Data framework for electricity price setting in competitive environment

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Abstract. The generic term of electricity market is in fact a very complex sector of activity, being the result of the interaction of several markets, such as: the bilateral contracts market, the day-ahead market, the balancing market, intra-day market, and the market for ancillary services. In these circumstances, an electricity supplier needs to address the setting of the selling electricity price to the end consumers. The basic objectives to be pursued are as follows: return on sale for a period of at least one year, maintaining competition on the market, use of a user-friendly price system, financial insurance against fluctuations in the market, and ensuring a cash-flow corresponding to the good functioning of the firm. Considering these objectives, in this paper, we propose a data framework to handle electricity consumption data and a procedure to set the electricity price in competitive environment of the electricity markets. In this regard, a case study for an office building that also includes a restaurant is depicted.

1. Introduction
The electricity time-of-use (ToU) tariff has to follow the load curve, encourage the consumption during off-peak time intervals and avoid load peaks that would require additional onerous grid infrastructure and stress the generators. Thus, it is challenging for suppliers to set the ToU tariffs considering many aspects, including the fine balancing between market competition and rentability of the business.

On one hand the hourly rates of the ToU tariff should be competitive enough to attract eligible consumers and enlarge the activity portfolio of the electricity supplier. On the other hand, the rates should be higher than the electricity acquiring market price and ensure the rentability of the main activity of a supplier. Therefore, it is essential to study and assess the impact of the ToU tariffs implementation on both electricity consumers and supplier.

Consumption data coming from smart meters and sensors serve as input data for load profiling using clustering techniques that group the electricity consumers behaviour and provide hints to model the ToU tariffs starting from the load curve characteristics.

ToU tariff consists in different rates depending on the consumption time period, with higher rates tariff at peak demand and lower rates tariff at off-peak time periods. It encourages the electricity consumers to shift their electricity usage from peak (usually daytime) to off-peak time (at night).

A heuristic-based method for scheduling tariffs for electricity consumers enabling demand response is proposed and tested in [1] for Portugal that considers different consumer clusters, and demand response potential [2] for each cluster and the fairness of electricity pricing for all consumers.
ToU tariffs for residential customers that could reduce the peak demand are analysed in [3] starting from the load profile data from Malaysian residential and commercial customers. The results of this study show a significant difference between the peak and off-peak rates to ensure the effectiveness of the ToU tariff.

To assess the impact of the mandatory ToU tariff in Italy, the residential consumption is analyzed in [4]. The results showed a limited shift of consumption from peak to off-peak hours, but the change in the consumers’ behavior was not negligible. The study analyzed the main causes that contributed to the limited shift and provided possible solutions to improve the efficacy of the ToU tariffs.

A methodology to develop a dynamic pricing systems based on costs and estimate electricity consumers’ short-term savings are proposed in [5]. Although, the results did not justify the dynamic pricing system, it could be further investigated due to the fact that savings were positive.

[6] evaluates several electricity prices applied by suppliers in the United Kingdom and their disadvantages, proposing diverse tariffs for different types of electricity consumers to better involve them in the demand response programs.

2. Analysis of the consumer's load curve
The supplier has to decide between increasing the electricity price up to the competitive level or decreasing the price up to the purchasing price. For setting the price, the following steps could be taken to establish it:
1. Analysis of the consumer's load curve;
2. Establishment of the electricity purchasing system;
3. Determining the level of imbalances;
4. Setting the final price.

An especially important element for the end-customer is the ease of applying and understanding the electricity price or tariff. We will further follow the steps to set the price for an office building including one or several restaurants. In this case, it is important that the tariff structure to be simple and allow unrestricted consumption at any time of the day.

Starting from the type of consumer (office building), the characteristic daily load curve is shown in Fig. 1.

![Fig. 1 - Typical daily workload curve for the type of consumer](image_url)

For each new customer, it is necessary to establish similar load curve with the best accuracy. Generally, historical consumer data is required for up to 5 years for existing consumers and for new consumer the forecast for at least 1 year. The past consumption data or forecast is loaded into database tables and processed with specific procedures to obtain the load curve profiles, estimate deviations and set electricity price (as in Fig. 2).
If applicable, the load curves will be differentiated according to the season or vacation period.

3. Establishment of the electricity purchasing system

Purchasing electricity is achieved through 3 markets:
- Centralized bilateral contracts market (PCCB),
- Day-Ahead Market (DAM),
- Balancing Market (PE).

PCCB (with the two subdivisions: Extended Auction - LE and Continuous Negotiation - NC) is the market in which long-term contracts are signed. Contracts that can be signed on this market (which is true for both the NC and the LE) offer the lowest prices, but the hourly energy supply are extremely rigid and do not allow the end-user load curve to be tracked in any way.

At present both PCCB LE and PCCB NC are available contract products in which hourly power is fixed throughout the day or only in peak and off-peak consumption, all weekdays or weekdays only.

Under these conditions, it is not possible to use only PCCB products in order to cover the electricity consumers' load curve, so it is necessary to resort to DAM.

The way of combining the two markets depends both on the supplying company's policy and on the consumers' characteristics. Figure 3 shows a possible approach to cover the load curve for the considered consumer (office block including restaurant).
\[ p_{ach} = \frac{\sum_{i=1}^{24}(p_{PCCB}^i \times P_{PCCB}^i + (p_{PCCB}^i - p_{cons}^i) \times p_{DAM}^i)}{24} \]  

(1)

where:
- \( p_{ach} \) – hourly electricity price [lei/kWh],
- \( P_{PCCB}^i \) – hourly power contracted on PCCB at hour \( i \) [kW],
- \( p_{PCCB} \) – electricity price on PCCB [lei/kWh],
- \( P_{cons}^i \) – hourly contracted power by a consumer at hour \( i \) [kW],
- \( p_{DAM}^i \) – electricity price on DAM at hour \( i \) [lei/kWh].

The generic term of imbalances refers to deviations (surplus or deficit) of the consumer's hourly consumption from the values indicated in the contract. The values indicated in the contract are covered in the manner described in the previous paragraph, but the deviations from these values are solved by the balancing market.

The balancing market is a market accessible only to producers and is operated in real time by the Transmission System Operator.

Electricity prices on this market are variable depending on cumulative factors such as daytime (night or day), seasons, hydrology (drought or heavy rainfall), planned or unplanned repairs of the large system generation, etc. Under these circumstances, it is very difficult to predict what will be the financial value of the imbalance, especially since the physical value itself (deviation) is a random element because usually (for market reasons) no customer consumption restrictions are imposed.

Thus, the supplier will buy electricity on the balancing market when consumption is higher than expected in the contract and will sell electricity on the same market when consumption is lower than stipulated in the contract.

In the same context, in order to simplify the price offer (for the same reasons of market competitiveness), the financial value of the imbalances is included in the price offered to the customer and is covered by the supplier in the current activity. The estimates of imbalances are the result of complex statistical evaluations and are differentiated as follows: consumer to be analysed has a history of operation (existing client); and consumer to be analysed does not have a history of operation (new client).

3.1. Existing customer

For this type of customer (whether it is a consumer or a generator), a history of operation is required for the longest previous period, if possible, for up to 5 years. The history of the operation is represented by the consumed/generated power and must refer to a period when the installed power has not changed significantly. The periods in which planned, partial or total stops have been achieved will be explicitly indicated including the reduction of the installed power.

Deviations from predicted hourly consumption power will be considered as a statistical population, following a normal distribution law. If information is available showing that another distribution law is followed, the mathematical relationships relating to it will be used. The characteristic form of probability density for normal distribution is shown in Fig. 4.
Fig. 4 - Standard form of the probability density graph for different normal distributions

where:
\( \mu \) - the mean value of the statistical variable,
\( \sigma \) - the value of the statistical variable dispersion.

To estimate these specific indicators, the following relationships are used:

\[
\mu = \int_{-\infty}^{\infty} x \cdot \frac{1}{\sigma \sqrt{2\pi}} \cdot e^{-\frac{(x-\mu)^2}{2\sigma^2}} \cdot dx
\]

(2)

\[
\sigma^2 = \int_{-\infty}^{\infty} (x - \mu)^2 \cdot \frac{1}{\sigma \sqrt{2\pi}} \cdot e^{-\frac{(x-\mu)^2}{2\sigma^2}} \cdot dx
\]

(3)

At the same time, the rule of 3s is taken into account: a normally distributed variable X: N (\( \mu; \sigma \)) and significant values only in the interval (\( \mu - 3\sigma, \mu + 3\sigma \)). Indeed, \( P(|x - \mu| > 3\sigma) = 1 - P(|x - \mu| < 3\sigma) = 1 - \phi(3) = 0.0027 \). This probability value can be considered negligible in most practical situations and certainly in our case.

In all of these relationships, "\( x \)" represents the value of the statistical variable that in our case is the deviation from the forecast hourly value for electricity consumption / production.

Based on historical information on deviations from predicted hourly values, average value and dispersion will be calculated. These values will be used to forecast the client's future behaviour in order to estimate the monthly imbalance value.

3.2. New consumer

In this case, there is obviously no historical customer records and consequently it is necessary to use the information in the literature about the type of customer for which the analysis is performed (in our case, office building with restaurant).

The starting point is the characteristic load curves for this type of consumers (Figures 5 and 6). These characteristic curves are different depending on the day type, season and the type of climate in which the consumer is located.
Based on these characteristic curves and installed power information, both hourly consumption and an estimate of expected hourly deviations will be performed with database procedures.

Obviously, in the case of this type of consumer, it will be stipulated in the contract the possibility of updating the price offer after one year of supplying services or at another mutually agreed term in order to integrate the information collected during this period.

After completing the calculations presented in sections 3.1. or 3.2., the second step is to estimate the cost of imbalances.

Electricity prices on the balancing market are very fluctuating with a margin of variation between 5 lei / MWh to 500 lei / MWh or even more. Under these circumstances, the electricity supplier must use historical information on hourly prices on the Balancing Market presented by the operator of this market, namely the Romanian Transmission System Operator.

By collating the two sets of information, the supplier will perform an estimate of the monthly financial value of the imbalances, which will usually be included in the price of electricity without being explicitly mentioned.

Where there is no significant data / information on the type of consumer or producer, a simplified, overlapping approach is proposed, i.e. a 10% increase per kWh for a fixed minimum period of 12 months (to include all seasons). After this period a post-factum statistical analysis will be carried out and it will be possible to assess whether a more precise approach is required or not.
4. Setting the final price

In order to establish the final price offer, we also need to take into account the profit that the power supply company has to gain in order to operate. Of course, this is different from customer to customer and company to company, making it a very difficult to establish a standard approach. Generally, a percentage is set between $3 \div 5\%$.

Another element that needs to be included in the price is the cost of activity on the Day-Ahead Market (DAM). The supplier has to operate on this market to minimize the cost of purchasing electricity, the cost of this action being different depending on the organizational aspects (number of staff) and the customer portfolio that is covered.

Finally, including all the aspects presented in the preceding sections, the price offer for a final consumer of the type considered (office building including restaurant) will be as follows:

$$p_{en,et} = (p_{ach} + \Delta p_{dez} + \Delta p_{DAM}) \times \left(1 + \frac{\Delta p_{profit}}{100}\right)$$

where:

- $p_{en,et}$ = final price set by supplier for electricity consumers [lei/kWh];
- $p_{ach}$ = electricity price electricity hourly price [lei/kWh];
- $\Delta p_{dez}$ = imbalances component [lei/kWh];
- $\Delta p_{DAM}$ = DAM costs [lei/kWh];
- $\Delta p_{profit}$ = profit component [%];

Conclusion

In this paper, we propose a procedure to set the electricity price following several steps, such as: analysis of the consumer's load curve; establishment of the electricity purchasing system; determining the level of imbalances and setting the final price considering all costs encountered by the supplier.

The electricity price is established considering different purchasing strategies of the suppliers sell and buy electricity on several markets to maximize the profit. Thus, setting the electricity price should be competitive to maintain and enlarge the share market and sustainable in the same time to allow the proper operation of the supplier.

The historical consumption data that come from sensors or smart meters is loaded into a relational database. Several procedures are developed to estimate the consumption load curve, estimate deviations and calculate the electricity price. In case the historical consumption data is not available, the estimation of the consumption and deviations are taken into account and adjustments are expected after a certain operation time.

Acknowledgment: This work was supported by a grant of the Romanian National Authority for Scientific Research and Innovation, CCCDI – UEFISCDI, project title “Multi-layer aggregator solutions to facilitate optimum demand response and grid flexibility”, contract number 71/2018, code: COFUND-ERANET-SMARTGRIDPLUS-SMART-MLA-1, within PNCDI III

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