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IMPACT OF AIR TEMPERATURE ON ACTIVE AND REACTIVE POWER CONSUMPTION - SARAJEVO CASE STUDY

UTJECAJ TEMPERATURE ZRAKA NA POTROŠNJU AKTIVNE I REAKTIVNE ENERGIJE –SARAJEVO STUDIJA

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Abstract: As the influence of ambient temperature on the consumption of electricity has been the subject of research for several decades, a number of different approaches has been developed and applied for this purpose. In the recent years, special attention has been drawn on techniques for time-frequency analysis of time series, such as the Wavelet Transform (WT) or the Hilbert-Huang Transform (HHT), providing observations of temperature influence on consumption of electricity over time and for varying periods of time / frequency. In this paper, using Huang's Empirical Mode Decomposition (EMD) and correlations between Intrinsic Mode Functions (IMFs), we investigated the impact of air temperature variations on the active and reactive power consumption (recorded during 2011) in the Sarajevo City. Applying the EMD approach, time series were decomposed into several Intrinsic Mode Functions (IMFs) and after that, correlations were applied to determine relationships between IMFs. Calculating the correlations between the individual IMFs, one can identify the periods when the time series have the strongest relationship, providing additional and useful information about the impact of temperature variations on active and reactive power consumption at different periods over the observed time horizon. The results of the analyses show moderate and strong interrelationships between temperature and active and reactive consumption for different periods/frequencies. Comparison was made between the results of the electricity consumption of other power distribution parts of the same public utility and it can be concluded that Sarajevo, as the capital and the area with a much higher Gross Domestic Product (GDP) than other parts of Bosnia and Herzegovina, does not have significant different characteristics in terms of the influence of temperature on the consumption of active and reactive energy.

Keywords: air temperature, active and reactive power, empirical mode decomposition, correlation

Sažetak: Kako je utjecaj temperature zraka na potrošnju električne energije predmet istraživanja već nekoliko decenija, u tu svrhu su razvijeni i primjenjuje se veliki broj različitih pristupa. U posljednjih nekoliko godina, posebna pažnja je na tehnikama za vremensko frekventnu analizu vremenskih serija, kao što su wavelet transformacija (WT) ili Hilbert-Huang transformacija (HHT). Ove tehnike omogućavaju analizu utjecaja temperature zraka na potrošnju električne energije tokom vremena i za različite periode vremena/frekvencija. U ovom radu, koristeći Huangovu metodu empirijskog razlaganja (engl.Empirical Mode Decomposition EMD) i korelacije između jednostavnih svojstvenih funkcija (engl. intrinsic mode functions, IMFs) istraženje utjecaj varijacija temperature zraka na potrošnju aktivne i reaktivne energije (tokom 2011. godine) u gradu Sarajevu. Primjenom EMD pristupa vremenske serije su rastavljene u nekoliko jednostavnih svojstvenih funkcija (IMFs) i nakon toga, korelacije se primjenjuju za određivanje odnosa između IMFs. Izračunavanjem korelacije između pojedinih IMFs moguće je identifikovati periode kada vremenske serije imaju najjaču povezanost, također, dodatne i korisne informacije o utjecaju varijacija temperature na potrošnju aktivne i reaktivne energije u različitim periodima u posmatranom vremenskom intervalu. Rezultati analize pokazuju umjerenu i jaku međusobnu ovisnost između temperature zraka i potrošnje aktivne i reaktivne energije za različite periode/frekvencije. Poređenje je napravljeno s rezultatima potrošnje električne energije drugih distributivnih dijelova Elektroprivrede i može se zaključiti da je Sarajevo kao glavni grad i područje s mnogo većim bruto domaćim proizvodom (BDP) u odnosu na ostale dijelove, nema značajno različite karakteristike u pogledu utjecaja temperature zraka na potrošnju aktivne i reaktivne energije.

Ključne riječi: temperatura zraka, aktivna i reaktivna energija, metoda empirijskog razlaganja, korelacija

INTRODUCTION

Planning the electric power system is a very complex process. One of the activities in this process includes the assessment of short, medium and long-term electricity needs. These requirements are defined by different approaches, taking into the account the various parameters that may affect the power consumption for a given period of time. Some of the parameters that are the subject of analysis are expected ambient temperature, different social events, religious and national holidays, economic activity or GDP, customs of population, etc. All information about the influence of certain factors on the power con-

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sumption are very important for power system operators. Besides the information about active power consumption, the information about reactive power consumption are also very important because in practical terms they have a significant effect on the voltage profiles in the power system and the distribution network [1], [2]. Activities related to the consumption (and management) of reactive power in the power system are the processes that take place within the framework of regulation contour QV. Special attention should be given to the reactive power consumption during extremely hot (summer) days, when significantly higher consumption of reactive power is registered due to intensive use of air conditioners. An impact of air temperature variations on power consumption has been a subject of research for many years. Meteorological parameters include the current state of time elements that may have a direct or indirect impact on the power consumption process. Data on meteorological conditions can be valuable and describe the environmental impact on the amount of electricity consumption. The most obvious variable affecting consumption is air temperature; it proved to be a good input variable, primarily because both, rises and drops in temperature lead to energy consumption increases, due to intensive use of air-conditioners and heating, respectively. Since the ambient temperature has the greatest impact on the consumption process, especially when it comes to residential consumers, most forecasting models use air temperature information as their input parameter. In the literature it is possible to find a number of different approaches for analysing the impact of GDP and air temperature variations on the power consumption. For example, a linear regression approach was applied in the analysis of impact of air temperature on power consumption in different areas around the world: UK, Slovakia and Bosnia and Herzegovina [1], [2], Iran [3], Bangladesh [4], and Australia [5]. Also, Valor et al. [6] presented a very interesting statistical analysis of the influence of air temperature on the power consumption in Spain, where inter-alia nonlinear relationship between these two variables was identified. A similar nonlinear relationship between the air temperature and the power consumption were found by Fung et al. [7] for Hong Kong area. The relationship between these variables analysed for Jordan also shows nonlinear relationship, where the increase of air temperature leads to a significant increase in power consumption [8]. The time-frequency techniques such as Wavelet Transform (WT) have found their application in the analysis of the influence of certain variables on the power consumption [1], [2], [9], [10]. This approach allows a multi-scale analysis and identifications of time series variations in different scales (periods). On the other hand, the importance and significance of identifying the basic characteristics of electricity consumption, whether at the local level (substations level) or consumption of the entire system are shown in [11], [12] using the CWT and Hilbert-Huang transform (HHT) approaches. Generally, it can be concluded that WT and HHT are the most popular and highly effective techniques for the analysis of non-stationary time series.

In this paper, an impact of air temperature variations on active and reactive power consumption in Sarajevo city is investigated using the Huang's Empirical Mode Decomposition (EMD) [13]-[15] and correlations between Intrinsic Mode Functions (IMFs). The results of the correlations between the IMFs show significant values for low-frequency components, indicating strong seasonal interrelationships. Also, the results of analyses show moderate and strong interrelationships between temperature and active and reactive consumption for the periods about 2 months. Comparison is made with the results of the electricity consumption of other power distribution parts of the same public utility. It can be concluded that Sarajevo, as a capital, is the area with a much larger GDP compared to other parts of the country, but there are no significant different characteristics in terms of the influence of temperature on the consumption of active and reactive energy. The approach used in this study (correlations between IMFs) has been successfully applied in various fields [16]-[19]. Also, the EMD and ensemble EMD, Pan and Min-sheng [16] applied for the analysis of the frequency characteristics of pressure fluctuations, while Fontugne et al. [17] and Radic et al. [18] investigated the correlations between the IMFs using signals from sensors and meteorological data, respectively. Barnhart in [19] applied this approach to analyze the interrelations between different variables in extended periods of time (between total solar irradiance and sunspot from 1749 to 2009, etc.).

The rest of the paper is organized as follows: the second chapter presents the specific historical data and those of the daily values of consumption of active and reactive power in 2011. Time series of daily consumption for the city of Sarajevo and other distributions of the same public utility are used for practical analysis and comparison presented in chapter three, and the conclusions are presented in chapter four.

1. A BRIEF TOUR INTO THE HISTORY OF BIH POWER SYSTEM

This section of the paper explains the history of Bosnia and Herzegovina's power system. Bosnia and Herzegovina (BiH) has several decades of tradition in electrical engineering. The use of electric power in Bosnia and Herzegovina began in 1888, and the development of the electricity system historically had various ups and downs. Significant coal reserves and water potentials have been the subject of interest of the professional and scientific community, as well as various investors, for decades. Innovation and Bosnian-Herzegovinian diligence experts in the field of energetics were recognised at the end of the

19th century, when, in cooperation with engineers from Europe they worked on relatively complex projects for that time. Also, the intensity of the development of electric power over time and effects of the general economic conditions that were prevalent in Europe and the world in different periods, caused that the implementation of planned projects (electrification of settlements, construction of power plants, etc.) did not always go according to the established plans. The development of power industry in BiH generally followed the trends and technical developments in the Western European countries and the USA. According to written documents in BiH, the beginning of electrification was recorded in 1888 in Zenica (construction of the first electric lighting), while the first public thermal power plants of 220 kW was built in 1895 in Sarajevo [PE Elektroprivreda BiH]. The first hydro power plant in Bosnia and Herzegovina was built in 1899 on the Pliva River, with power of about 7 MW (Elektrobosna); at that time, it was the largest hydro power plant in Europe [20]. In the period until 1918, 6 small hydropower plants and 41 thermal power plants with a total capacity of around 17 MW were built. By the end of 1938, in BiH there were 77 power stations with a total installed power of 34 MW, while the intensive development of production facilities and the whole network was recorded in the period from 1945 to 1990. Electricity consumption in BiH had a significant growth in the period between 1970 to 1990, when due to the war there is a significant destruction to the economy, and the entire power system. It was not until 2010, that the consumption in BiH reached the levels from 1990 (Figure 1), and the period from 1995 to 2005 was a period of intense reconstruction of the power system.

Today, in BiH, there are three power companies (Public Enterprise Elektroprivreda Bosnia and Herzegovina in Sarajevo (EP BiH), Elektroprivreda of HZHB Mostar (EP HZHB), Elektroprivreda of The Republika Srpska (ERS)) and the utility of Brcko charge electricity distribution in the District. Together, they supply more than 1,450,000 customers in BiH [21] with electricity.

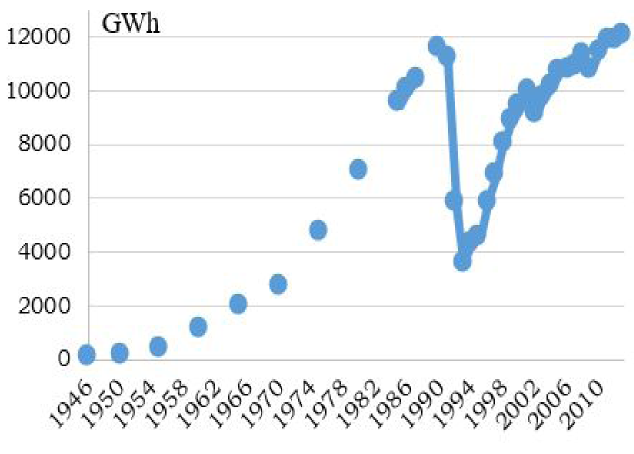

Figure 1: Electricity consumption for BiH in period 1946.-2013. [22], [23]

2. THE DATA - AN ACTIVE AND REACTIVE POWER CONSUMPTION

Total electricity consumption in 2011 in BiH was approximately 12,500 GWh, of which 4,700 GWh supplied to customers of PE EP BiH (included and customers at 110 kV) [21]. Specific maximum load of BiH system in 2011 was measured on December 31 and amounted to 2,150 MW, and the minimum system load was 872 MW, measured on July 22. [23]. Total electricity consumption in Sarajevo in 2011 was around 1,270 GWh, while other distributions of PE Elektroprivreda BiH had a consumption of 2,600 GWh. Customers at 110 kV delivered about 417 GWh [22]. Daily values of active and reactive power consumption of the city of Sarajevo and other distributions and EP BiH in 2011 are plotted in Figure 2. Also, in Figure 2 the average daily value of temperature is plotted. Active and reactive power consumption from Figure 2 represents the sum of power consumption from over 50 transformer substations of 110/x kV. Data are taken from the current measuring system at a 15-minute reading intervals in this energy inputs and energy required to cover electricity losses in the distribution network, which is for Sarajevo around 8% and for other distributions around 9%. Consumption of active energy in Sarajevo, as well as for other distributions, is higher in the winter months (January, February, November and December) than the other months (Figure 2).

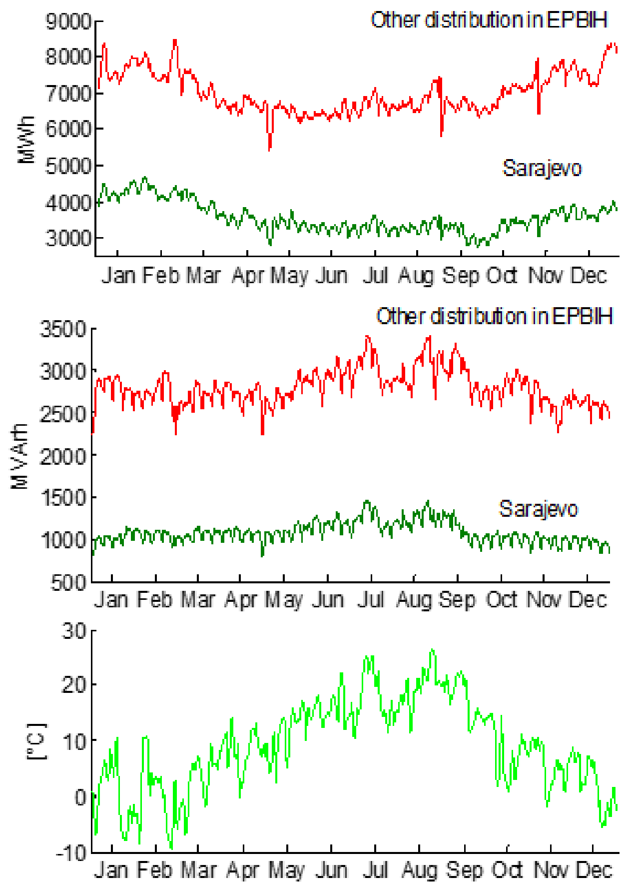

Figure 2: Daily values of active and reactive power consumption and air temperature of the Sarajevo city and other distributions in EP BiH in 2011

On the other hand, the consumption of reactive power is higher in the summer months as a result of the high temperatures in this period of the year (Figure 2). Time series in Figure 2 include 365 samples.

3. HILBERT-HUANG TRANSFORMATION METHOD

The Hilbert-Huang transformation consists of two parts. The first part, where the signal is first disassembled on the IMF function by the process of empirical mode decomposition (EMD) of the signal, and then on each of these IMF functions Hilbert transformation is performed. This method applies to nonlinear and non-stationary signals and its results are suitable for time, frequency and energy representation. The method was tested and verified as valid. In all previous applications, the Huang-Hilbert method provided results that were much sharper than those of any other method with the presentation of results in time-frequency-energy. The first step of this transformation, as already mentioned, is the EMD of the signal. Unlike other methods used, this method is intuitive, direct and adaptive with a posteriori-defined foundation. It is based on the assumption that any signal consists of various intrinsic mode functions (IMF). Every IMF, either linear or non-linear, represents simple oscillations, which have the same number of extremes and null points.

For real signals study, the HHT method has a very good performance, because it does not require advance knowledge on whether it is a linear or stationary signal (which is usually unknown). Next, HHT method does not need the information about the appearance of integral functions signal, so EMD algorithm adapts to local conditions and changes inside the observed signal [24].

4. APPLIED METHODOLOGY

In this section of the paper, the applied methodology for determination of the influence of ambient temperature on the consumption of electricity is explained. Special attention is put on techniques for time-frequency analysis of time series such as the Hilbert-Huang Transform (HHT), providing observations of temperature influence on consumption of electricity over time and for varying periods of time/frequency. In methodological terms, the EMD procedure is applied on the time series presented in Figure 2. As a result of the EMD approach, several IMFs are obtained and between every IMFs correlations were calculated. Applying the EMD approach, time series were decomposed into several Intrinsic Mode Functions (IMFs) and after that, correlations were applied to determine relationships between IMFs.

Calculating the correlations between the individual IMFs, one can identify the periods when the time series have the strongest relationship, providing additional and useful information about the impact of temperature variations on active and reactive power consumption at different periods over the observed time horizon. Based on [13-15], the EMD algorithm and IMFs extracting from original time series noted as $x(t)$ can be briefly explained in a several steps.

Each IMF must satisfy the following two conditions [13-15]:

a) In the analysed time series, the number of zero-crossing points and the number of extrema minima and maxima) should be equal or differ only by one.
b) The mean value of the envelope (obtained by the local maxima and the local minima) at any point is equal to zero.

The steps are:

(i) Detecting all local extremas for time series from Figure 2.

(ii) Connecting all minima and maxima and generating its upper and lower envelopes using a cubic spline line ($e_{up}(t)$ and $e_{low}(t)$, respectively);

(iii) Calculate the mean value of the $e_{up}(t)$ and $e_{low}(t)$:

$$m_1(t) = \left(e_{up}(t) + e_{low}(t)\right)/2 \tag{1}$$

and extract the $h_1(t)$:

$$h_1(t) = x(t) - m_1(t) \tag{2}$$

In case that h_1 satisfies the criteria for the IMF function as expressed $c=h_{1k}$.

(iv) In case that $h_1(t)$ does not meet the criteria for the existence of IMF, the previous procedure is repeated and determined $h_{11}(t)$ as a new signal: $h_{11}(t)=x(t)-m_{11}(t)$, while $m_{11}(t)$ is mean value of the upper and lower envelope of the signal $h_1(t)$.

(v) Procedure is repeated k times to obtain n IMFs and residual, then the new signal is as follow:

$$x(t) = \sum_{i=1}^{n} c_i(t) + r_n(t) \tag{3}$$

where $c_i(t)$ is ith IMF, and $r_n(t)$ is final residual.

(vi) The operation ends when the residue contains no more than two extremum.

Finally, correlations are calculated between IMFs, where correlation coefficients are in the range from -1 to 1. Overall, in the literature, it is possible to find a different scale for correlation describing the mutual relations between the two variables, and in this paper the following divisions are implied: the value of correlation coefficient from +0.70 to +1 or from -0.70 to -1 - very strong relationship; +0.40 to +0.69 or -0.40 to -0.69 - strong relationship; +0.30 to +0.39 or -0.30 to -0.39 - moderate relationship; 0 to +0.29 or 0 to -0.29 weak or negligible relationship.

Flow chart of applied methodology is given in Figure 3.

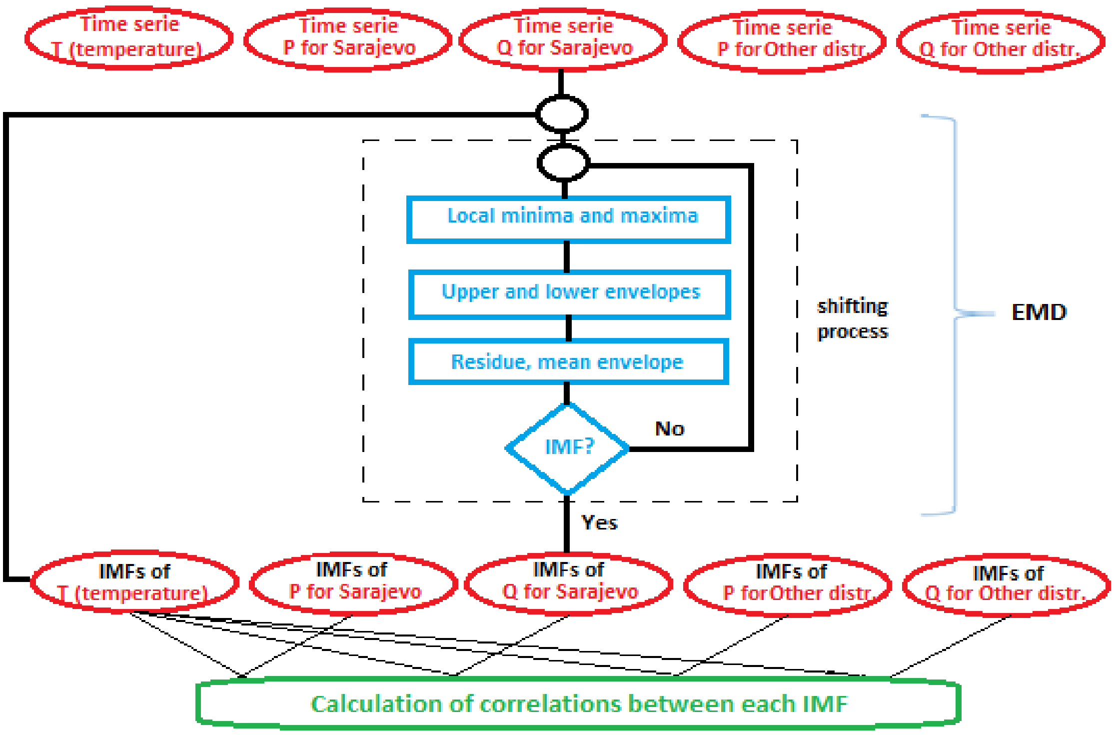

Figure 3: Flow chart of applied methodology

Figure 3 shows that decomposing process of EMD algorithm is applied on valid input data, time series of temperature, active and reactive power consumption for Sarajevo and active and reactive power consumption of other distributions.

This method is based on producing smooth envelopes defined by local maxima and minima of a sequence and subsequent subtraction of the mean of these envelopes from the input time series $x(t)$. Local extrema are then connected by cubic spline lines to produce the upper $e_{up}(t)$ and the lower envelopes $e_{low}(t)$. The mean $m_1(t)$ is calculated based on the two envelopes and, as such, it is further subtracted from the input time series. The $h_1(t)$ difference between the data and the mean and check $h_1(t)$ against the definition of IMF and the stoppage criterion is then extracted to determine if it is an IMF. If $h_1(t)$ does not meet the criteria for the existence of IMF to obtain the final IMF, new maxima and minima shall again be identified and all of the above steps repeated. This repeated process is called sifting. The sifting process is repeated until a certain given stoppage criterion is met. If the sifting process is successfully completed, we will get the first IMF. The next IMF $h_{11}(t)$ can be obtained by subtracting the previously extracted IMF $h_1(t)$ from the original signal and repeating the above described procedure once again. This continues until all IMFs are extracted and residual $r_n(t)$. The sifting process usually stops when the residue, for example, contains no more than two extrema.

After the EMD method is performed on input signal IMFs of temperature, active and reactive power consumption for Sarajevo and active and reactive power consumption of other distributions are obtained. Correlation coefficient is calculated between IMFs of temperature and IMFs of active power consumption for Sarajevo, IMFs of temperature and IMFs of active power consumption for other distributions, then between IMFs of temperature and IMFs of reactive power consumption for Sarajevo and between IMFs of temperature and IMFs of reactive power consumption for other distributions. Values of correlation coefficients identify the periods when the time series have the strongest relationship, providing additional and useful information about the impact of temperature variations on active and reactive power consumption at different periods over the observed time horizon.

5. THE ANALYSIS OF RESULTS

Based on the approach proposed in the previous chapter, several IMFs and their residuals are obtained from the time series (plotted in Figure 2). Seven IMFs and the residual (Figure 4) are obtained using EMD procedure for time series of active power consumption for Sarajevo (Figure 2), while for the other 4 time series provided 6 IMFs and residuals.

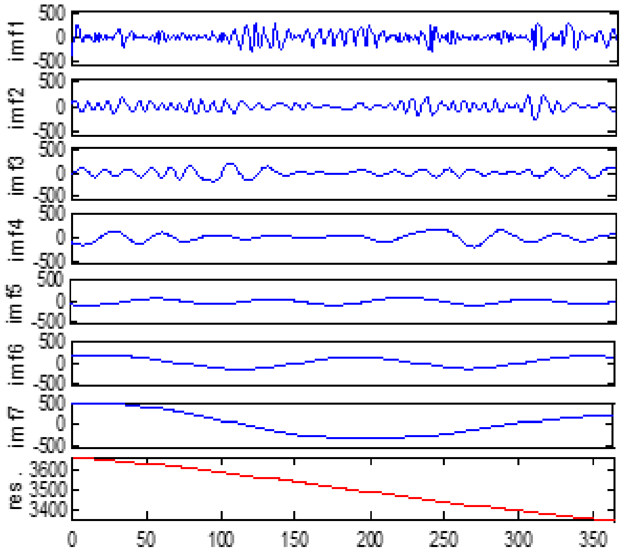

Figure 4: IMF components of active power consumption time series for Sarajevo in EPBiH.

Figure 5 represents IMF components of active power consumption time series for other distributions in EPBiH from Figure 2.

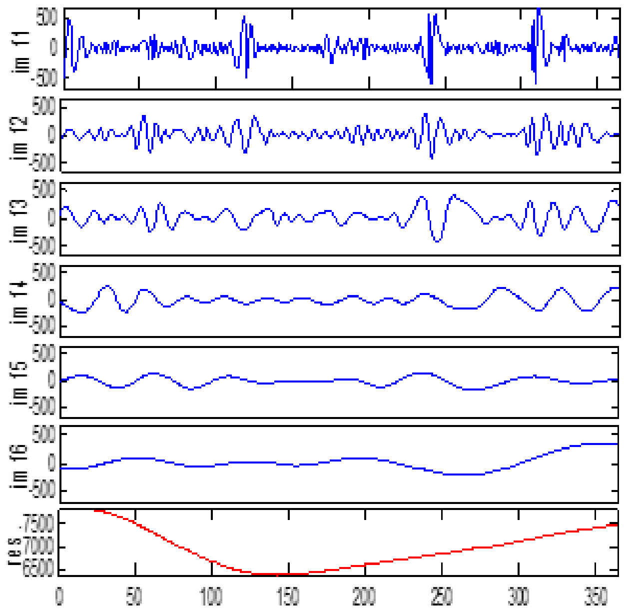

Figure 5: IMF components of active power consumption time series for other distributions in EPBiH.

The different amplitudes for all IMFs (Figure 4 and Figure 5) points out to the different variations of active power consumption during the course of the year in different frequencies/periods. From the first IMFs (Figure 4 and Figure 5) it is evident that these variations reach their peak in the winter period. Also larger amplitudes of variations are identified from IMF2 (Figure 4 and Figure 5) with the highest amplitude of variations identified during the spring, autumn and winter seasons. Fourth IMFs (Figure 4 and Figure 5) represent low frequencies oscillations of time series with negligible amplitude variations during summer season. The last IMFs (residue) (Figure 4 and Figure 5), representing the trend of the time series, have the highest amplitude.

On Figure 6 are plotted IMFs obtained from air temperature time series for 2011.

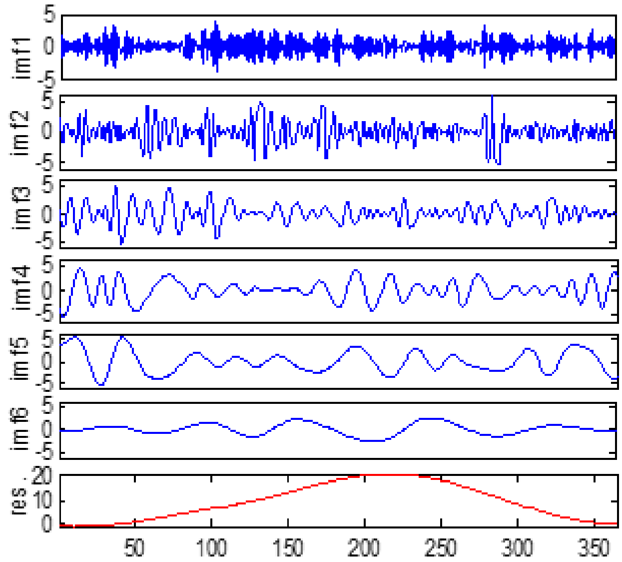

Figure 6: IMFs obtained from air temperature time series for 2011

From the obtained IMFs, we can draw some very interesting conclusions about the behaviour of active and reactive power consumption over time and for different periods in correlation with air temperature, where the first IMFs present higher frequencies. Due to the large number of figures, IMFs obtained from the reactive power consumption time series for Sarajevo and for other distributions are not presented separately. The last IMFs in Figures 4, 5 and 6 represent the trend of the time series of active power consumption for Sarajevo, other distributions in EPBiH and air temperature respectively.

Results of correlation between the basic time series and between IMFs are plotted in Table I. A very strong negative relationship (-0.71) is identified between the basic time series of active power consumption of the city of Sarajevo and the temperature, while the time series of active power consumption of other distributions and temperature present a strong negative relationship (-0.665). Strong positive relationships (+0.678 and +0.674, respectively) are identified for basic time series of reactive energy consumption of Sarajevo and other distributions with temperature. Very strong negative relationships between IMFs obtained from the time series of consumption of active energy and temperature are identified for the last IMFs or residues (Table I), which essentially describe the trends and illustrate changes in consumption and temperatures in the seasons (summer -winter).

On the other hand the same can be concluded for the consumption of reactive power of Sarajevo and for other distributions, where the values of correlation coefficients are very high and positive (Table I). In other words, the seasonal changes in temperature (summer - winter) directly result in an increase or decrease in the consumption of reactive power. Furthermore, strong negative relationship between IMFs 4 are identified between the time series of active energy consumption of Sarajevo and temperatures, along with moderate positive relationship between the IMF 4 and the IMF 5 (Table I).

Table I: Correlation coefficients between time series of active and reactive power consumption and temperature and between IMFs

	Sarajevo (MWh)	IMF1	IMF2	IMF3	IMF4	IMF5	IMF6	IMF7	IMF8
Temperature (°C)	-0.71	0.004	-0.074	-0.083	0.084	0.099	0.099	-0.294	-0.826
IMF1	-0.001	-0.02	0.03	0.00	-0.05	0.00	0.01	-0.01	0.04
IMF2	-0.077	-0.05	-0.20	-0.15	-0.01	0.01	-0.03	0.02	-0.04
IMF3	-0.060	0.02	-0.07	-0.03	0.00	0.00	-0.03	-0.03	-0.08
IMF4	0.043	0.03	0.04	-0.04	-0.42	-0.24	0.13	0.13	0.11
IMF5	0.064	0.02	0.01	-0.06	0.35	-0.03	0.05	-0.03	0.00
IMF6	-0.777	0.00	-0.04	-0.03	0.19	0.19	-0.37	-0.95	-0.27
IMF7	-0.525	0.01	-0.03	0.03	0.13	0.05	-0.04	-0.45	-1.00
	Other distributions (MWh)	IMF1	IMF2	IMF3	IMF4	IMF5	IMF6	IMF7	
Temperature (°C)	-0.665	-0.002	-0.049	0.055	-0.153	-0.036	-0.377	-0.687	
IMF1	-0.014	0.05	0.01	0.01	-0.08	0.00	0.03	-0.03	
IMF2	-0.070	-0.09	-0.16	-0.09	0.03	-0.03	0.03	0.01	
IMF3	-0.014	0.02	-0.05	0.01	-0.01	0.01	0.05	-0.03	
IMF4	-0.031	-0.05	-0.03	0.04	-0.56	0.01	-0.03	0.13	
IMF5	0.009	0.03	-0.02	-0.04	0.06	0.24	0.07	-0.06	
IMF6	-0.718	0.01	0.00	0.07	0.01	-0.07	-0.46	-0.79	
IMF7	0.000	0.04	-0.02	0.06	0.08	-0.07	0.27	-0.12	
	Sarajevo (MVArh)	IMF1	IMF2	IMF3	IMF4	IMF5	IMF6	IMF7	
Temperature (°C)	0.678	0.104	0.002	0.182	0.176	0.111	0.07	0.79	
IMF1	0.108	0.09	0.14	0.04	0.00	0.02	0.01	0.01	
IMF2	-0.065	-0.01	-0.08	0.09	0.01	0.00	-0.05	-0.06	
IMF3	0.110	0.03	0.02	0.42	0.05	-0.01	0.03	-0.03	
IMF4	0.012	0.00	0.02	0.05	0.09	0.08	-0.03	-0.06	
IMF5	0.282	-0.02	-0.04	0.08	0.60	0.55	0.15	0.00	
IMF6	0.678	0.09	-0.02	0.04	0.07	0.02	0.06	0.93	
IMF7	-0.022	-0.01	0.00	0.00	0.02	-0.11	0.14	-0.06	
	Other distributions (MVArh)	IMF1	IMF2	IMF3	IMF4	IMF5	IMF6	IMF7	
Temperature (°C)	0.674	0.059	0.047	0.038	0.11	0.17	0.529	0.809	
IMF1	0.098	0.14	0.17	0.00	-0.02	0.03	-0.02	0.00	
IMF2	-0.050	0.00	-0.06	0.05	0.01	0.00	-0.07	-0.01	
IMF3	0.137	0.01	0.01	0.38	0.07	0.02	-0.04	0.04	
IMF4	0.154	-0.01	0.01	0.01	0.53	0.09	-0.01	-0.17	
IMF5	0.233	0.00	0.04	-0.03	0.09	0.66	-0.06	0.04	
IMF6	0.624	0.03	0.01	-0.06	-0.08	0.06	0.64	0.94	
IMF7	0.067	0.00	0.01	0.01	0.06	-0.12	-0.04	0.36	

Strong negative relationship is also identified between the IMF 4 of active power consumption of other distribution and temperature. These IMFs are presented in Figure 4 and Figure 5. It is clear from Figure 4 that there are change periods of two months with much larger amplitudes in the months of January, May, October, November and December. The variation of consumption of the active power for the Sarajevo and the other distributions (which are in the range of ± 200 MWh) indicate strong negative relationship (Figure 7). In other words, a decrease in temperature causes an increase in the consumption of active energy and vice versa (Figure 7). On the other side it can be concluded from Figure 8 that changes for periods longer than 2 months in Sarajevo, increase in temperature results in an increase in the consumption of active energy. The most significant co-movements of these IMFs are identified for the summer months, July, August and September (Figure 8).

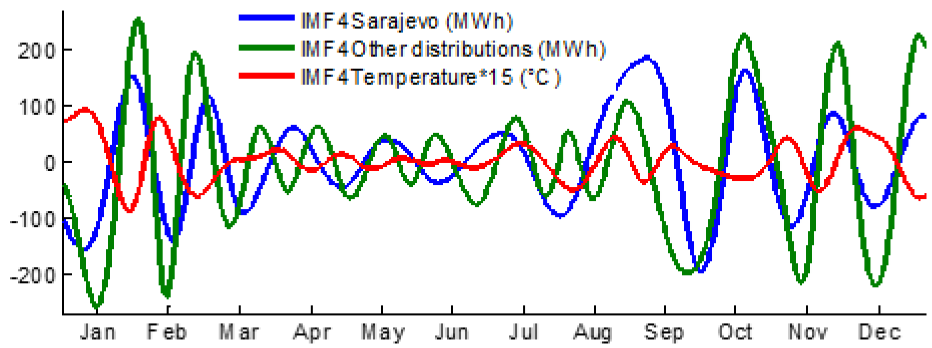

Figure 7: IMFs 4 of active power consumption for Sarajevo, other distributions and temperature with strong negative relationships

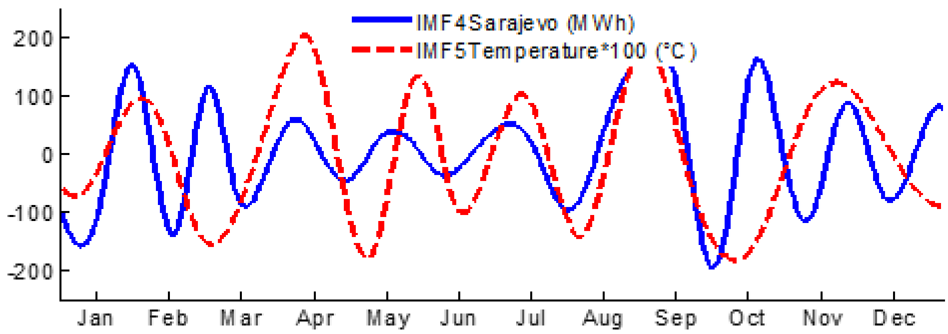

Figure 8: IMF 4 of active power consumption for Sarajevo and IMF 5 of temperature with moderate positive relationship

Moderate positive relationships are identified for IMFs 3 of reactive energy consumption for Sarajevo and for other distributions. These IMFs are plotted in Figure 9. It is clear from Figure 9 that the temperature increases in this period result in increase of consumption of reactive power for Sarajevo and also for other distributions, which is especially evident in the summer months with significantly greater amplitudes (June, July, August and September). Also, in characteristic of IMFs obtained from reactive power consumption and the temperature with the strong positive relationships are marked out in Figure 10 and Figure 11. These variations reflect the changes in the period of about 2 months and it is clear from Figure 10 and Figure 11 that an increase in temperature results in an increase

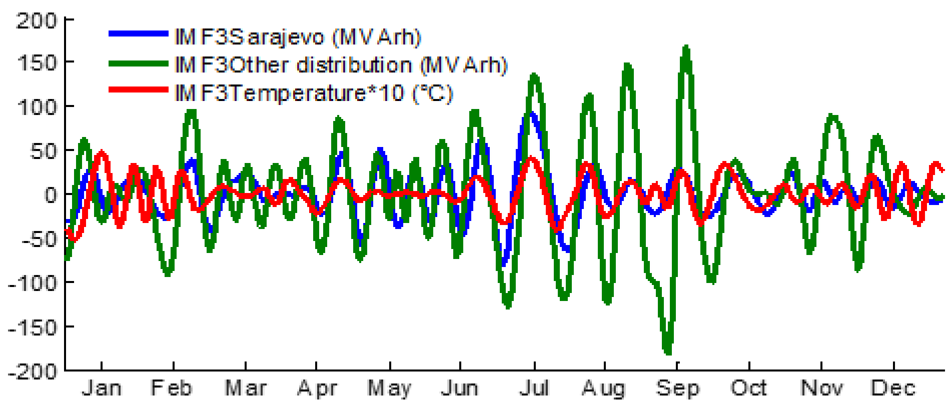

Figure 9: IMFs 3 of reactive power consumption for Sarajevo, other distributions and temperature with moderate positive relationships

in the consumption of reactive power for the city Sarajevo and for other distributions and PE BiH. Overall, from the analysis presented in this chapter, it can be concluded that Sarajevo as the capital city of BiH, the biggest administrative and economic centre in BiH, does not have different features in a sense of the influence of temperature on the consumption of active and reactive power compared to other parts of BiH.

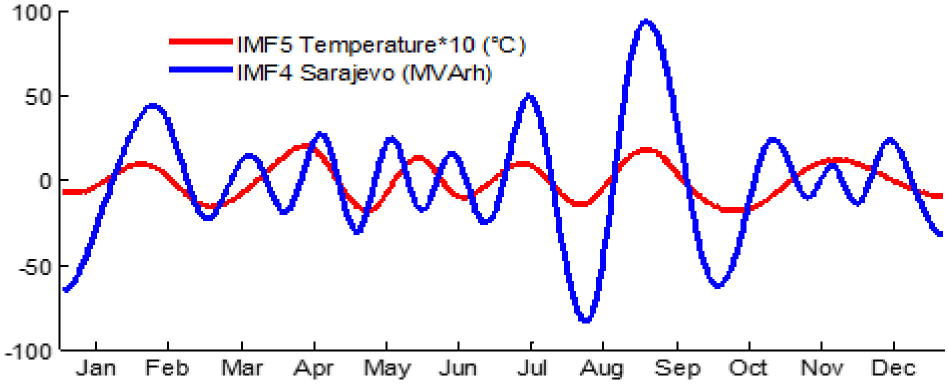

Figure 10: IMF 4 of reactive power consumption for Sarajevo and IMF 5 of temperature with strong positive relationship

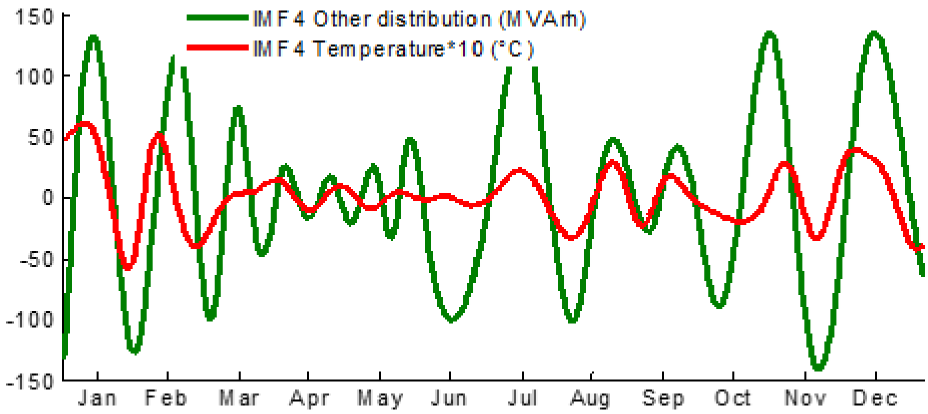

Figure 11: IMF 4 of reactive power consumption for other distributions and IMF 4 of temperature with strong positive relationship

CONCLUSION

The effect of temperature on consumption of active and reactive power was analysed in this paper through application of the Huang's EMD and correlations between IMFs. The focus of this paper was emphasized through two parts: (i) application of the EMD process to the time series of consumption of active and reactive energy and temperature change provides for singling out the IMFs, which identify specific changes for different periods. Correlations between IMFs identify periods and significance of relations between temperature and consumption of active and reactive energies; (ii) a specific focus is on the influence of temperature on the consumption of active and reactive power in the city of Sarajevo, and the results are compared with consumption in other parts of the same public utility.

The combination of EMD process and the correlation between IMFs in the analysed example identifies characteristic periods when the temperature has a significant impact on the consumption of electricity. Weak or negligible relationships are identified in the first IMFs suggesting that the temperature changes over short periods do not have significant impact on energy consumption. On the other side of the analysed time series, there are interesting changes in periods of about 2 months for both active and reactive energy. Also, very strong relationships are identified for seasonal changes. Overall, the results of the analysis lead to conclusion that an increase in temperature results in a decrease in the consumption of active energy (out of phase co-movement) and increase of consumption of reactive power (in phase co-movement) for this area. Also, Sarajevo in terms of the influence of temperature on power consumption does not have significantly different characteristics compared with other parts of BiH.

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