Feature Extraction of Conducted Electromagnetic Noise Based on KPCA and Its Application in Main Network

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Abstract. In this paper, a new method for conducting EMI noise source identification is proposed. Firstly, the basic principle of the classical KPCA method is analyzed. Then, the core principal component (KPCA) data is selected, and the input space is transformed into the feature space through nonlinear transformation. This method analyzes the relationship between the time and frequency of the electromagnetic interference signal from the frequency domain, so as to extract the time-domain characteristics of the noise signal, and finally diagnose the characteristics that cause the conduction of excessive signal, and according to the characteristics of the noise signal targeted suppression experiment.

1. Introduction
With the rapid development and wide application of power electronics technology, the problem of conducted electromagnetic interference (EMI) to the main network is becoming more and more serious. Due to the complexity and instability of conducting EMI noise of current electronic equipment, it is difficult to suppress conducting EMI noise [1]. If the noise characteristics can be suppressed, a better suppression effect can often be achieved. Against excessive noise, for noise source identification and separation but because there are multiple electronic devices of electronic equipment, and the vast majority of electronic devices of signal waveform with its unique characteristics, so before noise suppression measures, how to cause noise para-normal electronics noise effectively and rapidly the separation becomes very meaningful. In view of this, this paper proposes a KPCA algorithm for conducting EMI noise source identification method. The KPCA algorithm is applied to electronic equipment to extract and separate the conducted electromagnetic interference noise in the equipment and find the electronic devices that cause excessive noise [2]. In addition, effective means are adopted to suppress the noise, and finally the internal impedance of the noise source is determined. According to the impedance value, EMI filters are designed to suppress the noise of electronic devices that cause excessive noise.

2. Feature extraction and application of conducting EMI noise based on KPCA algorithm

2.1. Basic theory of KPCA
The basic idea of Kernel Principal Component Analysis (KPCA) can be summarized as follows: Firstly, input space is transformed into feature space through nonlinear mapping (inner product operation), and then Principal element Analysis is performed on the mapping data of feature space.
(inner product Kernel function) [3]. Transform the input space $\mathbb{R}^m$ into the feature space $F$ for nonlinear mapping. It is unnecessary to pay attention to the specific form of the nonlinear mapping. Point $X_i^\ast (=1,2,\cdots,n)$ in the input space is transformed into the corresponding map $\varphi(x_i^\ast)$. Normalized by $\varphi(x_i)$, the covariance of the first mapping function is expressed as:

$$C = \frac{1}{n} \sum_{i=1}^{n} \varphi(x_i) \varphi^T(x_i)$$

(1)

The eigenvector analysis of matrix $C$ is carried out to obtain:

$$\mu \nu = Cv$$

(2)

Where $\mu$ corresponds to the eigenvalue of $C$, and $\nu$ is the eigenvector of the corresponding eigenvalue.

Take the inner product of each mapping function in the sample and equation (2), and get:

$$\mu \left( \varphi(x_k) \cdot \nu \right) = \varphi(x_k) \cdot Cv$$

(3)

When $\mu = 0$, all the feature vectors $\nu$ of equation (3) are satisfied, then the feature vectors generated by $\varphi(x_1), \varphi(x_2), \cdots, \varphi(x_n)$ are mapped into space, so there is a corresponding set of coefficients $\{\alpha_i\}$, and the feature vector $\nu$ can be expressed as a linear combination of $\varphi(x_i)$ as:

$$\nu = \sum_{i=1}^{n} \alpha_i \varphi(x_i)$$

(4)

Define $n \times n$ dimensional matrix $K$ where:

$$K_{ij} = \left[ \varphi(x_j) \cdot \varphi(x_i) \right]$$

(5)

Since $K$ is a symmetric matrix, equation (5) can be expressed as:

$$\mu K \alpha = \frac{1}{n} KK \alpha$$

(6)

Obviously, it satisfies equation (6):

$$n \mu \alpha = K \alpha$$

(7)

From equation (7), different eigenvalues and corresponding eigenvectors are obtained. $K$ Alternative kernel function to determine.

For $K$ similar diagonalization, let $\mu_1 \geq \mu_2 \geq \cdots \mu_n$ be a different eigenvalue of $K$, $\alpha_1, \alpha_2, \cdots, \alpha_m$ is the corresponding eigenvector, let $\mu_p$ be the minimum non-zero value of the eigenvalue of $K$, which can be obtained by using formula (6), (7).

$$\alpha_k^T \cdot \alpha_k = \frac{1}{\mu_k} k=1,2,\ldots,p$$

(8)

By extracting pivot function, the characteristic quantity $\nu$ is projected onto the characteristic space to get:

$$t_k = \sum_{i=1}^{n} \alpha_{ki} K(x_i,x)$$

(9)

Where $\varphi(x)$ the input vector of the original is feature space and $\alpha_{ki}$ is the $i$-th feature vector of the $k$th eigenvalue of the matrix $K$. 
2.2. Theoretical analysis of conducting EMI noise by KPCA algorithm

Kernel principal component analysis is one of the commonly used methods in multivariate statistical analysis. In practical applications, due to frequent data collection and a large number of uncertainty errors, the original feature information is subject to variation, and the linear principal element cannot obtain the feature quantity and corresponding vector, which will weaken the model interpretation ability [4]. In this chapter, we propose an exponential weighting function with adaptive generation of new feature subspace and a few feature attributes to replace the multivariate model, which can well represent the information of variation features [5]. The corresponding multivariate nonlinear statistical model is as follows:

\[
(X^T X)_t = \gamma (X^T X)_{t-1} + x_t^T x_t
\]

Where \( t \) is the sampling instant, \( \gamma \) is the weighting factor, and \( x_t \) is the sample normalized at time \( t \), \( (X^T X)_{t-1} \) is the covariance matrix of the weighting model, and \( (X^T X)_t \) is the covariance matrix of the weighting model.

By optimizing the index, the new feature quantity kernel function is dynamically weighted [6]. The data matrix \( X \) and the new eigenvalues are reconstructed using the nonlinear vector \( x_t \) as follows:

\[
X_t = (x_{t2},...,x_n,x_t)^T
\]

\[
K_t = \gamma K_{t-1} + (1 - \gamma)K_t
\]

It can make the model KPCA have global optimization and reduce the number of iterations, and it has greater advantages in nonlinear analysis and research cycle.

According to the mechanism of conducting EMI noise, the interference in the loop formed by the phase line or the middle line and the ground line of the power supply is common mode interference, and the interference signal in the loop formed by the phase line and the middle line of the power supply is differential mode interference [7].

The conducted EMI noise obtained by the electronic device is expressed as the similarity and difference of the voltage values on the hot and zero lines, namely \( UL=UN \) and \( UL\neq UN \). Since the ratio of the noise voltage to the noise current is equivalent to the internal power network impedance, namely 50Ω, \( IL=IN \) and \( IL\neq IN \) can be used to indicate the current relationship when noise occurs [8]. It is worth noting that both \( IL=IN \) and \( IL\neq IN \), there are always IDM content:

\[
L_{DM} = N_{DM} = I_{CM}
\]

In the formula, IDM is the current flowing from the hot line into the neutral line, that is, the differential mode noise current. When the current is equal to the current on the zero line, the direction is opposite, IDM is zero; and when \( IL\neq IN \), IDM is not zero [9].

Regardless of \( IL=IN \) or \( IL\neq IN \), there is always ICM satisfied:

\[
I_L - I_{DM} = I_N + I_{DM}
\]

\[
\begin{aligned}
I_{CM} &= I_L - I_{DM} \\
I_{CM} &= I_N + I_{DM}
\end{aligned}
\]

Where, \( I_{CM} \) is the balance noise current, that is, after removing the non-balance noise current in the fire line and middle line noise, the remaining part should be equal, so it is called the balance noise current, that is, the common mode noise current [10].

Figure 1 shows the equivalent topology circuit model of common mode conducted EMI noise. The common mode noise source generates voltage UCM. The artificial power network provides a common mode equivalent test impedance of 25Ω. The internal impedance value of the common mode noise source is based on Ohm’s law is further determined.
From the formula and $I_{LN}=I_{DM}$ can be obtained:

$$I_{DM} = \frac{I_L - I_N}{2}$$  \hspace{1cm} (15)$$

Because of the noise voltage and the ratio of the noise current is 50Ω, so by type (15) available:

$$U_{DM} = \frac{U_L - U_N}{2}$$  \hspace{1cm} (16)$$

Figure 2 shows the transmission path and the equivalent circuit model of differential mode conducted EMI noise. The impedance $Z_{DM}$ of the differential mode noise source can be determined according to Ohm’s law.

It can be seen from equation (18) that the pair of signals $i_{o1}(t)$ and $i_{o2}(t)$ measured by the current probe are a linear combination of the source common mode current $i_{CM}(t)$ and the source differential mode current $i_{DM}(t)$, that is, a linear combination of $i'_{CM}(t)$ and $i'_{DM}(t)$. When $i_{CM}(t)$ and $i_{DM}(t)$ act independently, the corresponding $i'_{CM}(t)$ and $i'_{DM}(t)$ should also be independent of each other. Therefore, using the nuclear principal component analysis method, $i'_{CM}(t)$ and $i'_{DM}(t)$ can be obtained first by separating the measured signals $i_{o1}(t)$ and $i_{o2}(t)$, and $i_{CM}(t)$ and $i_{DM}(t)$ can be further obtained by the integral operation [12].

The algorithm flow of KPCA is shown as follows:
3. Research on the identification method of conducted EMI noise source based on KPCA

3.1. EMI noise source identification method

Figure 4 shows the structure diagram of the experimental device for conducting EMI noise source identification method based on core principal component analysis.

Using artificial mains network extraction products tested conductive EMI noise, the noise voltage on the phase and zero line through digital oscilloscope gathering into PC, using Matlab simulation analysis on the kernel principal yuan, it is concluded that under the condition of different noise voltage waveform characteristics, finally will isolate the noise of the signal and equipment of the original noise signal is being measured waveform comparison, qualitative identify noise source original features [13].

The identification method of conducted EMI noise sources based on the kernel principal element algorithm can be divided into three steps as follows:

(1) Use artificial power network to extract conducted EMI noise of the tested product [14];
6

(2) Decompose the noise voltage signal obtained in step (1) according to the kernel principal element algorithm, and obtain the waveform characteristic results of the noise voltage signal, which can be specifically divided into the following steps:

1) The original noise voltage signal obtained in the step (1) is respectively recorded as V1, V2…VM, wherein when the measured device has different working voltage levels and the corresponding M value is selected, and the single phase power supply, and the three-phase power supply, the M is correspondingly different [15];

2) The value of V1, V2, …, VM is measured by a digital oscilloscope, the signal data of the normal sample \( x_i(t) \) is selected, the principal element function is extracted, the eigenvalue and the feature vector are calculated, and the sample data is normalized to construct a data matrix \( x(t) = [x_1(t), …, x_M(t)]^T \).

3) The kernel pivot algorithm was used to analyze the characteristics of the above vector \( x(t) \) in the autoregressive sliding average (ARMA) model [16];

4) After iteratively solving the optimal solution N, it is substituted into the model to obtain a plurality of separated independent signals, that is, the noise voltage signal separated from V1, V2, …, VM, and correspondingly, the noise current signal can also be obtained.

(3) The characteristics of noise voltage signals obtained in step (2) after separation are compared and analysed with the original noise signals in the tested equipment, so as to determine the specific electronic devices that generate noise voltage signals, and finally determine the noise source of conducted electromagnetic interference.

3.2. Verification experiment of identification method of conducted EMI noise source

The experimental schematic diagram and real object diagram are shown in Figure 5. (a) and (b) respectively.

![Verification of experimental schematic diagram of noise source identification method](image)
(b) Physical diagram of verification experiment for noise source identification method

Figure 5. Verification experiment of noise source identification method

Connect the single-phase analogy noise source, LISN, digital oscilloscope, wire, etc. on the test bench as shown in figure 5. In the circuit schematic diagram of the test system shown in Figure 5. (a), V1 is the sinusoidal wave generator, which generates a signal frequency of 200 KHz and a peak-to-peak value of 4V, and its waveform is shown in Figure 6 (a). V2 is a square wave generator, which generates a signal frequency of 200KHz and a peak-to-peak value of 4V, and its waveform is shown in figure 6 (b). By the V1, V2, 50Ωresistance R3, 50Ωresistance of R4 simulated noise source [17]. The RF output port of the LISN is composed of 0.1uf capacitors C1, C2 and 50Ω resistors R1 and R2. The resistors R1 and R2 are the internal impedance of the digital oscilloscope, that is, the voltage across the resistor R1 is the noise voltage extracted on the live line L (the mixed noise of V1 and V2), and its waveform is as shown in Figure 7 (a). The voltage across the resistor R2 is the noise voltage extracted on the line N (the mixed noise of V1 and V2), and its waveform is as shown in Figure 8(b).

(a) The sine wave generated by V1
(b) The square wave generated by V2

Figure 6. Waveform generated by V1 and V2

(a) Signal extracted from live line L
(b) Signal extracted from zero line N

Figure 7. Voltage signal extracted by LISN
For the measured conduction noise voltages of the live line L and the neutral line N, the two sets of mixed signals are first formed into a matrix x of 2*N, and the observed signal x is whitened to obtain a matrix z for independent component analysis for the objective function [18]. Find the optimal solution of the separation matrix W, so that y=Wz has the largest Gaussianity and separate the signal into two independent signals.

The signals separated by KPCA algorithm are compared with the simulated noise sources V1 and V2 [19]. The two separated signals are shown in Figure 8 (a) and (b). Through comparative analysis, the waveform characteristics of the two separated signals are consistent with those generated by V1 and V2.

Finally, the devices causing excessive EMI noise are identified as V1 and V2.

(a) KPCA separated signal 1  
(b) KPCA separated signal 2  
Figure 8. Conducted EMI signal separated by KPCA

4. Summarizes
Aiming at the problem of conductive noise source identification, this paper analyses the basic principle of the classical kernel principal component method, summarizes the specific steps of the algorithm, and proposes a method of conductive electromagnetic interference noise source identification based on the kernel principal component algorithm. The conducted electromagnetic noise on common mode and differential mode is separated experimentally and compared with the original noise to further verify the effectiveness of the conducted noise source identification based on the kernel principal component algorithm.

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