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Daily load profile and monthly power peaks evaluation of the urban substation of the capital of Jordan Amman

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ABSTRACT

The hourly recorded power of an urban substation of the National Electric Power Company (NEPCO) in the capital of Jordan Amman is used to calculate the diversity and conversion factors of the substation. These factors are used to estimate the daily load power profile and the monthly peak power of the substation. The results show that the conversion factors are almost independent of the number of feeders in the substation, while the diversity factors vary in substations that have six feeders or less. The results show a good correlation between the estimated and actual recorded data of the daily load profile with less than 5% percentage error.

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1. Introduction

The electrical peak demand in Jordan is continuously increasing as shown in Table A.1. In a recent report the growth of the annual peak demand in Jordan in the last 7 years increased between 9.2% and 15.2% [1]. The National Electric Power Company (NEPCO) has been taking the proper measures and precautions to face such a continuous growth. In general, load estimation constitutes the major source of data that is required for future planning of power distribution systems. This includes, but not limited to, transformer sizing, capacitor banks and conductor size selection. Accurate load estimation, an essential requirement procedure for future planning of power networks, can be achieved using different methodologies. In all cases, the operators experience is proved to be not sufficient for this purpose [2].

Several methods have been utilized, with different degrees of accuracy, to analyze the kWh consumption by electric utilities. The maximum diversified demand is estimated as a function of the average kWh per customer. The multiplying factors, denoted by "*K* Factors", are used to estimate the consumed electric energy by each consumer connected to the network [3].

In [4] a method is introduced to estimate a synthesized load shapes to identify typical daily load curves and to figure out the best way to represent its model. It shows that using historical data, one may predict both the maximum peak demand and the daily accumulated consumed energy. In [5], however, another method is presented to calculate the electrical power demand and the load factors of different class of customers. This method is based on constructing the load duration curves and predicting the annual peak load. In [6] a virtual instrument to predict the short, medium and long term load forecasting is designed using three Artificial Neural Networks (ANN) models. The ANN model is trained using historical data taking in consideration weather conditions. An accurate and a stable method to predict the medium and long term load forecasting method was also introduced using the radial basis function neural networks.

Another method to minimize the energy losses in a distribution system is presented in [7]. The method is based on selecting dispatch capacitors based on loop analysis algorithm which determines the optimal setting of capacitors for all operating times [8]. The maximum annual power, P_{max}, can be evaluated using Velanders formula. Annual energy consumption is translated into a power demand by the aid of certain mathematical methods [9]. His formulation assumes that the maximum demands of the partial loads were normally distributed. However, Velander's model provides no information as to when the maximum demand occurs. However, this model is proved to be quit reliable in medium voltage networks [10].

A popular method for estimating the maximum load based on similar load behavior was also reported by Hsu et al. [11] and Kato and Naito [12]. This method, as described by Eq. (1) for completeness, assumes that the maximum demands of the partial loads were normally distributed

$$\widehat{P}_{max} = K_1 W_a + K_2 \sqrt{W_a} \quad (1)$$

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Table 1
Maximum number of samples in a group of feeders.

N_{fg}	1	2	3	4	5	6	7	8	9	10	11	12
$N_{l,max}$	12	66	220	495	792	924	792	495	220	286	66	1

where $\widehat{P}_{max}$ is the maximum estimated power, K_1 and K_2 are coefficients related to the level of different consumer energy, while W_a is the total annual energy consumption [10].

Another method used to estimate the power is based on estimating the load currents of network branching nodes. The estimated load current at any branching point is given by the following formula [11,12]:

$$\widehat{I}_{Load,i} = I_{FD} \times \frac{S_{ci}}{\sum_{i=1}^{N} S_{ci}} \tag{2}$$

where I_{FD} is the available current feeder, S_{ci} is the sum of rated capacities of transformers at a branching point i, N is the number of branching points that are supplied from the feeder, and $\widehat{I}_{Load,i}$ is the estimated feeder current under consideration.

Load estimation using Eq. (2) is inaccurate since the loads of the distribution system do not have similar profile. For example, the peak load of a certain industrial customer may appear in the afternoon, while that of a commercial one may take place in the evening.

An approach based on fuzzy set theory is proposed [13] to estimate the loads in the distribution system. This approach benefits from the operators' experience and the knowledge of experts. The load patterns are characterized using fuzzy set to reflect the actual behavior of a power substation. The load nodes within the same category of customers are assumed to have similar hourly load pattern per day. However, this approach can only be considered as an approximate one due to the fact that the exact historical records of the branching nodes usually do not exist. A fuzzy model reported in [14] is applied to express the correlation between the active peak load of a certain substation and the supplied active load of a certain customer in the electric power distribution network. Neural Network and Fuzzy set were later applied to estimate the load for the active demand in radial networks [15]. The load curve was generated based on the energy consumption of certain classes of customers.

The conversion and diversity factors for the main substation in the north of Jordan were evaluated to estimate the daily profile and the monthly peak demands [17]. A similar approach is applied to an urban substation in the capital of Jordan Amman to analyze its load profiles. The conversion and diversity factors are evaluated and the daily load profile is also estimated. The methodology presented in [16,17] was adopted for this purpose. The impact of the variations of the number of feeders on the load diversity factors in the substation under investigation is thoroughly investigated. The monthly peak MW demand of the system and the daily load profile were also calculated. The estimated daily load profile using these factors is then compared with the actual measured load for the considered group of feeders for validation purposes.

This paper is organized as follows: Section 2 outlines the method to calculate the monthly based diversity factor. Section 3 introduces a method to evaluate the conversion factor. The monthly peak and daily load profiles are presented in Section 4. An estimation algorithm and nemrical simulation is summarized in Section 5. Finally, Section 6 presents concluding remarks.

2. Monthly based diversity factor

Diversity factor in a distribution network is the ratio of the sum of the peak demands of the individual customers to the peak demand of the network. This will be determined by the type of service, i.e., residential, commercial, industrial or a combination of these loads [18,19]. These factors model the peak demand of groups of customers, which does not characterize the aggregate of individual customer peak demands [18]. The diversity factor, DF, is greater than unity and defined by the following formula:

$$\mathbf{DF} = \frac{\sum_{j=1}^{n} P_j}{P_g} \tag{3}$$

where P_j is the maximum demand of load j, disregarding time of occurrence, P_g is the maximum demand of group of n loads, and j is the index of the individual feeder.

In order to estimate the diversity factor for the substation under consideration, the number of feeders in the substation, the combination of these feeders, and the maximum number of samples in a group of feeders must be identified. Hence, let N_f, N_{fg}, $N_{l,max}$ be the number of feeders in the substation, the combination feeders in a group of feeders, and the maximum number of samples in the same group of feeders, respectively, while the order of sample groups is assumed to be l.

For the substation under consideration, $N_f = 12$, $N_{fg} = 1, 2, \ldots, 12$, while the number of sample groups l takes the values $l = 1, 2, \ldots, N_{l,max}$, where $N_{l,max}$ is given by:

$$N_{l,max} = \binom{N_f}{N_{fg}} = \frac{N_f!}{N_{fg}!(N_f - N_{fg})!} \tag{4}$$

The values of $N_{l,max}$ for different substation feeders are presented in Table 1.

The hourly measured power data can then be analyzed according to the type of day, defined by the d, where d takes two different values according to the type of day; i.e.,

$$d = \begin{cases} 1 & \text{for working days} \\ 2 & \text{for holidays and weekenddays} \end{cases} \tag{5}$$

The hourly consumption of peak power for a given feeder, j, in a given type of day, d, during a certain month, m, is calculated by:

$$P_{j,max}(m,d) = \max_{h,d} P_j(m,D,h) \tag{6}$$

where D represents the day of the month the peak occurs. Clearly, the days of the month in which $D = 1, 2, \ldots 28, 30$, or 31 depending on the month are classified as weekdays and weekends. Hence, the peak recording is classified accordingly as Eq. (5) shows.

The power consumption of each group of l samples in the substation is calculated by:

$$P_{gl}(m,D,h,N_{fg}) = \sum_{j=1}^{N_{fg}} P_j(m,D,h) \tag{7}$$

Similarly, the hourly consumption of peak power $P_{gl,max}$, for a certain group of feeders is given by:

$$P_{gl,max}(m,d,N_{fg}) = \max_{h,d} P_{gl}(m,D,h,N_{fg}) \tag{8}$$

Substituting (6) and (8) into (3) yields the following diversity factor for the group of l samples:

$$\mathbf{DF}_l(m,d,N_{fg}) = \frac{\sum_{j=1}^{N_{fg}} P_{j,max(m,d)}}{P_{gl,max}(m,d,N_{fg})} \tag{9}$$

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