ABSTRACT

Error in predicting electricity load has significant cost implications for suppliers operating in a competitive power markets. Besides uncertainties that are inherent to all supply business, acting as a public service supplier presumes a myriad of other aggravating circumstances mainly related to operating under regulated regime. This paper proposes a model for a short-term load forecasting serving as a basis for short-term energy procurement activities of supplier under public service obligation.

1. INTRODUCTION

Load forecasting is vitally important for electricity suppliers energy purchasing. Introduction of electricity markets and separation of competitive functions bring both opportunities and challenges to the supplier load forecasting practice due to complex forecasting requirements, small forecasting team, historic data (un)availability, customer switching, etc. Besides uncertainties that are inherent to all supply business, acting as a supplier under public service obligation presumes a myriad of other aggravating circumstances. For example, they perform electricity supply according to regulated conditions, they cannot reject customers, in theirs portfolio prevail customers without quarter-hourly metering, etc. This paper proposes a comprehensive forecasting model for a short-term load forecasting serving as a basis for short-term energy procurement activities of supplier under public service obligation.

2. CROATIAN RETAIL MARKET - SUPPLIER UNDER PUBLIC SERVICE OBLIGATION

The main features of the Croatian electricity market are its size (consumption of the Croatian retail market is 17,5 TWh), structure and the dominance of the incumbent company. The retail market is dominated by two incumbent suppliers: a supplier under public service obligation (regulated regime) in charge of households and customers without a supplier (its market share is roughly 53 %) and a market supplier (subsidy of the incumbent company). Market shares of electricity suppliers in Croatia are: 43 % (6,2 TWh) universal service supplier, 10 % (1,4 TWh) supplier of last resort, 47 % (6,9 TWh) competitive suppliers.

The new Electricity Market Act [1] passed in 2013 (harmonized with the 3rd Energy Package) introduces significant structural and organizational changes. The latter and Croatian accession to the EU encouraged other market suppliers to enter the retail market. Currently approximately 12% of customers leaved suppliers of the vertically-integrated undertaking. 8,3 % of households consumption is supplied by market suppliers. Universal service in Croatia is a unique method of sale of electricity within the framework of electricity supply performed as a public service, ensuring the right of Croatian household customers to supply of electricity of a prescribed quality on the entire territory of the Republic of Croatia, under reasonable, easily and clearly comparable, transparent and non-discriminatory prices. This activity is performed by universal service supplier (USS).

In Croatia, all non-household customers were obliged to switch from supplier under public service obligation (i.e. “regulated supply”). Non-household customers that did not manage to find a supplier are supplied by supplier of last resort (this supply can last indefinitely). Besides, the supplier of last resort (SoLR) supplies also, according to regulated conditions, those non-household customers which have lost their supplier under specific circumstances.

2.1. Customers supplied by USS and SoLR

Besides for households that freely choose such a method of supply, the Electricity market Act stipulates that universal service supplier acts as a supplier of last resort for households which have lost their supplier and also vulnerable customers (means a household customer which due to its social status and/or health condition has the right to network use and/or electricity supply under special conditions).

<table>
<thead>
<tr>
<th>Supplier of last resort</th>
<th>Consumption registered</th>
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<tbody>
<tr>
<td>Suppliers only non-households</td>
<td>Monthly basis (≥30kW) and 15-min basis (≤30kW)</td>
</tr>
</tbody>
</table>

![Figure 1 Suppliers under public service obligation in Croatia](Figure 1 Suppliers under public service obligation in Croatia)

SoLR in Croatia supplies only non-households customers (Figure 1). Both obligations, of supplying final customers who are entitled to universal service and supply of last resort, have been given to distribution system operator (DSO). In line with unbundling requirements placed on DSOs under 3rd Energy Package, activities are underway to separate DSO and supply business. So, currently these activities are performed within one legal person (which is also DSO), but in the future there might be a number of universal service suppliers and one supplier of last resort (activity might remain at DSO). In this paper “public supplier (PS)” is used as the abbreviation of “supplier under public service obligation” (e.g. USS and/or SoLR).

2.2. Distribution system facts and figures

In 2013 Croatian distribution system (DS) brutto...
consumption equaled 15,9 TWh:

- DS losses (technical and non-technical): 1,46 TWh (9,16%),
- consumption of final customers connected to DS (netto DS consumption): households 6,2 TWh (39 %), LV non-households 4,6 TWh (29 %), MV final customers 3,5 TWh (22 %) and HV final customers connected to DS 0,15 TWh (1 %).

Electricity production of distributed generation connected to DS equaled 0,24 TWh (1,5 % of DS brutto consumption). At the end of 2013 there were: 2,148.375 households, 211.376 LV non-household customers, 2.114 MV commercial customers, 4 HV commercial customers and 674 producers (distributed generation) connected to DS. Among them there were 69.826 non-household customers supplied by SoLR. Theirs consumption in 2013 equaled 1,4 TWh.

2.3. Procurement of energy

Efficiency of PS depends on the ability to accurately forecast hourly demand of their customers. Even marginal improvements in forecasting the load can lead to substantial decrease in total procurement costs.

As establish by [2], Croatian market operator (MO) is responsible for purchasing the subsidized eco-electricity and allocating/selling it to the electricity suppliers (purchase is based on monthly values valid for the following month). For the remaining energy (greater part) PS shall conduct necessary market-based purchasing activities to cover consumption of their customers (Figure 2). Based on the indicative forecasts for 2015 (comprising also forecasts of customer switching from PS to the market), PS will be responsible for procuring: 5 TWh for households (supplied by USS) and 0,7 TWh for non-households (supplied by SoLR).

In order to minimize the price risk procurement shall be conducted through several tenders of standard products at different times (long-term procurement process). Any remaining quantities (shortfalls/surpluses) shall be covered by trades on the daily basis (short-term procurement process).

Currently undertakings with obligation to provide public services (i.e. DSO, TSO, PS) are exempted from imbalance charging until enactment of new Market Rules (expected in 2015). Operating within incumbent company (central forecasting/planning), accompanied with no economic incentives (exemption from imbalance charging) resulted with DSO, in its capacity of a PS, having no adequate forecasting skills, official methodology and/or tools. Analysis and suggestions provided in this paper represent authors’ thinking about conducting public supplier STLF under current legal framework. The work from this paper should be seen as a contribution to improve the load forecasting practice in Croatian public supplier(s).

3. LEGAL FRAMEWORK

3.1. Metering

In Croatia electricity consumption of households and low voltage commercial customers with subscribed power below 30 kW is not quarter-hourly or hourly registered. Households’ electricity meters are read twice a year and commercial customers on a monthly basis. According to the official figures for 2013, in Croatian DS there were 2,3 million LV consumers without quarter-hourly metering. Theirs’ consumption in 2013 equaled 8,5 TWh (59 % of total consumption of final customers connected to DS). Pursuant to the Rules on balancing the electric power system [3], these customers shall be settled using characteristic load profiles (CLP) and monthly/semiannual consumption readings from electricity meters.

3.2. Representative customers classes and characteristic load profiles

Based on extensive survey [4], the following 4 representative customer classes (RCC) have been stipulated to represent LV customers without quarter-hourly metering in Croatia [5]: households (denominated K0), LV commercial customers with connection power ≤ 13 kW (P1), LV commercial customers with connection power > 13 kW (P2) and public lighting (JR0).

To introduce distinction among loading conditions in the course of calendar year, one CLP comprises 9 daily load profiles (DLP) [6]. Daily load profiles are defined at intervals of 15 min, resulting therefore in 96 values in a day curve. Calendar year is divided into 3 seasons: winter.
season (1.11.-20.3.), summer season (15.5.-14.9.) and intermediate season (21.3.-14.5.; 15.9.-31.10.). For each season 3 daily load profiles describe typical days load pattern: working day, Saturday and Sunday/holiday. Figure 3 depicts households’ class CLP (9 DLPs) and dynamizing polynomial (i.e. besides seasons DLPs, 4th degree polynomial is used to make K0 CLP “more dynamic”). CLPs are normalized to 1,000 kWh/a annual consumption.

3.3. Extended analytical methodology

Pursuant to the Rules on application of characteristic load profiles [5], for calculation of hourly realization of customers without quarter-hourly metering “extended analytical methodology” (EAM) is used.

Residual distribution system load profile

In this analytical procedure hourly profiling of consumers without quarter-hourly metering is carried out using residual distribution system load profile (RDSLp). RDSLp represents total energy consumed by customers that are not metered on a quarter-hourly basis and is calculated as given in Figure 4.

![Image 4 EAM – calculation of residual DS load profile](image)

Load profile for DS losses

With regard of load profile for losses, in Croatia there are no precise data on losses (losses are not measured). Beside, currently there is no official methodology for determining DS losses. In the monthly first clearing round (clearing of the previous month), losses are estimated on the basis of the past accounting data [5]. The approach assumes linear dependency between losses and distribution system LP. DSO calculates annual quotient (%) of losses on the basis of data on actual DS losses (on the annual level) in the preceding 4 years. Annual level of actual DS losses (technical and non-technical) is calculated as a difference between total energy provided within DSO and total energy invoiced to customers. Estimated load profile for losses is calculated in each hour by multiplying the annual quotient and DS load. Actual losses of the DS are considered in the second clearing round.

LP of customers not registered quarter-hourly

In the EAM RDSLp is completely decomposed into RCC load profiles $P_{RCC_i}(t)$ based on customers’ annual consumption data and characteristic load profiles (Figure 5). This is realized by the utilization of the so-called resolution factor of customer classes $Z_{RCC_i}(t)$, which is determined for each RCC, $i = 1...4$. For every 15-minute time interval, the resolution factor of a given RCC, $Z_{RCC_i}(t)$, defines the share of the observed RCC in the overall load of RDSLp(t).

$$Z_{RCC_i}(t) = \frac{P_{RCC_i}(t)}{\sum_i P_{RCC_i}(t)}$$

$$P_{RCC_i}(t) = CLP_{RCC_i}(t) \times \frac{W_{RCC_i}}{1000}$$

Where $W_{RCC_i}$ represents total annual consumption of customers belonging to RCCi and $CLP_{RCC_i}(t)$ represents normalized characteristic load profile of RCCi.

![Image 5 EAM – determining RCC* load profiles](image)

The sum of $Z_{RCC_i}(t)$ values of all representative customer classes $i = 1...4$ for a given observed 15-minute time interval equals 1 (100 %). Load profile of a representative customer class $P_{RCC_i}(t)$ is calculated by multiplying $Z_{RCC_i}(t)$ by the RDSLp(t).

$$P_{RCC_i}(t) = RDSLp(t) \times Z_{RCC_i}(t)$$

What follows is the decomposition of RCC load profiles into suppliers load profiles with the use of the so-called supplier’s weighting factor “G”. The supplier’s weighting factor is determined for each RCC and represents energy (consumption) share of the supplier in the observed RCC. Load profile of a supplier “Sj” in RCCi, $P_{Sj,RCC_i}(t)$, is calculated by multiplying $G_{Sj,RCC_i}$ by the RCCi load profile:

$$P_{Sj,RCC_i}(t) = P_{RCC_i}(t) \times G_{Sj,RCC_i}$$

Where $G_{Sj,RCC_i}$ represents weighting factor of supplier Sj in RCCi.

4. MODEL FOR SUPPLIER UNDER PUBLIC SERVICE OBLIGATION LOAD FORECASTING

As indicated in [7], commonly short term forecasting has a cut-off horizon at two weeks. In this paper we focus on hourly short term load forecasting (STLF) with a lead time of one day to a week ahead, serving as a basis for short-term energy procurement process.

This paper proposes separate day ahead LP forecasting: (i) for customers with (commercial customers > 30kW of SoLR) and (ii) for customers without quarter-hourly metering (households of USS and commercial customers ≤ 30kW of SoLR) (Figure 6). Forecasting of customers with quarter-hourly metering is outside of the scope of this paper. We simply mention it should be conducted separately for each customers (larger customers) and jointly per consumption categories (smaller customers). Forecasting for customers without quarter-hourly metering
is divided in 4 consecutive steps: (1) forecasting DS LP (see section 5), (2) determining LP for DS losses (see section 3.3), (3) forecasting LP for all customers connected to DS with quarter-hourly metering (similar to previously mentioned procedure for forecasting of supplier customers with quarter-hourly metering, but here related to all customers on DS with quarter-hourly metering) and (4) determining public supplier LP (see section 3.3).

5. DISTRIBUTION SYSTEM SHORT TERM LOAD FORECASTING

The forecasting methods analyzed in the paper include: Artificial Neural Networks (ANN) and Auto Regressive Integrated Moving Average (ARIMA).

5.1. ANN

In this paper 5 ANN models have been analysed, differing in selection of weather related input variables (Table 1). A three-layer feed-forward network with sigmoid hidden neurons and linear output neuron (forecasted hourly load) has been used in MATLAB Toolbox. ANN was trained with Lavenberg-Marquardt backpropagation algorithm.

<table>
<thead>
<tr>
<th>Inputs of five ANN models</th>
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<tbody>
<tr>
<td>Hour of the day (e.g. 8-22)</td>
</tr>
<tr>
<td>Wind (e.g. strong, weaker, or intermediate)</td>
</tr>
<tr>
<td>Temperature in 240</td>
</tr>
<tr>
<td>Pressure in Mbar</td>
</tr>
<tr>
<td>Hour from the previous day</td>
</tr>
<tr>
<td>Number of neurons in input layer</td>
</tr>
</tbody>
</table>

5.2. ARIMA

ARIMA belongs to a group of time series methods. They are based on the assumption that the data have an internal structure, such as autocorrelation, trend, or seasonal variation. ARIMA uses the time and load as the only input variables for forecasting.

5.3. Historical weather and load data

The dataset used comprises historical hourly distribution system quarter-hourly loads (publicly available on [5]) and weather observations from DHMZ (State Meteorological and Hydrological Service) for period 2011 (May) to 2014 (September). It has been divided into two sets: a training set with 85% and a validation set with 15% of historical data.

Across Croatia there are 40 main weather stations from DHMZ taking readings on an hourly basis (map with stations is given in Figure 7). Requested readily obtainable hourly weather data in the observed 2.5 years period have limited number of observed stations to five located in 5 largest cities: Zagreb, Split, Rijeka, Osijek and Zadar. Impact of the following 3 weather variables have been analyzed: temperature, wind speed and humidity.

Table 2 Error measures - test month October 2014

<table>
<thead>
<tr>
<th>Algorithm</th>
<th>ANN</th>
<th>ARIMA</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAPE</td>
<td>2.13%</td>
<td>1.91%</td>
</tr>
<tr>
<td>max hourly APE</td>
<td>17.32%</td>
<td>15.38%</td>
</tr>
</tbody>
</table>

Figure 8 compares the actual and predicted DS load by ANN M4 in the 4th week of the test month in which occurs maximum hourly APE (14.73%). Figure 9 depicts hourly APEs for ANN M4 in test month. Maximum APE occurs on Wednesday 22nd October in 5th hour. It could be observed form Figure 10 (actual temperatures) and Figure 11 (actual wind speeds) that maximum APE coincides with decline in temperature and rise in wind speed in coastal area (is coastal area prevails heating on electricity). As can be seen, even by data from limited number of weather stations (only five) satisfactory STLF of entire Croatian DS load profile can be achieved.
Figure 9 Absolute percentage error of forecasting with M4 ANN for each hour in October 2014.

Figure 10 Temperatures in observed 5 cities in Croatia in October 2014.

Figure 11 Wind speeds in observed 5 cities in Croatia in October 2014.

6. CONCLUSIONS
Accurate load forecasting is very important for suppliers in a competitive environment created by deregulation. In this paper we review two methods for DS STLF: artificial intelligence (ANN) and time-series (ARIMA). Besides, a comprehensive forecasting model for a STLF serving as a basis for short-term energy procurement activities of supplier under public service obligation has been proposed. Future research directions shall be: (i) improving accuracy of developed STLF methods, i.e. forecasting by regions (supply areas), research in ARIMAX (ARIMA with exogenous (weather) variables), (ii) development of suitable (tailored) forecasting method for customers with quarter-hourly metering, (iii) improving legal framework: transparent methodology for scheduling (estimation) and determining (actual) hourly load profile for DS losses, then investigating suitability of replacing EAM (described in section 3.3) by some other (simpler) methodology (i.e. synthetic [4]) and also further research in CLP of representative customers classes for non-quarter-hourly metered customers.

7. REFERENCES