Electricity tariff systems for informatics system design regarding consumption optimization in smart grids

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High volume of data is gathered via sensors and recorded by smart meters. These data are processed at the electricity consumer and grid operators' side by big data analytics. Electricity consumption optimization offers multiple advantages for both consumers and grid operators. At the electricity customer level, by optimizing electricity consumption savings are significant, but the main benefits will come from indirect aspects such as avoiding onerous grid investments, higher volume of renewable energy sources' integration, less polluted environment etc. In order to optimize electricity consumption, advanced tariff systems are essential due to the financial incentive they provide for electricity consumers' behaviour change. In this paper several advanced tariff systems are described in details. These systems are applied in England, Spain, Italy, France, Norway and Germany. These systems are compared from characteristics, advantages/disadvantages point of view. Then, different tariff systems applied in Romania are presented. Romanian tariff systems have been designed for various electricity consumers' types. Different tariff systems applied by grid operators or electricity supplierswill be includedin the database model that is part of an informatics system for electricity consumption optimization.
Keywords: *Time of use tariff, critical peak pricing tariff, real time pricing tariff systems, sensors, smart-metering*

1 Introduction

Apart from previous periods before electricity market liberalization, tariffs' structure for end users is continually changing almost similar to mobile phones' technology.
Modifications of electricity tariff structure are consequences of competition and dynamic electricity consumers' behaviours. They will also change in the near future due to further implementation of smart metering systems.
There are different advanced tariff systems that can be applied together with smart metering systems. They will be described in details, compared and included in the database model for electricity consumption optimization.

2. Time of use tariff system

In the time of use (ToU) tariff system, the tariffs are fixed for certain time periods. Also, tariffs for working days can be different from tariffs for weekends.
This system has several advantages such as: easy implementation, high transparency, low risk, but it also has some disadvantages such as: rewarding low potential, lack of flexibility, etc. The time of use tariff system applied in Italy, electricity consumers have to reschedule electricity consumption in order to obtain savings.
In [1] the comparison between the German project „Intelliekon" with one single fix tariff and time of use tariff system that is dependent on the moment of consumption with two distinct intervals(specific for peak and for off-peak consumption) is performed. The tariff for peak consumption period is 77% bigger than the tariff for off-peak consumption period.
In Finland, grid operators are obliged by law to implement at large scale this tariff system. By it they could flatten load curve. Similar cases were noticed in England (time of use tariff system called „Economy 7"), Spain („Interval Tariff"), Italy („OfferteBiorarie"), etc.

3. Critical peak pricing tariff system

By critical peak pricing tariff system that combines tariff system that depends on the moment of electricity consumption and different tariffs levels of ToU system for certain days notified by electricity suppliers, the French consumers could reduce annual electricity expenses by 10%. This system is characterised by certain maximum critical days a year and certain minimum time for notification.

„Tempo" tariff system is a critical peak pricing tariff system that was launched in France in 1995 for residential and small business consumers with minimum capacity of 9 kW. In 2008, tariff system „Tempo" was implemented to 350000 residential consumers and over 100000 consumers that carried out small business. This tariff system is based on time of use tariff system with different levels. It defines three types of days: blue (with low tariffs), white (with average tariffs) and red (with high tariffs). The colour of the day is announced in the previous day, around 5:30 p.m. According to **Fig. 1**, between 2009 – 2010, from 1st of November and 31st of March were identified 22 red days, 43 white days identified mainly from October to May and 300 blue days (all Sundays are blue).

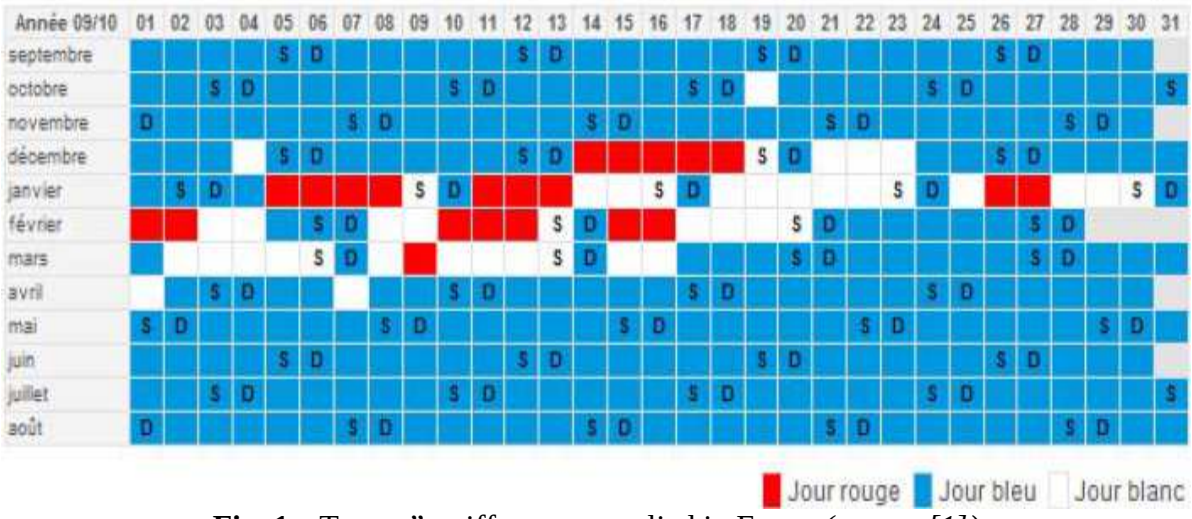

Fig. 1. „Tempo" tariff system applied in France*(source [1])*

During winter months, red and white days are numerous due to the high mix generation costs. Even five consecutive red days were recorded, that makes this tariff system more difficult to be implemented especially to those consumers with special problems.

According to **Fig. 2**, days' patternis identic with ToU tariff system, with off-peak (low tariffs) and peak (high tariffs) consumption intervals. Difference between specific tariffs for blue and red days is significant. Peak consumption tariff for red days are five times higher than peak consumption for blue days. Peak consumption tariff is five times higher than off-peak consumption tariff for red days.

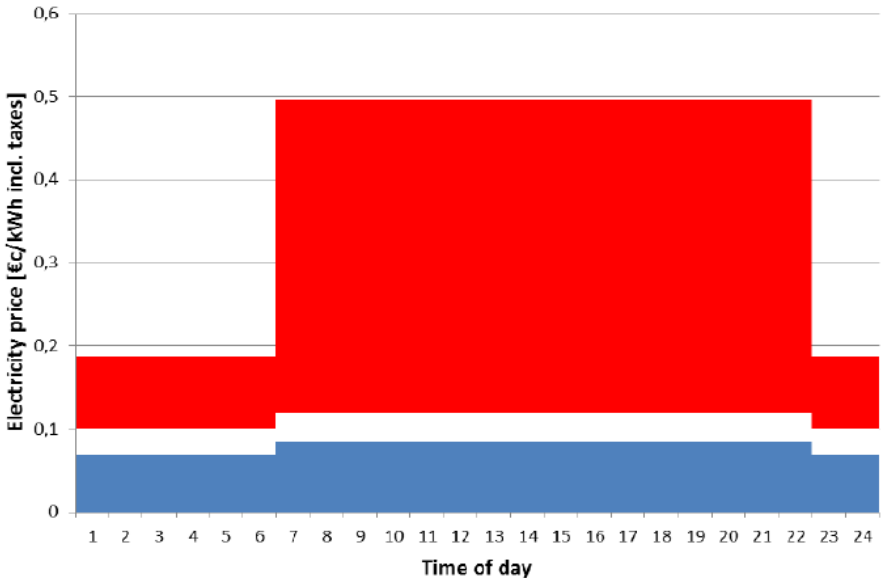

Fig. 2.„Tempo" tariff system structure applied in France*(source [1])*

The difference between peak consumption tariff and off-peak consumption tariff for white and blue days is only 20%. „Tempo" tariff system applied in France reflects energy generation costs that could vary each month, but it is more difficult to be implemented in societies with many consumers with social problems.

4. Real time tariff system

Through real time tariff system the electricity consumers know information about tariff in real time. They can respond to tariff fluctuation by raising or reducing the electricity consumption. On one hand, this tariff system allows the maximization of savings out of electricity consumption based on consumers' involvement. On the other hand, electricity consumers that are not involved in optimizing their consumption could have higher expenses.

Smart metering system allows consumers to manage in details electricity consumption. They can postpone some activities when the tariffs are higher for time intervals when tariff are low.

This tariff system is applied by some Norwegian electricity suppliers. The tariff represents the monthly average of spot price. In 2011, it varied between 3.1 €c/kWh in September and 9.3 €c/kWh in January. In 2010, the spot price was up to 57.7 €c/kWh and it recorded small variations.

Other Norwegian electricity suppliers apply tariff based on hourly average of spot price from electricity market Nordpool that could be correlated with hourly electricity consumption recorded by smart meters. According to figure 3, the price fluctuation was about ±53% compared to the average price or between 5.5 and 17.5 €c/kWh.

As shown in **Fig. 3**, fluctuations significantly depend on the season. In Norway case, the hourly fluctuations are low as a consequence of Norwegian power system particularities that are mainly based on hydro-power plants, but in other power systems, these hourly fluctuations can be high. They are intensified by the operation of power plants that are based on renewablesources.

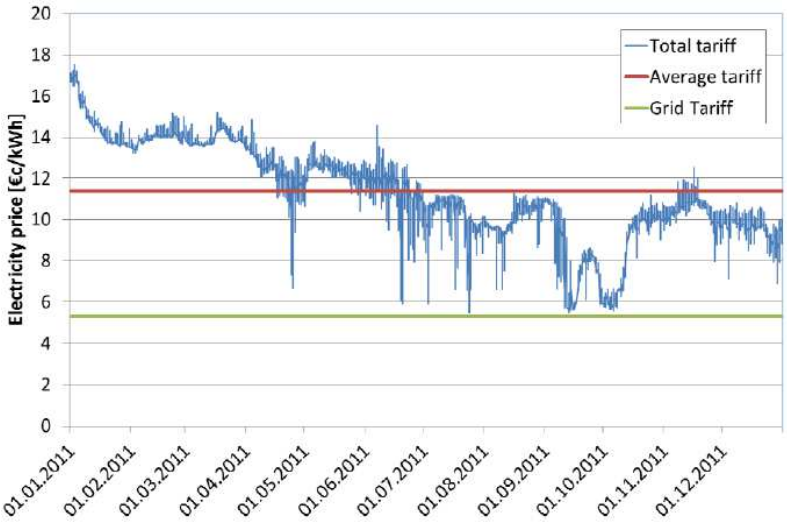

Fig. 3. Spot market price fluctuations for setting real time tariff system*(source [1])*

In Germany, some suppliers apply this tariff system. In 2010, spot market price varied between -2.945 €c/kWh and 13.179 €c/kWh. Total tariff, including grid tariff, varies between +49% and -35% compared to average of 21.1 €c/kWh.

This real time tariff system shows a series of advantages such as: increasing savings from electricity consumption, increasing the number of active electricity consumersthat are able to contribute to production-consumption balance, but also it has disadvantages, such as: increasing complexity of tariff system. In case that the settings of this system are not properly designed, price and consumption fluctuations could be uncontrollable. The real time tariff system changes the classical forecasting methods.

In **Table 1.**, I compared the three tariff systems, by shortly describing their characteristics, advantages and disadvantages.

Table 1. Comparative analysis of the advanced tariff systems

	Time of use tariff system	**Critical peak pricing tariff system**	**Real time tariff system**
Characteristics	It depends on the consumption moment; It does not need information exchange (IT&C).	It depends on the critical moments (events); It does not need information exchange (IT&C).	It depends on real time electricity request and supply; It does need information exchange (IT&C).
Advantages	Easy and simple to be implemented; Transparent, low risk.	Compared with ToU tariff system, it better reflects the market mechanisms and generation costs that depend on season.	Flexible; It involves consumers; It encourages consumption optimization; It reflects market mechanisms; Performance in dynamic control of load.

Disadvantages	It has limited potential of rewarding; Low flexibility; It involves consumers to certain extend; No performance in dynamic control of load.	Limited performance in dynamic control of load; It is difficult to estimate the critical moments; Medium complexity; It is difficult to be implemented to consumers with social problems.	Complex; Low transparency; If it is not well designed it can lead to unbalances; High volume of data.

It can be concluded that all described tariff systems are suitable for smart metering systems. It should be compatible with the most of the electricity consumers to whom it will be applied.

Taking into account that smart metering systems integration is an on-going developing process, it is reasonable to appear new improved tariff systems that will be more and more adaptable to electricity consumers' behaviour.

5. Tariff system included into the database model

In the previous paragraphs, different advanced tariff systems have been described. They are mature tariff systems, being already applied in some European countries. In this paper we design a database model that includes the tariff system. It is part of consumption records table. This table is linked to contract table that is related to electricity suppliers and consumers (figure 4).

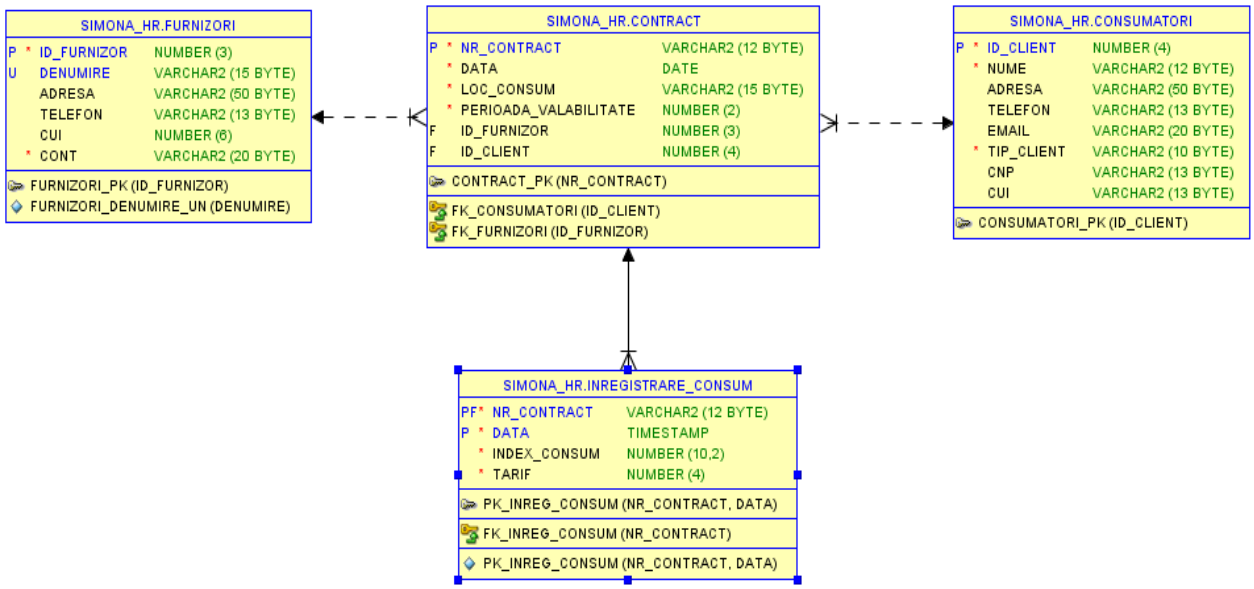

Fig.4. Database model including tariff system

For the electricity consumers the following data are stored: identification number, name, address, phone, email, type, personal numeric code, identification unique code in case of legal entities. One electricity consumers may have one or two contracts;also one electricity supplier may conclude one or more contracts. Each contract is defined by the following data: contract number, data, consumption place and validity period. For the electricity suppliers the following data are stored: id,

name, address, phone, identification unique code and bank account. For each contract, one or many consumption records can be stored. The consumption record is defined by: contract number, data (this combination will form the primary key), consumption index and tariff system, since at different contracts can be applied different tariff systems. They are included in the database model that is part of informatics system for electricity consumption optimization [3], [4].

6. Electricity tariff system applied in Romania

In Romania, electricity market has two components: regulated market and competitive market. On the regulated market, the tariff system for electricity consumers is diverse and has several components.

Social tariff (known as CS tariff) is a fix tariff, available only for electricity consumers with net monthly revenue for family member less or equal to economy minimum wage. It is recommended for monthly consumption less than 110 kWh; under this limit, it is the most economic tariff. As for the invoice calculation, the total consumption monthly is divided into three parts: the first part is defined up to 2 kWh per day (for instance 60 kWh / 30 days), that is invoiced at smallest tariff, the second part of monthly consumption is from 2 to 3 kWh per day (between 60 and 90 kWh / 30 days) that is invoiced with a medium tariff and the third part of consumption that is above 3 kWh per day (over 90 kWh / 30 days) that is invoiced at a very high tariff, design to discourage the wrong choice of tariff. If the consumer choose social tariff, but its electricity consumption exceed certain limit, his invoice could be very expensive.

Monomial tariff without reservation (known as CD tariff) is a single component tariff that includes only the price for electricity. It is suitable for monthly consumption of maximum 43 kWh. Taking into account that this tariff has no reservation and only electricity consumption is paid, when there is no consumption, the consumer has nothing to pay, but it has the disadvantage that in case of higher consumption, expenses become higher and higher compared to other tariffs. It is recommended for small monthly consumption, up to the suggested limit, for cases when social tariff couldn't be applied. It is also recommended for non-permanently inhabited houses, in case supply interruption is undesirable or for holiday houses with monthly consumption less than 43 kWh.

Monomial tariff with reservation (known as CR tariff) is the most common option for electricity consumers because it allows any daily variations of consumption and there is no limitation of monthly consumption. It is non-restrictive tariff, without risks due to inconsistency with imposed conditions of other tariff systems types.

It has two components of tariff: reservation tariff that is applied for every invoicing day and electricity consumption tariff that is applied for each kWh. Reservation component represents grid operator's maintenance expenses. It is necessary to maintain the grid in good state and permanently available to consumers.

Monomial tariff including the consumption (known as CI tariff) is recommended for daily average consumption bigger than 1 kWh. It is a tariff with subscription that includes reservation costs and daily consumption of 1 kWh.

It has two components: subscription tariff that is applied per invoice regardless the consumption and electricity tariff applied for each kWh; both components of tariff have different values depending on voltage level. Since the subscription has the same value for 1 or less than 1 kWh/day, this tariff is disadvantageous when the consumption is not performed; it will not rollover the next period.

Monomial tariff with differential reservation for two pricing zones (known as CR2 tariff) has two components:

reservation tariff that applies for each invoicing day, regardless the consumption volume and electricity tariff that applies based on the two pricing zones.
The two pricing zones are: "the day zone" that refers to Monday to Friday from 7 a.m. to 10 p.m. and "the night zone" that refers to Monday to Friday from 10 p.m. to 7 a.m. and weekend hours from Friday 10 p.m. until Monday 7 a.m.
Electricity tariff is lower at night and it is higher during the day, this difference was created in order to diminish the electricity expenses by increasing the consumption at night and weekend. This tariff can be applied only whether smart meters are implemented; regular meters are not able to keep track of different pricing zones.
Monomial tariffwith differential reservation for three pricing zones (known as CR3 tariff) is the most complex tariff for residential consumption. It requires good management of daily load curve from consumers' side.
The tariff has two components: reservation tariff that applies for each invoicing day, regardless the consumption volume and electricity tariff that applies based on voltage level, the three pricing zones and seasons. The seasons are: summer season, from 1st of April to 30th of September and winter season from 1st of October to 31st of March.
Electricity tariff has the smallest value during night hours, average value during "normal" consumption hours and highest value during peak hours.
Monomial tariff (known as CTP) has three levels of power (written in the contract): up to 3 kW, between 3 and 6 kW, over 6 kW. Based on the three levels of power, the different three tariffs are applied.It is recommended for medium-size consumers that well know each equipment from the installed power and operation simultaneity control point of view in order to determine the right absorbed power [4].
On non-regulated or competitive market, electricity consumers can negotiate with suppliers the tariff. The negotiated tariff can be:

- Variable in case of exceeding certain referential values, agreed between parties, for instance, the level of average tariff on regulated market. In these cases negotiated tariff is less than the average tariff on regulated market;
- Fix for certain time period. Whether the tariffs increase over the time, the benefit is on consumer side and whether the tariffs decrease, the benefit is on supplier side. In these cases, the supplier keeps the tariff constant;
- Otherwise agreed by parties [5].

7. Conclusions

The advanced tariff systems are essential for electricity consumption optimization due to financial incentives that could transform into savings due to consumers' behaviour changing. In this paper, advanced tariff systems (time of use, critical peak pricing, real time tariff systems) have been described.
They are applied in England, Spain, Italy, France, Norway and Germany. These tariff systems have been compared taking into account their characteristics, advantages and disadvantages. The tariff system is part of the database model that has been design by the author.
Then different tariff systems applied in Romania have been described. They have been designed for different electricity consumers types.

Acknowledgment

This paper presents results of the research project: Intelligent system for predicting, analyzing and monitoring performance indicators and business processes in the field of renewable energies (SIPAMER), research project, PNII – Collaborative Projects, PCCA 2013, code 0996, no. 49/2014 funded by NASR.

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