

AN APPLICATION OF DENOISING BASED ON WAVELET TRANSFORM FOR TEMPERATURE SIGNALS OF THE ALTERNATORS IN A PASSENGER COACH

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ABSTRACT

This paper deals with a passenger coach alternators. In this study, temperature variations, which are depended on load conditions of alternators in a passenger coach, have been investigated using the wavelet transform based denoising and statistical methods. To obtain real road data from the bus alternators, the bus was driven 456 km on the roadway in Turkey. During the collecting alternators data, interior lighting lamps on/off locations, air conditioner operation position, bus headlights situations and other electrical/electronic devices on/off positions have been considered. MATLAB program was used for the signal analysis of the alternators.

Keywords: *Wavelet transformation, alternator, passenger coach, temperature signal analysis.*

1. INTRODUCTION

The vehicle electric power system, which consists of two major components: a alternator and a battery, which have to provide numerous electrical and electronic systems with enough electrical energy. A detailed understand ding of the characteristics of the electric power system, electrical load demands, and the driving environment such as road, season, and vehicle weight is required when the capacities of the alternator and the battery are to be determined for a vehicle. The customer requirements and expectations are the driving force behind the increase in electrical power demand, and must be the strongest influence in determining future strategy. In order for the entire system to be reliable and trouble free in any operating it is necessary that the electric power output from a battery and an alternator should be matched with the remaining electrical loads as optimally as possible. An improper decision of the capacity of electric power system, such as the alternator and battery, will cause serious problems in real driving conditions. For example, if the

alternator capacity is designed too small, cold cranking problems and roadside breakdowns may occur. On the contrary, over-

design of alternator capacity will degrade fuel economy due to vehicle weight and loss of propulsion power, and it will increase the cost of the vehicles [1].

An alternator is an electromechanical device that converts rotational motion into a DC voltage output. Alternators are widely used as generators in passenger cars. They have to generate sufficient energy for all electric consumers and to keep the battery charge in balance. A controller provides constant voltage at variable speed and load. The output performance is highly depending on the alternator speed. In order to reduce emissions and fuel consumption, to increase comfort and security and to improve drive dynamics more electric and electronic consumers, which require higher output performance, are installed [2].

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The technology used within starter motors and alternators has become more advanced in response to the installation of an increasing number of electrical components in vehicles. Alternator converts rotational motion into DC voltage output. In general, the alternators are composed of an AC generator, rectifier, and voltage regulator. The regulator, which is connected the terminal of the AC generator, regulates the terminal voltage of the alternator at the constant value. Alternators are coupled with the engine by a pulley. Owing to the constant pulley ratio between the alternator and the engine, the alternator operates at greatly different speeds. So, the generated energy of the alternator heavily depends on the engine rpm [3,4]. This connection schema is shown by Fig. 1.

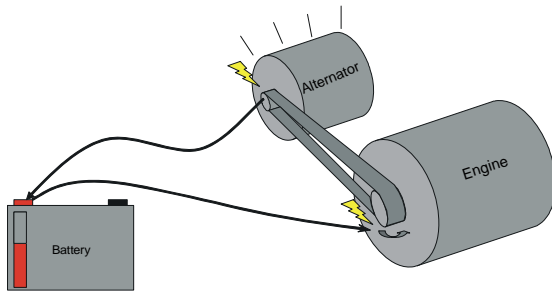


Figure 1. General electrical connection schema for the vehicles

In order to supply the electric power, vehicles need an efficient and highly reliable source of energy of their own which must always be available at any time. When the engine is running, the alternator becomes the on-board electricity generating plant, whereas, either when the engine stopped or when the alternator's output power is insufficient, the battery is the vehicles energy storage [1]. The connection schema is shown in Fig. 2.

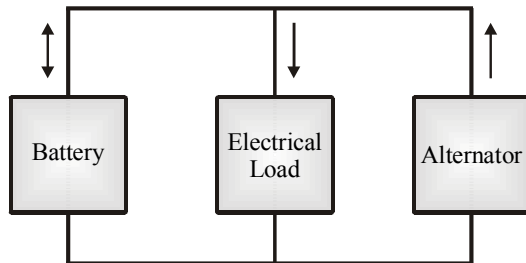


Figure 2. Diagram of supply/demand of vehicle electric power

In Fig. 3, the maximum available output current of the alternator at a variety of different speeds is shown by the characteristic curve.

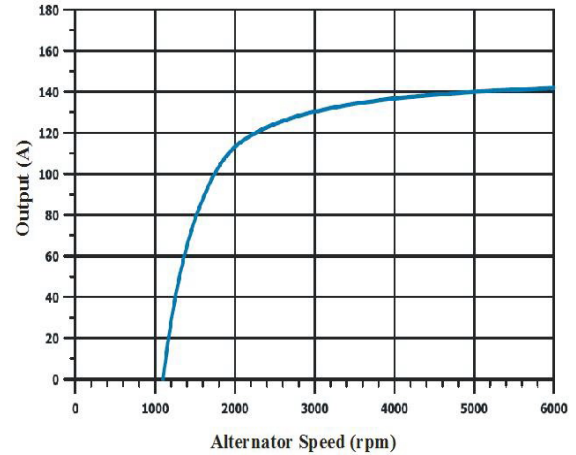


Figure 3. Characteristic curve of the alternator

Temperature measurement is one of the significant functions in the field of measurement, which has been most frequently conducted in meteorological observation, environmental research, laboratories, and various other production processes. Temperature measurement is fundamental and important in terms of manufacturing products in a specified condition and maintaining consistent quality in the industry [5].

In this study, temperature variations, which are depended on load conditions of alternators in a passenger coach, have been investigated using the wavelet transform based denoising and statistical methods. For this aim, calculating coherence function defined between two temperature variations related to the alternator, hence most correlated peak appeared at around the coherence level of 0.7, can be estimated to describe the equal load sharing of the alternators in time domain.

2. MATHEMATICAL METHODS

2.1 Statistical Method

Several statistical parameters, calculated in the time domain, are generally used to define average properties of machinery data. The two basic parameters are the mean value, μ and the standard deviation, σ . For a given data set $\{x_i\}$ these are defined as follows:

$$\mu = \frac{1}{N} \sum_{i=1}^N x_i \tag{1}$$

where N is the number of the data points.

For the Gaussian (normal) probability distribution, two parameters that reflect the departure from the normal distribution are skewness (c) and kurtosis (k). These are calculated as follows,

$$c = \frac{\left[\frac{1}{N} \sum_{i=1}^N (x_i - \mu)^3 \right]}{\sigma^3} \quad (2)$$

$$k = \frac{\left[\frac{1}{N} \sum_{i=1}^N (x_i - \mu)^4 \right]}{\sigma^4} \quad (3)$$

For a perfect normal distribution, c is equal to zero. A negative value is due to skewness towards lower values while a positive value indicates non-symmetry towards higher values. For small data sets, one often gets values that differ from zero. The kurtosis or flatness k , is very close to unity for a normal distribution. These statistical parameters may be used to perform a quick check of the changes in the statistical behaviour of a signal [6,7].

2.2 Spectral Methods

A common approach for extracting the information about the frequency features of a random signal is to transform the signal to the frequency domain by computing the discrete Fourier transform. For a block of data of length N samples the transform at frequency $m\Delta f$ is given by

$$X(m\Delta f) = \sum_{k=0}^{N-1} x(k\Delta t) \exp[-j2\pi km / N] \quad (4)$$

Where Δf is the frequency resolution and Δt is the data-sampling interval. The auto-power spectral density (APSD) of $x(t)$ is estimated as

$$S_{xx}(f) = \frac{1}{N} |X(m\Delta f)|^2, f = m\Delta f \quad (5)$$

The cross power spectral density (CPSD) between $x(t)$ and $y(t)$ is similarly estimated. The statistical accuracy of the estimate in Equation (2) increases as the number of data points or the number of blocks of data increases.

The cause and effect relationship between two signals or the commonality between them is generally estimated using the coherence function. The coherence function is given by

$$\gamma_{xy}(f) = \frac{|S_{xy}(f)|}{\sqrt{S_{xx}(f)S_{yy}(f)}}, 0 < \gamma_{xy} < 1 \quad (6)$$

Where S_{xx} and S_{yy} are the APSD's of $x(t)$ and $y(t)$, respectively, and S_{xy} is the CPSD between $x(t)$ and $y(t)$. A value of coherence close to unity indicates highly linear and close relationship between the two signals [8-10].

2.3 Wavelet Transform

The use of wavelet transform is particularly appropriate since it gives information about the signal both in frequency and time domains. Let $f(x)$ be the signal, the continuous wavelet transform of $f(x)$ is then defined as

$$W_f(a, b) = \int_{-\infty}^{+\infty} f(x)\psi_{a,b}(x)dx, \quad (7)$$

Where;

$$\psi_{a,b}(x) = \frac{1}{\sqrt{|a|}} \psi\left(\frac{x-b}{a}\right), a, b \in R, a \neq 0 \quad (8)$$

And it provides the admissibility condition as below

$$C_\psi = \int_0^{+\infty} \frac{|\psi(\omega)|^2}{\omega} d\omega < \infty \quad (9)$$

And for this reason, it is

$$\int_{-\infty}^{+\infty} \psi(x)dx = 0 \quad (10)$$

Here $\psi(\omega)$ stands for the Fourier transform of $\psi(x)$. The admissibility condition implies that the Fourier transform of $\psi(x)$ vanishes at the zero frequency. Therefore ψ is called as a wave or the mother wavelet and it have two characteristic parameters, namely, dilation (a) and translation (b), which vary continuously. The translation parameter, “ b ”, controls the position of the wavelet in time. A “narrow” wavelet can access high-frequency information, while a more dilated wavelet can access low-frequency information. This means

that the parameter “a” varies with different frequency. The parameters “a” and “b” take discrete values, $a = a_0^j$, $b = nb_0 a_0^j$, where $n, j \in \mathbb{Z}$, $a_0 > 1$, and $b_0 > 0$. The discrete wavelet transformation (DWT) is defined as [11-14];

$$DWT [j, k] = \frac{1}{\sqrt{a_0^j}} \sum_n f[n] \psi \left[\frac{k - na_0^j}{a_0^j} \right] \quad (11)$$

3. MEASUREMENT SYSTEM and DATA ACQUISITION

This study based on temperature variation measurement of alternators in bus. During the data acquisition, environmental temperature measurements and battery temperature were also collected by sampling frequency at 1 Hz, while the bus is driven total 456 km on the roadway under the specific load conditions as given in Table 1. Hence, the data were saved using a hybrid temperature recorder via K type thermocouples. Fig. 4 shows the replacements of the alternators in the bus.

Table 1. Bus Load Conditions

Mechanical Load	Electrical Loads	Battery
Weight 18 T	Air conditioner, low beam lamp, position lamps, fog lamps, internal lamps.	Good (Acid ratio:1.30 g/ml)

Also, other electrical specifications of the bus are summarized:

- 24 V - central electrical systems
- 28 V - 140 A for each alternator
- 24 V - 5.4 kW starter motor
- 200 Ah for each battery.

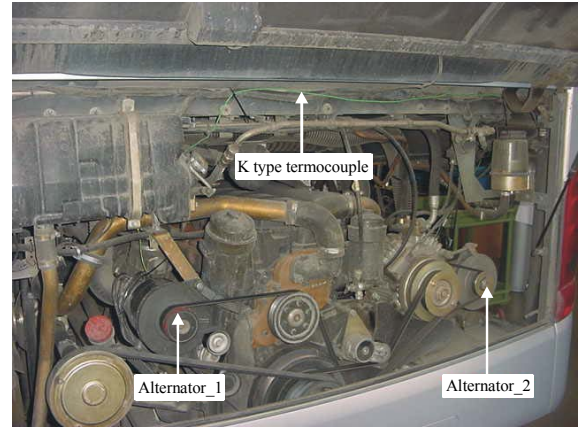


Figure 4. Picture for locations of alternators in the bus

4. APPLICATION

Data sets used in this application are shown by the following figures. Here Fig. 5 and Fig. 6 are related to temperature variations of the alternators, namely alternator #1 and #2 respectively.

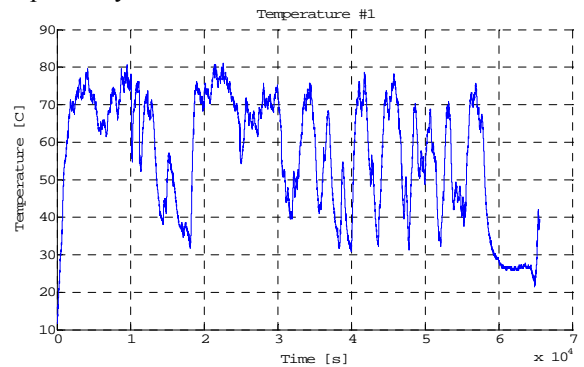


Figure 5. Temperature variation for the alternator #1

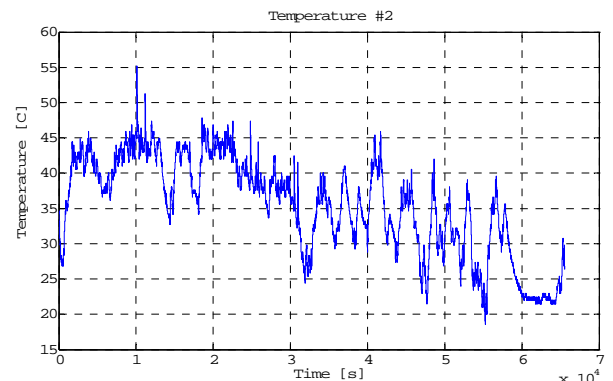


Figure 6. Temperature variation for the alternator #2

As seen in Figure 5 and 6, their mean values are at around the 55°C and 35°C respectively. However both of them reflect noise parts. These noise parts can be interpreted as useful

information in terms of the feature extraction. For this reason, as a first step, it can be considered their probability density functions. Section 4.1 contains the statistical interpretations of the data.

4.1 Statistical Interpretation

The probability density functions of the temperature signals for alternator #1 and #2 are given as below figures,

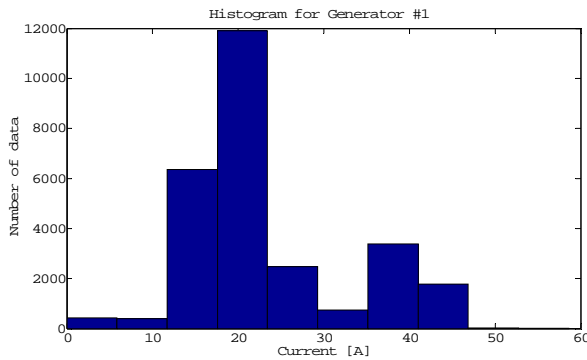


Figure 7. Histogram for the temperature variation for alternator #1

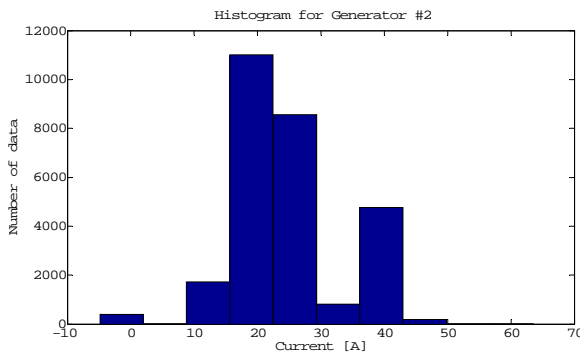
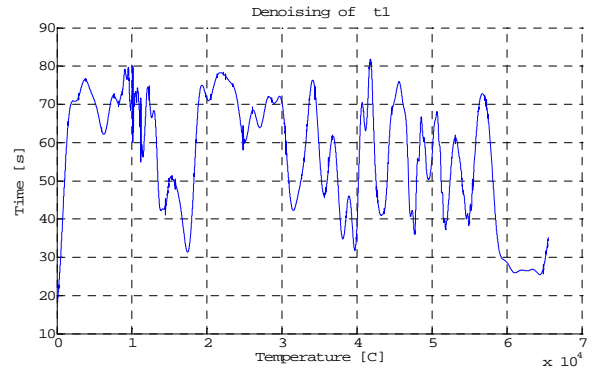


Figure 8. Histogram for the temperature variation for alternator #2

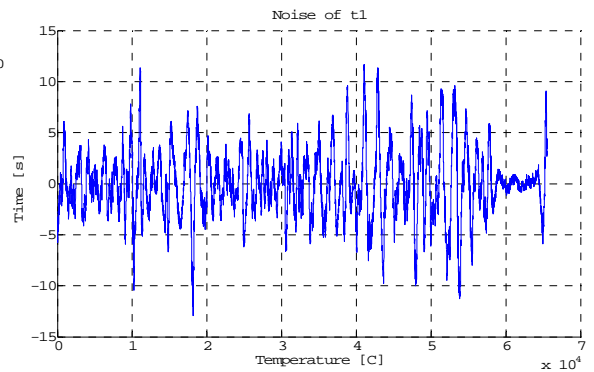
From the above figures, it is seen that they have the non-Gaussian probability distributions. Considering these histograms it can be said that the statistical distributions show asymmetric distributions at around their mean values. In order to get the more statistical information by these data, denoising application is realized considering the wavelet transform.

4.2. Denoising by Wavelet Transform for temperature data of the alternator 1 and 2

As a denoising method, threshold level can be determined as *universal threshold* which is defined by $\sqrt{2\log(.)}$. Using wavelet transform for the denoising, main waveforms of the temperature variations can be separated from their noise parts. These separations can be shown by Fig. 9 and 10.

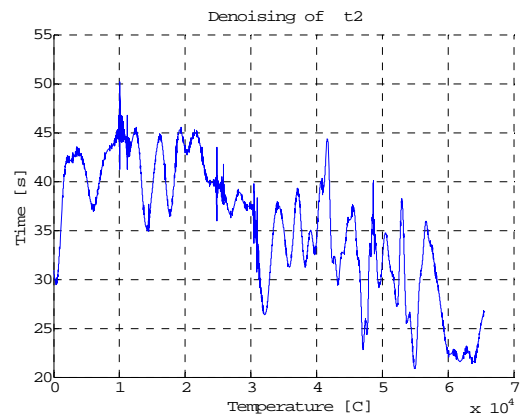


(a)

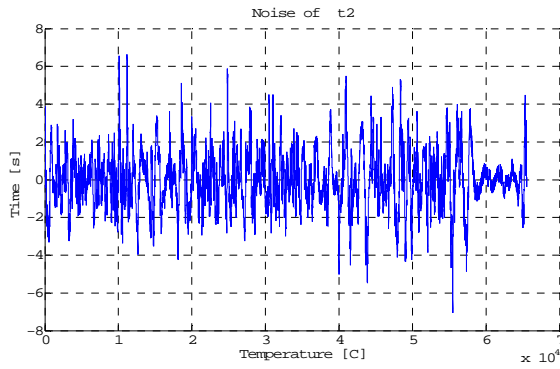


(b)

Figure 9. Mean value (a) and noise part (b) of the temp. measurement for alternator #1



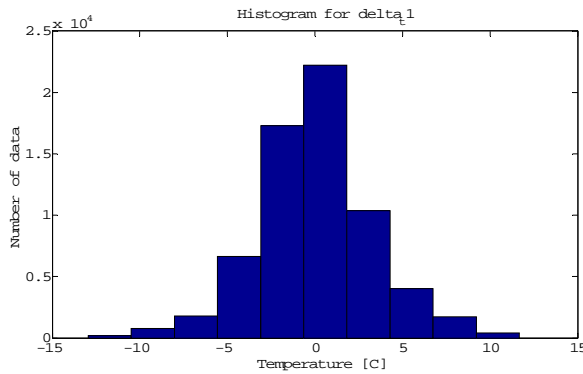
(a)



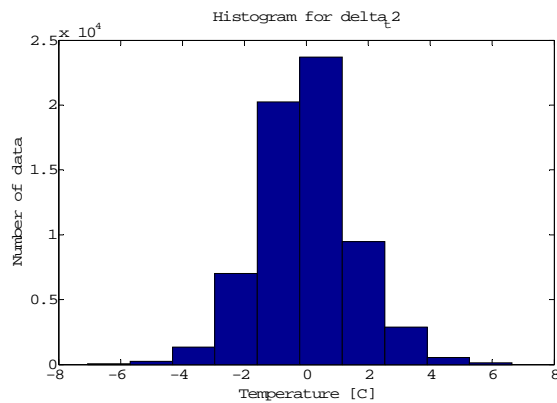
(b)

Figure 10. Mean value (a) and noise part (b) of the temp. measurement for alternator #2

Using the noise parts of the separated signals, their probability distribution functions can be shown by Fig. 11.



(a)



(b)

Figure 11. Noise distributions: a) alternator #1 b) alternator #2

4.3. Coherence Calculations

After the denoising procedure, coherence function is calculated between the denoised temperature signals of the alternator 1 and 2. Hence some peaks are indicated at the special frequency values to describe the physical behaviour of the alternators like load sharing of the alternators. This correlation, which is defined between the denoised signals in the frequency domain, is given by Fig. 12.

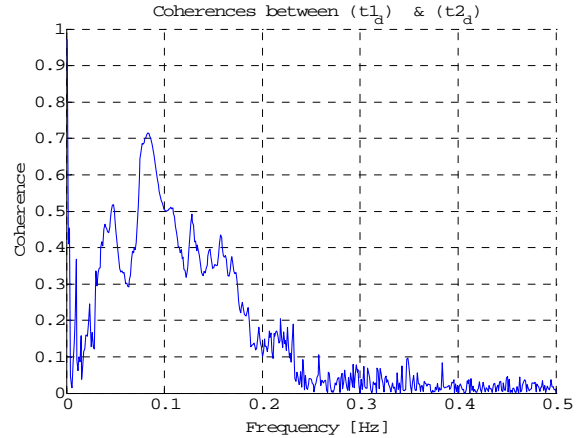


Figure 12. Coherence between the denoised temperature signals for alternator 1 and 2.

According to the Fig. 12, if it is determined correlation levels at 0.4 of the coherence axis, most correlated peaks are seen between 0.05 and 0.15 Hz. This situation denotes that the side-band effects appear at around a central frequency value of 0.1 Hz with the frequency interval 0.05 Hz. As a result, the biggest peak is observed at 0.1 Hz with the coherence value of 0.7. This feature can be interpreted as having an equal-load sharing of the alternators in consideration of time.

5. CONCLUSIONS and DISCUSSIONS

In this research, temperature measurements related to two alternators of a coach passenger are considered. Firstly, their noise parts are removed using the denoising method based upon the wavelet technique. Then, statistical properties are examined for these noise parts of the temperature signals. In this sense their statistical parameters are given by the following table.

Table 2. The Alternators Statistical Parameters

Statistical Parameters for noise parts of alternator 1 and 2	Mean	Standard deviation	Skewness	Kurtosis
Alternator-1	0.0021	3.3132	0.1209	4.0091
Alternator-2	-0.0022	1.5018	0.1088	3.9790

According to the results of the Table 2, the statistical parameters of the noise parts for the temperature variations are close to each other. Also, they have similar non-Gaussian characteristics by their similar statistical parameters. Under these statistical determinations, their histograms show almost symmetrical distribution as seen in Fig. 11 (a) and (b). After the denoising, in terms of the denoised signals, their coherence variations are considered and then, highly correlated peaks are determined for the denoised temperature signals at the 0.1 ± 0.05 Hz. Hence most correlated peak, which reveals at the coherence level of 0.7, can be used to describe the equal load sharing of the alternators in time domain.

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