Load curve classification for the evaluation of demand side management programs

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Abstract. The demand side management of electrical power systems is an issue of growing concern. In this study, annual load curves those have been obtained by field measurements on MV (31.5kV) feeders in an electricity distribution company in Turkey have been studied. Feeders supplying different type of customers (Agricultural irrigation, Commercial & Industrial and Residential) are classified through Peak and Night Ratio for the assessment of convenient incentive or price based methods. Statistical parameters, such as peak-to-average ratio, load factor and standard deviation are calculated. Active power deviations on annual and daily load curves are discussed.

1. Introduction

Historically, electrical power systems consist of limited number of large power plants feeding and balancing whole demand in a centralized concept. The system is top-down designed and the power is supplied through transmission and distribution systems in unidirectional way [1]. In 1973, the oil embargo led to increase the costs in the generation of electricity. Subsequently, instead of increasing generation capacity to supply the growing demand, the idea of reducing and/or managing the demand started to be considered in power systems [2, 3].

The electrical power demand varies over the course of the day, week and year due to several factors, such as seasonal and environmental changes. Load management refers to a wide category of methods and instruments to control power demand in electrical systems to be in balance with the electricity supply. It is defined as any activity done by customer and/or electricity supplier to modulate the demand fluctuation with the objectives of reducing total peak load, increasing load factor, improving capacity and utilization of power system [4].

In the literature, the terms of load management (LM), demand side management (DSM) and demand response (DR) can be found as overlapping definitions for similar concepts [5, 6]. Load management actions can be installing energy-efficient equipment, load curtailment, load shifting, peak clipping, valley filling, and using distributed generation and energy storage technologies for the benefit of the whole utility system.

Load management methods can be divided into two subgroups, such as direct and indirect methods. In direct programs, utilities have the option to control customers’ equipment based on an agreement. In
indirect programs, it is customers’ decision to involve or not to the program. If customers participate in the program, then they get the benefits which is offered by the utility. The LM methods are schematically illustrated in figure 1.

![Figure 1. Load management methods [6]](image)

Direct load management is based on remote control of the end-users’ specific equipment to turn on and off during peak demand periods and critical events [7-9]. Water heaters, pool pumps, air conditioners, washing machines and dishwashers are examples of the appliances commonly used in residential customers.

Interruptible tariffs [10, 11] is a pricing option that customer permits the utility to reduce the demand in peak loading or emergency conditions. An agreement between the customer and the utility is required for assessment of the interruptible load (IL). Demand limiters or remote signaling can be used for load reduction.

Load curtailment programs offer payment or discounted rate in return for reduction on the peak demand to a given amount when there is an urgent unbalance in the power system. This program commonly used for large industrial customers.

The pricing program is a subsection under indirect load management methods. There are tariff related programs containing price discounts for demand reduction [12]:

- Time-of-use (TOU) pricing: Different prices for different time durations over a day, week or season. The prices are constant for the time periods.
- Real time pricing (RTP): Prices vary over short time periods (commonly hourly) enabling a better reflection of the supply costs.
- Critical peak pricing (CPP): Dynamic pricing based on TOU and RTP, pre-set higher rates during for a limited number of critical days or hours.
- Extreme day pricing (EDP): Similar to CPP, higher price is for the whole 24 hours of the extreme day (unknown until a day-ahead).
- Extreme day critical peak pricing (ED-CPP): CPP rates are used during peak and off-peak periods during extreme days. A flat rate is used for the other days.

Rebates and subsidies are offered as a motivation to the customers to increase the usage of energy efficient equipment or participation in demand reduction. Education programs are for increasing customers’ awareness on load management programs.

The direct programs (direct load control, interruptible and curtailable services) given in figure 1 can also be categorized as incentive based programs. These services depends on the offered incentives to the customers and based on contracts designed by policymakers, grid operators, and utilities. Customer participation is voluntary and there could be penalties in case of failures on the agreed commitments. The price based programs can be implemented indirectly and designed to reflect the costs of electricity
production. It fully depends on customer choice. Customers are expected to change their electricity usage to low priced time periods by an internal economic decision.

It is needed to classify load curves in order to analyze the demand variations. Classification would help to decide if incentive (direct methods) or price based methods is suitable for the specific loading conditions. Furthermore, the investigation of load characteristics with load management perspective helps the utility for the assessment of load management feasibility. In this study, field measurements of MV feeders in a distribution company service area in Turkey with different load characteristics are classified using Peak and Night Ratios. And also customer characteristics are evaluated through statistical parameters.

2. Load curve classification and evaluation

Load curve classification can be performed using Peak Ratio, Night Ratio and statistical parameters, such as peak-to-average-ratio (PAR), load factor and standard deviation. The definitions of the related parameters are reviewed in this section.

2.1. Peak ratio and night ratio

Peak Ratio (PR) is defined as the ratio of average power absorbed during peak hours in a certain time duration, to average power absorbed during off-peak day hours in the same period. Similarly, Night Ratio (NR) is defined as the ratio of average power absorbed during night hours in a certain time duration, to average power absorbed during off-peak day hours in the same period. [13, 14] The defined certain time duration can be a day, a month or a year.

In Turkey, there are two options in the national retail electricity tariff programs: flat and time variant (time-of-use, TOU) pricing [15]. The TOU tariff program defines three time durations, such as day period (06:00 ≤ t < 17:00), peak period (17:00 ≤ t < 22:00) and night period (22:00 ≤ t < 06:00). As expected, the price is highest in the peak period and the price is lowest in the night period. The definitions of PR and NR values based on Turkish TOU tariff program are given in equation (1) and (2).

\[
\text{Peak Ratio} = \frac{\text{Average power absorbed during peak period}}{\text{Average power absorbed during day period}}
\]

\[
\text{Night Ratio} = \frac{\text{Average power absorbed during night period}}{\text{Average power absorbed during day period}}
\]

If PR value is greater than 1, it means the average power consumption during peak period is higher than the average power consumption during day hours. Likewise, if NR value is greater than 1, it means the average power consumption during night period is higher than the average power consumption during day hours.

According to the calculated PR and NR values, load curves can be classified and analyzed for the determination of convenient demand side management methods. The expected output from the application of selected method is to decrease the PR value and increase the NR value. Figure 2 represents an approach for the classification according to PR and NR values. The explanation for the classes are as follows:

- **Class 1**: Permanent use. This customer type represents a flat consumption. There is no high deviation in the load curve.
- **Class 2**: Off peak and small peak period usage. This customer type have relatively high PR and NR values. The peak period usage could be reduced using demand side management methods. Mandatory or voluntary tariff programs is suitable for this kind of customers.
- **Class 3**: Off peak disconnection usage. In this area, NR is very low and PR is lightly modulated. This means the power consumption in night period is very low, the power consumption in day and peak periods is modulated. NR could be increased and PR could be decreased. Incentive programs are suitable for this type of load curves. Energy storage, ice
storage or standby generators could be utilized for decreasing consumption in day and peak periods.

- **Class 4**: Peak hour disconnection usage. In this type of customers, PR is very low and NR is very high. Mandatory or tariffs programs are not convenient methods for this kind of load curves. Very strong incentive based programs are recommended.

- **Class 5**: Average off-peak usage. Incentive program is recommended in order to increase NR and decrease PR values.

![Figure 2. Classification regarding to PR and NR values](image)

2.2. Statistical parameters [16]

In this subsection, the definitions of statistical parameters which can be used to evaluate load curves of different customer types are given.

- **Peak-to-average-ratio (PAR)**: It is defined as the ratio of the peak load to the average load which is given in equation (3). In load management applications, it is expected to reduce PAR value [17].

\[
PAR = \frac{P_{\text{peak}}}{P_{\text{average}}} \tag{3}
\]

- **Load factor (LF)**: It is defined as the ratio of average load to peak load during a time period. If the load curve is in smoother characteristic, LF value becomes higher. The highest possible LF value, which presents a flat load profile, is 1. The higher LF means power consumption is comparably constant and the utilization rate of infrastructure is also higher. LF is the inverse of PAR.

- **Standard deviation (\(\sigma\))**: It is given in equation (4) and defined as the square root of the variance. Variance is the average of the squared difference of the values from their average value. It is a measure of the deviation from mean value. The higher standard deviation indicates the more spread apart from mean value. The unit of this parameter is same with the data. In the scope of this study, it is kW.

\[
\sigma = \sqrt{\frac{1}{N} \sum_{i=1}^{N} (P_i - P_{\text{average}})^2} \tag{4}
\]
3. **Field measurements**

The active power demands are measured at the beginning of selected MV (31.5 kV) feeders using a multifunction power analyser “UMG 96RM-E” and the measurements are taken through grid visualisation software “GridVis” which are both provided by Janitza. The measurements are in 10 minute periods and covers one year starting from 15 January 2015 and ending on 15 January 2016. There are three kind of load types: agricultural irrigation, commercial&industrial and residential.

### 3.1. Agricultural irrigation feeders

These feeders are supplying mostly agricultural irrigation pumps (above %80 percent of the total loads). Rest of the loads are residential and commercial customers. The annual load curves can be seen in figure 3. It can been that there are high seasonal deviations in the load demand. Demand of irrigation pumps becomes dominant between “April last week – June first week” and “June last week – September last week”. Maximum demand for both feeders is higher than 15 MW, while base load for the feeder 1 and feeder 2 is 1.3 MW and 0.5 MW, respectively. During heavy agricultural irrigation, base load is also increases up to 5-8 MW. Daily load curves are given in figure A1 in Appendix. On daily basis, the demand of irrigation pumps starts from 7 a.m. and increases till noon. After noon the demand decreases to base load continuously until 5 p.m. A sudden increase occurs after 10 p.m. and continues till midnight. Then, demand gradually decreases to base load.

### 3.2. Commercial and industrial feeders

Feeders are fully supplying (100%) commercial and industrial loads. The annual load curves can be seen in figure 4. Daily load curves are given in figure A2 in Appendix. Different from the agricultural irrigation feeders, there is no fluctuation depending on seasons. But during national holidays in Turkey between 16-19 July 2015 and 23-27 September 2015, the demand is in the lowest level for a few days. Maximum demand for both feeders is higher than 25 MW and base load is about 3 MW. According to daily load curves, the demand of utilities start in the morning 8 a.m. and the demand continuously increases till noon. There is a temporal decrease during lunch break for 1 hour and demand gradually decreases to base load until 7 p.m. It is holiday on Sundays, thus the demand is on base load level.

### 3.3. Residential feeders

Figure 5 shows the annual load curves of the feeders. These feeders are supplying 100% residential customers at the city center. Maximum demands of the feeders are higher than 6.5 MW and 3.5 MW. Base loads are 1.8 MW and 0.8 MW. Figure A3 in Appendix shows the daily load curves for residential feeders. The demand of the customers starts increasing from the base level at 6 a.m. to the first peak point at noon. Until 7 p.m., there is relatively flat consumption. Around 9 p.m., the second (also higher) peak occurs. Afterwards, demand gradually decreases until 6 a.m.
4. Analysis results

The results of PR and NR ratios of the feeders according to the equations (1) and (2) can be seen in figure 6. PR ratios of residential feeders are greater than 1, which means average power absorbed during peak hours is higher than the day hours. For the rest of the feeders, PR ratios are less than 1. NR values of the agricultural irrigation feeders are the highest.

According to figure 2, residential customers fall into Class 2 and tariff programs are suitable for them. The peak period usage could be reduced by mandatory or voluntary tariff programs. Agricultural irrigation feeders fall in Class 4. In this type of customers, mandatory or tariff programs are not convenient methods. Very strong incentive based programs are recommended to shift the peak loads.

Commercial and industrial feeders are fall between Class 3 and 5. The power consumption in night period is very low and the power consumption in day and peak periods is modulated. Load shifting or peak clipping can be implemented using energy storage technologies or standby generators. Incentive programs are suitable for these customers.

Table 1 lists the results of statistical parameters. The smallest maximum and average demand occurs in residential feeders. Average demand is the highest in commercial and industrial feeders. PAR and LF are inverse each other. The highest LF is in residential feeders, meaning utilization rate of infrastructure is higher than the other types. As it can be seen, the lowest LF is in agricultural feeders. Standard
deviation of the residential customers is quite low. The highest deviation occurs in commercial and industrial feeders.

![Figure 6. Peak and night ratios of the feeders.](image)

**Table 1. Results of statistical parameters**

|                  | Agricultural  | Residential  | Comm&Ind.   |
|------------------|---------------|--------------|-------------|
|                  | Feeder 1      | Feeder 2     | Feeder 1    | Feeder 2     | Feeder 1 | Feeder 2     |
| Min. (MW)        | 1.3           | 0.5          | 1.8         | 0.8          | 2.5      | 3.0          |
| Max. (MW)        | 22.78         | 18.29        | 7.17        | 3.66         | 27.44    | 27.55        |
| Average (MW)     | 5.13          | 4.61         | 3.79        | 1.55         | 8.58     | 10.12        |
| PAR              | 4.44          | 3.97         | 1.89        | 2.36         | 3.20     | 2.72         |
| Load Factor      | 0.23          | 0.25         | 0.53        | 0.42         | 0.31     | 0.37         |
| Std. Dev. (MW)   | 3.77          | 4.16         | 1.26        | 0.41         | 4.57     | 5.96         |

5. Conclusions

Active power measurements are performed on several MV feeders in a distribution company in Turkey. The annual and daily load curves are given and demand deviations are discussed. Feeders with different type of customers (Agricultural irrigation, Commercial& Industrial and Residential) are classified and reviewed using PR and NR ratios. Since the PR values of residential feeders are higher than 1, tariff programs are found to be suitable for demand side management purposes. For agricultural feeders, instead of price based programs, strong incentive based methods are recommended. For commercial and industrial feeders, incentive programs with energy storage or local generation technologies are appeared to be suitable. According to numerical analysis, load factor is found to be the lowest in agricultural feeders. In residential feeders, LF is the highest and standard deviation is the lowest. The maximum and average power demand of commercial and industrial feeders are found to be higher than the other feeders.
Appendix

Figure A1. Daily load curves of agricultural irrigation feeders.

Figure A2. Daily load curves of commercial and industrial feeders.

Figure A3. Daily load curves of residential feeders.
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