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A New Harmonic Current Forecasting Method for HAPF of Micro-grid

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Abstract

There are a lot of power quality problems such as a large number of harmonic, caused by quickly changing diverse types of loads and power resources in micro-grid. This paper proposed a hybrid active power filter (HAPF) harmonic current prediction method based on the hybrid intelligent prediction model of Empirical Mode Decomposition (EMD) and Intrinsic Mode Regression (SVR). This method Combine the EMD method and SVR module, First, the harmonic current is decomposed into every harmonic current using EMD method; Then using different kernel function in SVR module to predict different times harmonic currents at the next time; Finally, the predicted value of each harmonic weighted summation. Simulation results show that, this method can be well to improve the prediction performance.

Keywords*: EMD, SVR, hybrid intelligent prediction model, micro-grid, HAPF*

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1. Introduction

Micro-grid is a new power system builded on the basis of power electronics technology, due to a large number of power electronic devices and nonlinear loads put into use, piconet harmonic problem is getting worse [1-3]. In many devices to improve power quality, HAPF has the advantages of low cost and high filtering performance.But, HAPF tend to have a more serious delay, delay better solution for this problem is harmonic tracking and forecasting.

Using neural network prediction method, it's advantage is the tracking and detection capability, but it is difficult to achieve the digitized, and the analog circuit itself is relatively difficult [4]. It proposed a modified adaptive harmonic current prediction methods, adaptive algorithm within the interpolation algorithm to achieve a combination of active power filter harmonic current forecast, it with high accuracy and strong adaptive ability to adjust [5]. Reference [6] proposed a prediction control method based on gray theory of active power filter, although it has no delay prediction control, but the calculation process is too complicated, more difficult to achieve. In this paper, due to the micro-grid harmonic current had some feature of randomness, non-stationary and nonlinear, proposed a harmonic current prediction methods based on EMD-SVR theory, and to build a micro-grid harmonic power prediction model based on EMD-SVR theory, where the simulation tests prove that the model is valid.

2. Theoretical Basis

2.1. Empirical Mode Decomposition

EMD can make any signal be decomposed into several Intrinsic Mode Function (IMF) and a remainder [7-8]. The so-called IMF is a function or signal to satisfy the following two conditions: (1) Its extreme points and the number of zero-crossing point should be equal to or up to the Poor 1. (2) The two envelope formed by respectively connected to the local minimum value Means zero at any point. The EMD decomposition flow chart shown in Figure 1.

At this point, remaining signal $r_n(t)$ has little significance for the research or content into a monotonous function can no longer be screened IMF. The signal $x(t)$ has been decomposed into n -IMF $f_i(i=1,2,\cdots n)$ and a remaining signal $r_n(t)$:

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

Formula (1) shows that the EMD decomposition of the signal with the completeness, this is caused by the decomposition process of the decision.

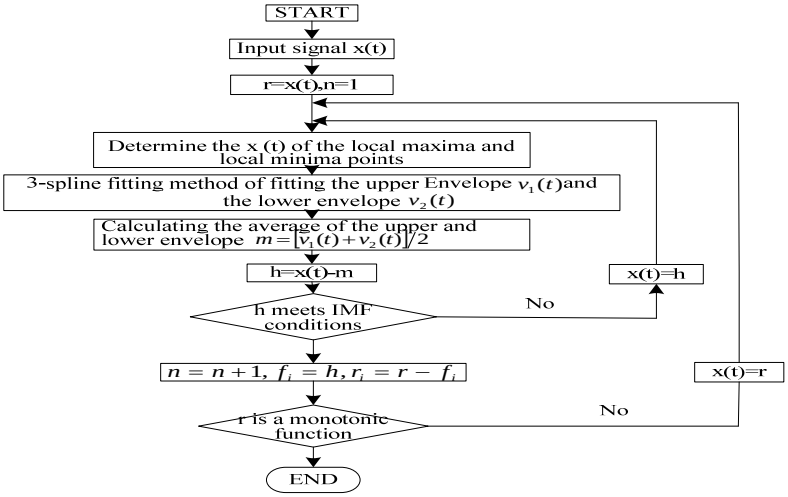


Figure 1. The decomposition Flow Chart of EMD

2.2. Intrinsic Mode Regression

SVR method [9] is based on a given sample data $T=\{(x_i,y_i)|i=1,2,\cdots l\}$, wherein $x_i \in R^n$ is an input variable, $y_i \in R$ is the corresponding output value, l is the number of samples, seek an optimal function $f \in F=\{f \mid f: R^n \to R\}$ to fit the sample data, while ensuring good generalization capability. First with a non-linear mapping $\varphi: R^n \to R^m (m \geq n)$ maked the input space mapped into a high dimensional feature space, Follows a linear function to fit the sample data in the feature space with:

$$y=f(x)=\langle w \cdot \varphi(x) \rangle + b \tag{2}$$

Where, $w, \varphi(x)$ are m-dimensional vectors, $\langle w \cdot \varphi(x) \rangle$ is the inner product of w and $\varphi(x)$, b is the threshold.

SVR using structural risk minimization principle to determine the coefficient w and b, introduction the slack variables ζ and ζ^*, then determine the regression function $f(x)$, the following formula is:

$$\begin{aligned} &\min_{w,b} \ \frac{1}{2}\|w\|^2 + c\sum_{i=1}^{l}(\zeta_i + \zeta_i^*) \\ &y_i\langle w \cdot \varphi(x_i)\rangle - b \leq \varepsilon + \zeta_i, \zeta_i \geq 0 \\ &\langle w \cdot \varphi(x_i)\rangle + b - y_i \leq \varepsilon + \zeta_i^*, \zeta_i^* \geq 0 \end{aligned} \tag{3}$$

The best regression function $f(x)$ will be able to get when the formula (3) get minimum, Wherein c is a normal number. the first make function flat, thus can improve the generalization

ability, the second is to reduce the error, constant c which called the penalty factor can balance two item; $\left|y-\left\langle w\cdot\varphi(x)-b\right\rangle\right|$ is linea ε insensitive loss function. By introducing within the area of the kernel function $k(x_i, y_i)$, and utilize the skills of the Wolfe dual, established the Lagrangian function, finally, forecast function can be get:

$$f(x,\alpha_i,\alpha_i^*)=\sum_{i=1}^{l}(\alpha_i-\alpha_i^*)k(x_i,y_i)+b \quad (4)$$

Where, $k(x_i, y_i)$ is a symmetric function satisfying Mercer condition, it implements the mapping from the low-dimensional space to high-dimensional space, so make the non-linear problem in low-dimensional space into linear problem of high-dimensional space.

3. Harmonic Current Prediction Model Based on EMD-SVR

When using single SVR to predict, a signal of the same frequency using different kernel function of the inner product will have a greater difference between predicted results. Therefore, this paper proposes a EMD-SVR-based harmonic current prediction model to improve the prediction. The prediction model system block diagram shown in Figure 2.

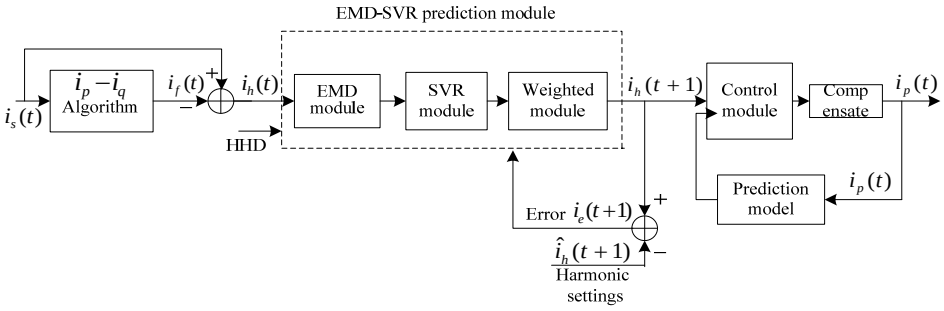


Figure 2. The System Block Diagram of Harmonic Prediction Model

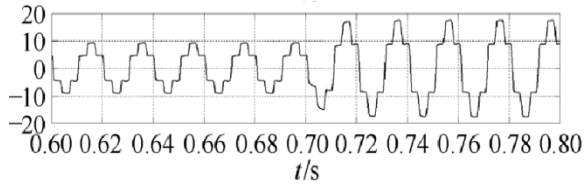
The harmonic detection module using i_p - i_q algorithm, calculated the micro-grid fundamental current at time t, and superimposed with micro-grid original current to get the harmonic current at time t, and fed it into the EMD-SVR prediction module. In this prediction module, the first use of the EMD method to decompose the harmonic current $i_h(t)$ at time t, get each harmonic component $i_{hj}(t)(j=1,2,\cdots n)$, and a remainder $i_r(t)$. Then in the SVR module, depending on the frequency of the different harmonic component, different kernel functions were used to their forecast. Higher frequency harmonic component exponential radial basis kernel function; the low-frequency harmonic components using Gaussian radial basis function; The forecast of remainder using polynomial kernel function. Last, generating n different sub-harmonic prediction component, and a remainder of the predicted amount after SVR module, weighted summation of them, to draw harmonic forecast value $i_h(t+1)$, so the error $i_e(t+1)$ can be calculated by the harmonic setting value $\hat{i}_h(t+1)$, then re-use of the error correcting the predicted value, to get a more accurate harmonic current predicted value, ensure minimum error compensation.

The control module using a control algorithm which combining the adaptive and the interpolated, calculate the pulse width modulated signal at the next time, this is the control function of the main circuit of HAPF. Here the model prediction and feedback correction

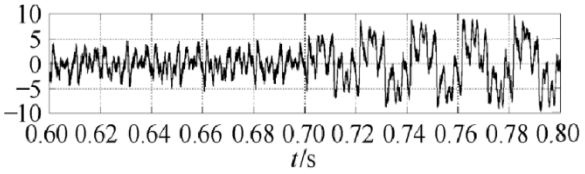
process, make the whole forecast system has the ability of strong anti-interference and overcome instabilities, robustness also can be improved.

4. Simulation and Analysis

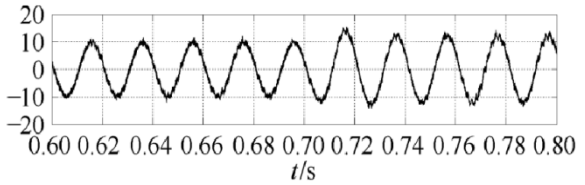
Establish a micro-grid HAPF simulation model in simulation software MATLAB. Micro-grid line voltage $U_m = 380V$, frequency $f = 50Hz$, the linear loads using constant impedance load, nonlinear loads using a three-phase bridge controlled rectifier circuit to simulation, the filter inductor $L = 0.03H$,DC voltage $U_d = 200V$, load resistance $R = 10\Omega$. Now the micro-grid at islanded operation, Considering the effect of harmonic currents in the governance of micro-grid based on the prediction theory HAPF of the EMD-SVR forecasting method.



(a) The Current Before Compensation



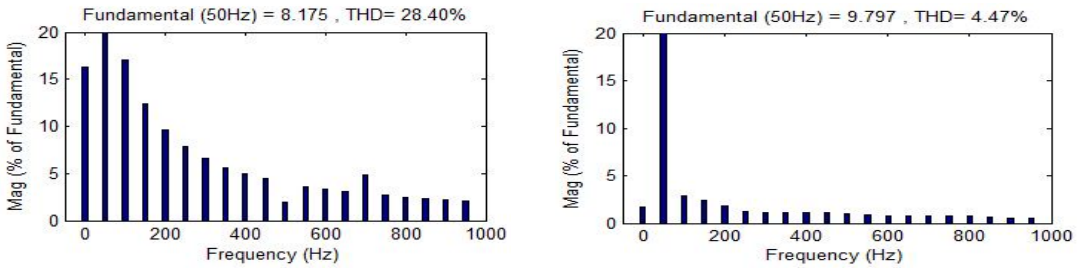
(b) Injection Current



(c) The Current After Compensation

Figure 3. Current Compensation by HAPF of EMD-SVR Prediction the Control

Figure 3(a) is the microgrid bus current graph before HAPF compensation in 0.7s, nonlinear load resistance R changes by 10Ω to 5Ω ; Figure 3(b) is a compensation current injected by the HAPF controled by the EMD-SVR predictive method; Figure 3(c) is a side of the system current figure after compensation.



(a) Before Compensation (b) After Compensation

Figure 4. Current Spectrogram

As can be seen from Figure 4, the microgrid bus current had a high harmonic components before compensation, the total harmonic distortion reach 28.40%. After compensated of HAPF, the total harmonic distortion only be 4.47%, harmonics had significantly reduced. This shows that, EMD-SVR based prediction control theory HAPF can compensate the nonlinear load harmonic current injection system very well.

5. The Experiment and Analysis

In order to verify the predictive control method this paper proposed is correct, test on the HAPF, the topology of HAPF show in Figure 5. Passive filter is mainly composed of 3, 5, 7, 9 times of filter, and the active filter is mainly composed of harmonic detection, prediction, control and compensation circuit, etc.

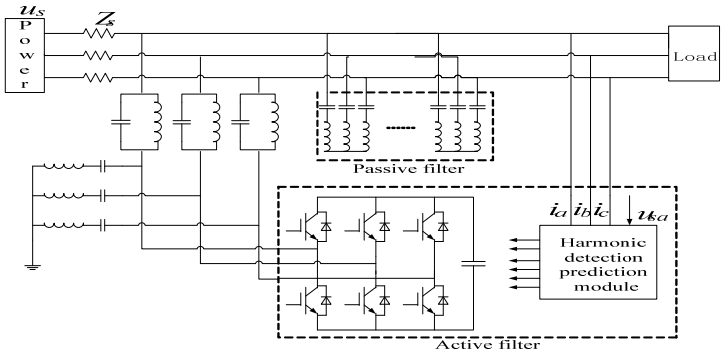
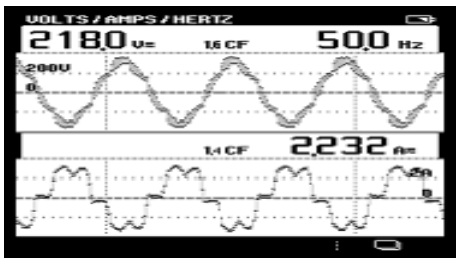
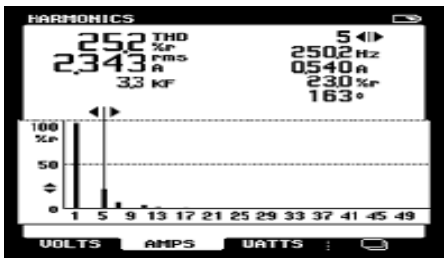


Figure 5. Topology of HAPF

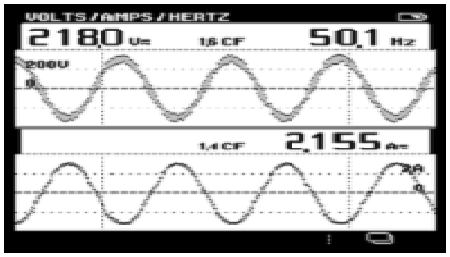
The network side current waveform before put HAPF shown in Figure 6(a) and (b), the distortion of waveform is serious, up to 25.20%. After put HAPF, the network side current waveform when use the forecast method based on the EMD and SVR hybrid intelligent prediction model show in Figure 6(c) and (d), the distortion of waveform is 3.30%, has been greatly reduced, The waveform is very close to the sine wave.



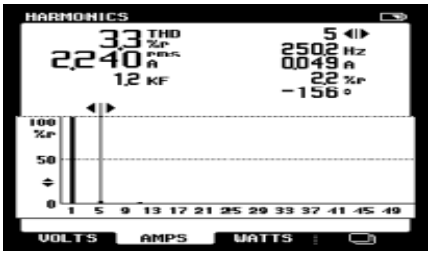
(a) Before HAPF be Putted



(b)Current Spectrogram before HAPF be Putted



(c) After HAPF be Putted



(d) Current Spectrogram after HAPF be Putted

Figure 6. The Experiment Waveform and Current Spectrogram

The network side current of 3, 5, 7, 9 times harmonic distortion rate and total harmonic distortion rate show in Table 1. Analysis of every harmonic distortion rate in Table 1, we can get that the filter effects of HAPF when use the forecast method based on the EMD and SVR hybrid intelligent prediction model can be greatly improved.

Table 1. Harmonic η_{THD} of System Currents

The forecast method	Harmonic Distortion Rate				
	3 times	5 times	7 times	9 times	Total Harmonic Distortion Rate
Before compensation	20.12	21.82	19.20	18.04	25.2
After compensation	2.02	1.97	2.82	1.90	3.3

6. Conclusion

In this paper, a harmonic current prediction methods based on EMD-SVR theory be proposed, and be successfully applied in the microgrid HAPF harmonic current forecast. Simulation results show that: First, the harmonic current is decomposed into every harmonic current using EMD method; Then using different kernel function in SVR module to predict different times harmonic currents at the next time; Finally, the predicted value of each harmonic weighted summation, harmonic currents at the next time can be accurately predicted, achieve harmonic current minimum error compensation.

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