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Thermometer approach-based energy distribution with fine calibration in a smart grid tree network☆

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ABSTRACT

For the benefit of mankind, future technologies should be eco-friendly, eschew CO_2, be capable of smart energy generation using renewable energy sources and be effective in raising the energy efficiency of individual users. This leads to the optimization of energy generation, distribution and utility at the user level, which helps in handling demand-side management (DSM) of the smart grid effectively.

The energy distribution flow in a smart grid can be modeled as a smart grid tree network (SGTN). To promote the requirement of secondary energy generation using renewable energy sources at the customer level, secondary energy generated by the customer with a load demand is included in order to calculate the energy demand on the smart grid. Depending on the load request and demand, the energy is granted for various levels of child nodes in an SGTN using load weight (LW) and demand. In this paper, thermometer approach-based energy distribution with a load (TAEDL) is proposed in order to derive energy efficiency at various levels of the SGTN. The proposed technique is refined to attain maximum energy distribution efficiency and fairness using a thermometer approach with fine calibration (FC).

The total energy distributed to the users, the number of satisfied users, the energy distribution efficiency, and the fairness index (FI) of the SGTN are evaluated at various levels. The simulation results show that the suggested technique outperforms in terms of energy distribution with fairness and initiates a revolutionary change in future smart grid technology.

1. Introduction

Futuristic technology, which paves the way to the latest smart electrical utilities with smart meters, advanced electrical home appliances, smart home atomization with smart kitchens, and electrical vehicles, is bringing about revolutionary changes in the power utility. A future generation needs the integration of intelligent techniques, advanced communication and control for energy distribution based on the demand and pricing on the smart grid. The various issues, opportunities, advances and challenges are discussed in [1].

In the literature survey, many researchers worked on various issues of DSM, dynamic demand scheduling methods, distributed home energy management systems, appliance scheduling and incentive load scheduling schemes, resource allocation, smart energy distribution, etc., as presented in [2–17].

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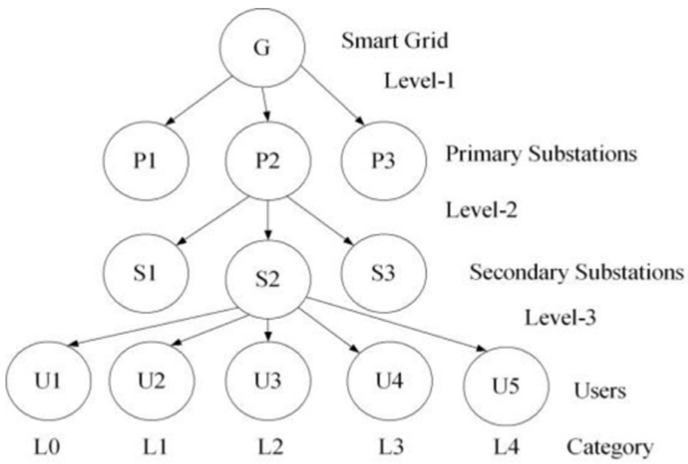

Fig. 1. Smart energy distribution in an SGTN model.

The FI of various energy allocation schemes in an SGTN was investigated in [18]. It was observed that the modified round robin method results in a high fairness close to 0.96–0.999. To meet the dynamic demand of users, LW-based energy distribution for different categories of users in order to improve the FI was proposed in [19]. By this method, the distribution to the substations varies with the load, while maintaining a high fairness of 0.95–0.999 at various levels of the SGTN. Technological developments and smart home technology, as well as the growing usage of electrical appliances, have led to a huge demand for electricity. Everybody is looking for alternative energy generation using renewable energy sources [20–22], such as wind, biomass, solar, and hydroelectric power. From the above findings, some of the best techniques are considered and included in this paper for implementation.

In this paper, a thermometer approach-based energy distribution is proposed. Further, an FC technique at various levels of a smart grid is incorporated in the thermometer-based energy distribution approach to improve the smart grid performance. This paper pursues the following objectives:

- Optimize energy allocation to the primary and secondary substation using LWs.
- Refine energy distribution and distribution efficiency using thermometer approach-based energy distribution with FC (TAEDFC).
- To achieve a high FI using TAEDFC according to the users' demand.

The following sections describe the rest of the work. Section 2 explains the load request evaluation, Section 3 describes weights-based load allocation, and thermometer-based energy distribution in an SGTN is discussed in Section 4. Later, TAEDFC is explained in Section 5. Simulation results are explained in Section 6 and conclusions are drawn in Section 7.

2. Load request in a smart grid tree network

The major blocks in a smart grid [24,25] are: (i) energy generation, (ii) energy transmission, and (iii) energy distribution. The energy distribution from the grid to users via substations is modeled as an SGTN [23] as shown in Fig. 1. The distribution path flow from the grid to the users is fixed. The SGTN representation has the following advantages: straight-forward implementation, simplified mathematical modeling, adaptability, less computational complexity, and less computational delay.

The primary substation p under a grid has various secondary substations s under it, from which energy is distributed to the different categories of user u via transformers. Here, $p = 1$ to P, $s = 1$ to S, $u = 1$ to U, where $P =$ total number of primary substations, $S =$ total number of substations, and $U =$ total number of users under s. The energy distribution path between the grid and the users is fixed, while the entire distribution flow can be implemented as a tree network model, which simplifies the mathematical model for evaluating load request and energy distribution.

The entire time in a day is divided into different time slots t_m, where m indicates the mth slot in a day. Based on the load, the users are classified into five categories$\{L_0,L_1,L_2,L_3,L_4\}$. The load request from each user is $E_{i-1}^{t_m} < E_{LR}^{t_m}(p,s,u) \le E_i^{t_m}$, where $L_i$represents the load from a user category, and $i = 0$ to 4. E_i is the energy requests from different L_i users (for no load $E_0 = 0$, $E_i = 1$ kWh, 2 kWh, 5 kWh, and 10 kWh for $i = 1$ to 4, respectively). Users with a load, i.e., users of category L_1,L_2,L_3,L_4, are called active users. The notions used in this work are described in Table 1.

Most of the users are capable of generating some energy using secondary renewable sources, such as solar panels; this is represented by $E_R^{t_m}(p,s,u)$. To avoid fractional wastage, the renewable energies of all users are added at s, with total