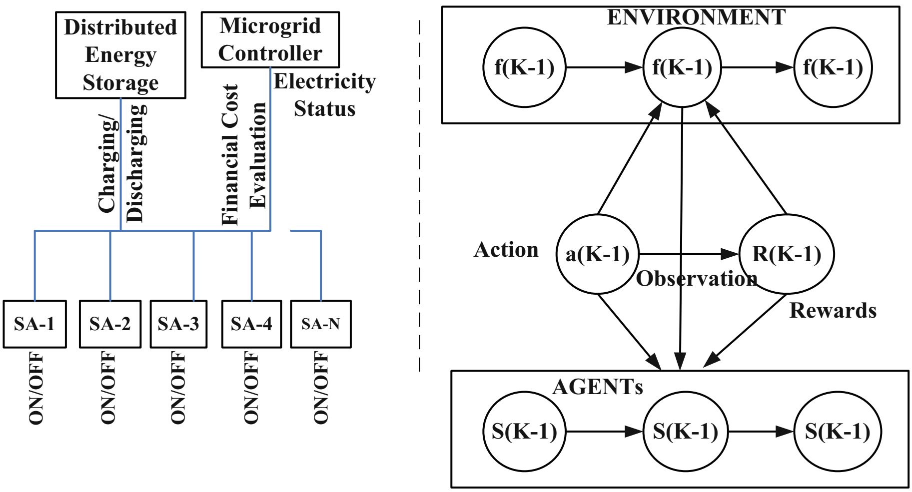

Fig. 3. Integrated Markov Decision Process

framework where Markov Decision process provides an efficient decision making to evaluate distributed energy storage power pricing and allocation policy.

The analytical modeling for distributed energy storage information set, Decision and Action set is presented below.

(i) **Information Set**

The information is defined by the following mathematical expression

$$\beta(k) = \{p(k),\ d(k),\ m(k),\ l(k)\} \tag{1}$$

where p(k) denotes the current electricity price per energy unit the vector d(k) represents the energy demand states it is also represented by $d(k) = [d_1(k), d_2(k)\ldots. d_M(k)]^T \in B^M$ where B = {0,1} and M is the index associated with Micro-grids and SAs.

(ii) **Decision and Action Set**

The distributed energy storage decision set is derived by the following mathematical expression

$$\eta(k) = \{a(k),\ t(k)\} \tag{2}$$

And the action set is defined in the following Eq. (3)

$$a(k) = \begin{Bmatrix} 1 \\ 0 \\ -i \end{Bmatrix} \tag{3}$$

1 will be considered when distributed energy storage will be in charging state similarly, 0 denotes the idle state and –i considers discharging scenario where μ_i where i = {1, 2, 3}. An optimization process also carried out to reduce the financial cost which is basically derived by the following equation.

$$\lim_{L \to \infty} \text{Min}\ (\eta\ (\ k),\eta(k)) \tag{4}$$

The next section discusses about the results obtained by extensive simulation carried out in MATLAB environment.

5 Results and Discussion

The proposed framework is executed in Matlab considering an objective to decrease the financial price of electrical appliances in smart grid. The simulation framework considers the input parameters such as delay constraints, distributed energy storage capacity which have been considered in between (5–20) and high price state in USD. It also considers the number of frames 50. The results obtained from the simulation environment shows that the proposed optimal framework can significantly reduce the financial cost of electrical appliances in smart grid.

The above Fig. 4 shows the financial cost obtained by simulating three different baselines such as BL-1, BL-2, and Myopic considering delay constraints which are further compared with the values obtained by simulating the proposed optimal framework. Therefore the comparative analysis depicts that the proposed model achieves optimal and minimized financial cost in comparison with baselines.

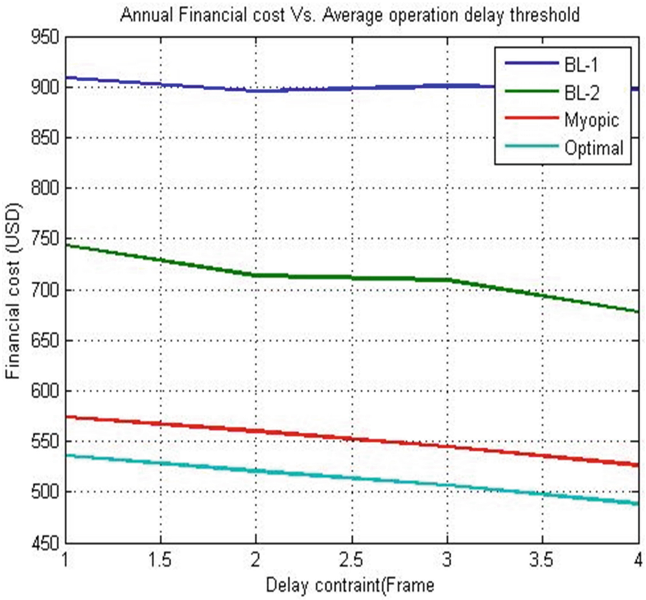

Fig. 4. Annual Financial cost Vs Average operational threshold

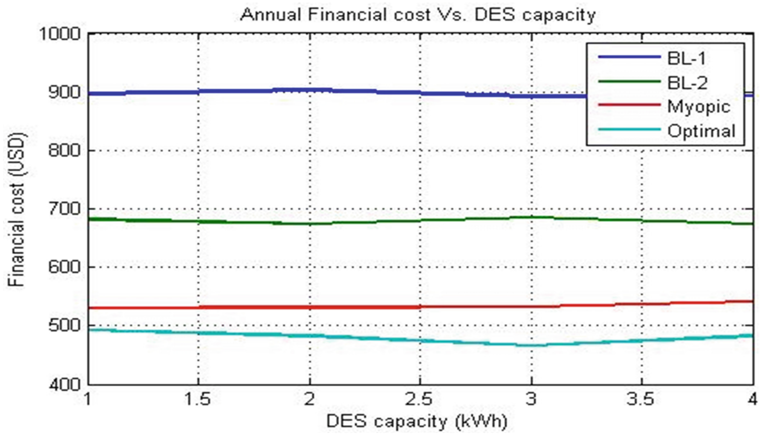

Fig. 5. Annual Financial cost Vs DES Capacity

The Fig. 5 shows that the optimal framework reduces the long term financial cost (USD) significantly with respect to distributed energy storage capacity (kWh). The performance improvement of the proposed optimal framework has been carried out by incorporating distributed energy storage power allocation and pricing policy which imposed an optimal Markov decision making process for efficient power allocation and distribution over an information network. The comparative analysis depicts the effectiveness of the proposed system.

6 Conclusion and Future Research Work

In this paper, an optimal framework for reducing long term financial cost of electrical appliances was proposed for deferrable smart appliances. The proposed modeling determines distributed energy storage charging/discharging actions and the distributed energy storage power allocation policy with the consideration of their expected impact on the future cost. This paper discussed a novel approach of modeling energy buffering. Simulation results showed that the proposed optimal framework outperforms the conventional baselines by reducing the long term financial cost efficiently. It also shows the effectiveness of the proposed optimal framework by taking various performance parameters such as financial cost, distributed energy storage capacity and delay constraint into consideration.

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