A Study of Air Temperature Impact on the Power System Load

Metodija Atanasovski, Mitko Kostov, Blagoja Arapinoski, Igor Andreevski
Faculty of Technical Sciences-Bitola
St. Kliment Ohridski University, Republic of Macedonia
{metodija.atanasovski@tfb.uklo.edu.mk}

ABSTRACT: *We in this paper, studied the relation between the power system load and air temperature. The power system load obtained during the period 2014 and 2015 are used as input data for the study period. We found that the data available addressed the day period and variation in the hourly basis is not possible. We use air temperature as independent variable and the linear and nonlinear correlation coefficients are measured between minimum, mean and maximum load as dependent variables. We found during the testing that the there is a strong relation between air temperature and power system. We did a work of linear and nonlinear regression in order to find a relation between three typical loads and relevant air temperature.*

Keywords: Power System Load, Air temperature, Regression

Received: 23 February 2021, Revised 10 June 2021, Accepted 18 June 2021

DOI: 10.6025/pca/2021/10/2/48-54

1. Introduction

Power system load curve shows load variation as a function of time and its analysis is very important for determination of a set of factors that have impact on consumption of electricity in power system. Those factors are: increase and structure of gross domestic product, demographic changes, people's standard, energy efficiency, climate changes, people's mobility, habits, customs etc. Air temperature is one of the factors which can have significant impact on electricity consumption and power system load. This fact is evident in power system of Republic of Macedonia due to high variations of consumption and load in year seasons.

Correlation between power system load and air temperature is deeply investigated in the literature. There are number of techniques which have been used for load forecast, such as: single or multiple linear or nonlinear regressions, stochastic time series, exponential smoothing, state space and Kalman filter, knowledge based approach, neural networks, wavelet transformations, semi parametric additive model, etc.

The goal of this paper is to investigate the correlation between power system load and air temperature in Republic of Macedonia. Power system load hourly values (8760 per year) for years 2014 and 2015 are used as input data. In absence of hourly values for air temperature in Republic of Macedonia, data from Internet is used for minimum, average and maximum air temperature in city of Skopje for each day of years 2014 and 2015 [1]. Complete analysis in the paper is performed with EXCEL and SPSS (Statistical Package for the Social Sciences) software package specialized for statistical analysis (demo version for educational and research purposes) [2].

The paper is consisted of five sections. Input data is elaborated in section II and basic statistical analysis is done. Coefficients of correlation for linear and nonlinear dependence between minimum, average and maximum load as dependent variables and minimum, average and maximum air temperatures as independent variables are calculated in section III. Results show very strong dependence between power system load and air temperature. Section IV is the main contribution of this paper. Namely, procedure of linear and nonlinear regression is performed for determining the functions of variation between three typical loads and average air temperature. Several conclusions and further work possibilities about this matter are presented in section 5.

2. Input Data and Basic Statistical Analysis

Power system load hourly values (8760 per year) for year 2014 and 2015 are used as input data (Fig. 1) [3]. As it was emphasized in the introduction, in absence of hourly values for air temperature in Republic of Macedonia, data from Internet is used for minimum, average and maximum air temperature in city of Skopje for each day of year 2014 and 2015. According to this 3x730 temperatures are available (3 for each day in 2014 and 2015) and in order to have equal number of data for both stochastic variables (load and air temperature), minimum, average and maximum load is determined for each day of year 2014 and 2015. This pproach gives opportunity to investigate the correlation between 3 daily loads in power system maximum (Pmax), average (Pavg) (average of 24 hourly load values for each day), minimum (Pmin) and respective temperatures for each day of year 2014 and 2015. Figure 2 depicts one daily diagram of power system of Republic of Macedonia for the day 08.01.2014. Three typical points are marked on the diagram and they are used in the analysis from each daily diagram. Average load is average of all 24 hourly loads in one daily diagram.

Maximum load of 1507 MW was obtained in year 2014. It is registered on December 31 at 6.00 PM. Minimum temperature of - 10^0C in year 2014 was also registered on December 31. Maximum load of 1439 MW was obtained in year 2015 on January 8 at 11.00 PM. Minimum daily temperature of -16^0C in year 2015 is registered on January 2. Minimum daily temperature on January 8 was -14^0C.

Maximum summer load of 1017 MW in year 2014 was registered on July 27 at 10.00 PM (maximum daily temperature on that day was 31 ^{0}C, what is 5^0C less than maximum daily temperature of 36 ^{0}C registered on August 13 in year 2014).

Maximum summer load of 976 MW in year 2015 was registered on July 21 at 2.00 PM (maximum daily temperature on that day was 37^0C, what is 1^0C less than maximum daily temperature of 38^0C registered on July 29 in year 2015).

Minimum system load of 555 MW is registered on September 14 at 5 AM in year 2014 (temperature at that day varied in range from 15^0C to 22^0C). Minimum system load of 530 MW is registered on June 2 at 6.00 AM in year 2015 (temperature at that day varied in range from 12 ^{0}C to 29^0C).

Minimum - maximum load ratio in power system of Republic of Macedonia in both years was 0.3683. This ratio implies high variation between hourly loads in the power system on year basis.

Hourly loads at days when maximum load (31. 12. 2014; 8. 1. 2015) and minimum load (14. 9. 2014; 2. 6. 2015) is registered in the system, have shown daily variation of several hundred of MWs (from 370 MW to 470 MW). Basic statistical parameters for minimum (Pmin), average (Pavg) and maximum (Pmax) load of power system and minimum (Tmin), average (Tavg) and maximum (Tmax) air temperature are given in Table I for year 2014 and 2015.

Maximum daily load during years 2014 and 2015 varied in range of 684 MW (823-1507) MW, with mean value of 1073±164.6 MW. Average daily load in year 2014 and 2015 varied in range of 593 MW (696-1289) MW, with mean value of 896.6±141.2 MW. Minimum daily load during year 2014 and 2015 varied in range of 513 MW (530-1043) MW with mean value of 698.2±118 MW.

Statistical parameter	Pmax (MW)	Pavg (MW)	Pmin (MW)	Tmax (^{0}C)	Tavg (^{0}C)	Tmin (^{0}C)
Mean	1073	896,9	698,2	18,9	13	7
Stdev	164,6	141,2	118	9,96	8,3	7,3
Median	1039,5	850	658,5	19	13.5	7
Range	684	593	513	42	39	38
Minimum	823	696	530	-4	-9	-16
Maximum	1507	1289	1043	38	30	22

Table 1. Basic Statistical Analysis of Input Data for Daily Loads and Air Temperatures for Year 2014 and 2015

Maximum daily temperature during year 2014 and 2015 aried in range of 42 ^{0}C (-4 - 38) ^{0}C, with mean value of 18.9±9.96 ^{0}C. Average daily temperature during year 2014 and 2015 varied in range of 39 ^{0}C (-9 - 30) ^{0}C, with mean value of 13±8.28 ^{0}C. Minimum daily temperature during year 2014 and 2015 varied in range of 38 0C (-16 - 22) 0C, with mean value of 7±7.3 ^{0}C.

3. Coefficients of Correlation

Coefficients of correlation (Pierson coefficients) are given in Table 2. These coefficients are measure for linear relation between daily maximum, average, minimum power system load and daily maximum, average and minimum air temperature. Coefficients of correlation can have values in range from -1 to 1 (negative to positive linear relation). Empiric rules for correlation coefficients are [4]: Correlation coefficient less or equal of 0.3 shows not significant linear relation; Correlation coefficient between 0.5 and 0.7 shows linear correlation with practical importance; Correlation coefficient between 0.7 and 0.9 shows close linear correlation; Correlation coefficient greater than 0.9 shows very close linear correlation.

According to results presented in Table 2, the dependence between daily power system typical loads and air temperature can be defined as close to very close linear relation. Correlation coefficients have values in range from -0.8 to -0.9 what implies close to very close negative linear relation between all combinations of typical daily loads and air temperatures.

P/T	Tmax	Tavg	Tmin
Pmax	-0.873	-0.909	-0.875
Pavg	-0.868	-0.895	-0.850
Pmin	-0.839	-0.864	-0.825

Table 2. Pierson Coefficients Of Correlation

Index of nonlinear correlation is used as a measure for nonlinear relation between two variables (has values between 0 and 1). Table 3 summarizes indexes of nonlinear correlation for the case when relation between power system load and air temperature is treated as quadratic and as cubic function. Indexes of correlation are in range from 0.85 to 0.95.These values have shown very close nonlinear correlation between all combinations of daily loads and air temperatures.

Coefficients are calculated with EXCEL and SPSS.

Quadratic			
P/T	**Tmax**	**Tavg**	**Tmin**
Pmax	0.892	0.923	0.876
Pavg	0.901	0.921	0.856
Pmin	0.851	0.889	0.848
Cubic			
P/T	**Tmax**	**Tavg**	**Tmin**
Pmax	0.902	0.939	0.887
Pavg	0.917	0.943	0.869
Pmin	0.860	0.903	0.858

Table 3. Indexes for Nonlinear Correlation for Quadratic and Cubic Function

4. Regression Analysis

Linear and nonlinear regression analysis is performed using SPSS software package. The goal of this analysis is to estimate dependence curve of the three typical loads (Pmin, Pavg, Pmax) from independent variables presented with three typical temperatures (“min, “avg, “max). The curve estimation of linear, quadratic and cubic function of typical daily loads from average temperature is only presented in the paper. Figure 4 depicts estimated linear, quadratic and cubic functions between minimum (Pmin), average (Pavg) and maximum (Pmax) daily load and average daily temperature (Tavg).

Table 4 summarizes function equations presenting polynomial coefficients and determination coefficients (R2). Determination coefficient shows how many percent of dependent variable are predictable with independent variable using regression analysis (it is in range from 0 to 1) [4].

For example determination coefficient of maximum daily load due to average daily temperature is in range from 88.2% to 82.7%, depending on used nonlinear and linear regression. Determination coefficient of average daily load due to average daily temperature is between 89% and 80.1%, depending on used nonlinear and linear regression.

Minimum daily load due to average daily temperature is predictable 81.5% with estimated cubic function, 79% with quadratic function and 74.6% with linear estimated function.

Regression analysis shows high prediction degree of daily typical loads from air temperature. Cubic estimated function of daily loads from average daily temperature shows highest degree of prediction.

5. Conclusion

According to authors information the paper is the first one which has investigated correlation between power system load and air temperature in Republic of Macedonia. In absence of hourly values for air temperature in Republic of Macedonia, correlation between daily minimum, average and maximum load and air temperature for all days in year 2014 and 2015 is investigated.

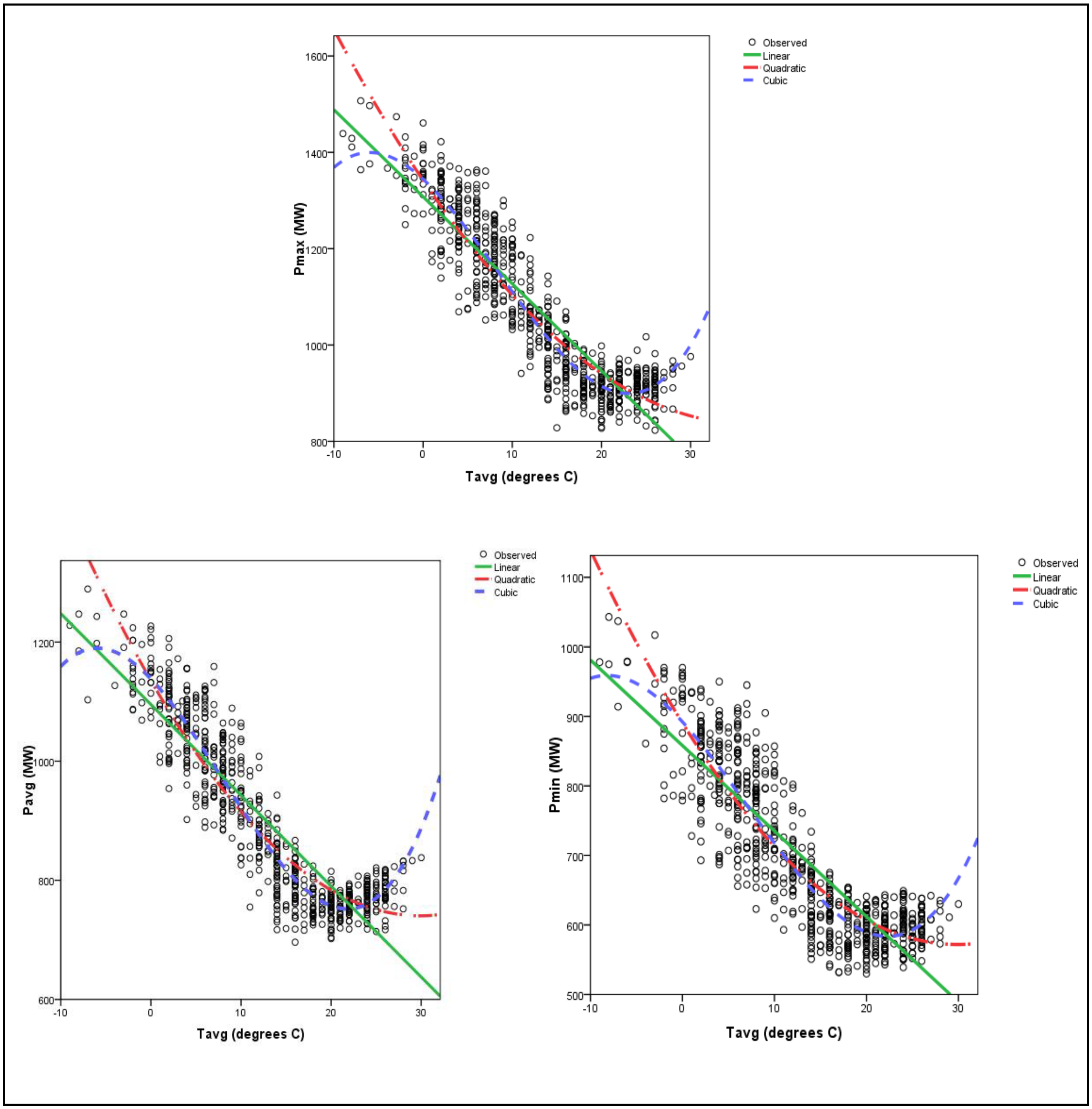

Figure 3. Estimated linear quadratic and cubic functions of maximum (Pmax), average (Pavg) and minimum (Pmin) daily load from average daily temperature (Tavg) Sozopol

On the basis of statistical analysis it can be noticed that there is close time matching in appearance of power system maximum load and minimum air temperature. The same time matching is noticed between power system summer maximum load and registered maximum temperature in analyzed years.

The usual approach in investigation of load correlation with air temperature is to establish the multi regression model, because the load depends on temperature, wind, season, hour, day in the week and other factors (holidays for instance). However, in

Function	R2	Constant	b1*T	b2*T2	b3*T3
		Pmax=F(Tavg)			
Linear	0.827	1307.618	-18.073		
Quadratic	0.852	1341.734	-17.54	0.375	
Cubic	0.882	1344.212	-16.986	-1.045	0.041
		Pavg=F(Tavg)			
Linear	0.801	1095.251	-15.262		
Quadratic	0.849	1135.576	-26.452	0.443	
Cubic	0.890	1138.047	-15.921	-0.974	0.041
		Pmin=F(Tavg)			
Linear	0.746	858.073	-12.304		
Quadratic	0.790	890.537	-21.313	0.356	
Cubic	0.815	892.136	-14.504	-0.56	0.026

Table 4. Estimated Functions Coefficients and Determination Indexes

absence of relevant and available data about temperature, wind, solar radiation and other factors, the analysis in the paper was performed on the basis of single linear and nonlinear regression approach. Temperature is only used as climate parameter that has significant impact on load variation in power system of Republic of Macedonia.

Also it has to be emphasized that in Macedonia electricity is widely used for heating of residential and commercial buildings and houses. This fact explains the very close linear and nonlinear relation between power system load and air temperature in Macedonian power system.

Calculation of linear and nonlinear correlation coefficients has shown close to very close linear and nonlinear relation between all combinations of daily typical loads and air temperatures.

Regression analysis and obtained estimated functions have shown high degree of predictability of power system minimum, average and maximum load and average air temperature. High values of determination coefficients between 70% and 89% are the best prove for this fact. Cubic estimated function has shown highest degree of predictability.

Authors' opinion is that achievement of higher exactness in regression analysis for obtaining estimated functions between power system load and air temperature can be done with use of hourly values for air temperature for total territory of Republic of Macedonia. In that case presented analysis can be done for months of the year, using hourly allocation of load to substations and air temperature in the town where substation is located. However, having on mind consumers load temperature inertia, the hourly temperature may not be a good solution as a predictor variable, and the usage of minimum, average and maximum temperature is possible to be a better option. These facts have to be verified by intensive analysis using multiple years in the past.

Also sophisticated mathematical algorithms can be implemented for correlation investigation, such as wavelet transformations which are adequate for correlation analysis in time-frequency space.

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