International Journal of Hybrid Information Technology
Vol.8, No.10 (2015), pp.81-90
http://dx.doi.org/10.14257/ijhit.2015.8.10.08

# Research on Key Problems of Channel Estimation Based on Plural RBF Neural Network

Nan Wang[1], Bo Hu[2, 3], Junyang Zhang[1], Jinsong Liu[1] and Xinyu Zhang[1]

*[1]Electric Power Research Institute, State Grid Liaoning Electric Power Supply Co. Ltd., Shenyang China*
*[2]North China Electric Power University, Beijing China*
*[3]State Grid Liaoning Electric Power Co. Ltd., Shenyang China*
** Corresponding author: adaozb@163.com*

***Abstract***

*A new channel estimation method of neural network based on complex radial basis function (CRBF) is proposed to enhance the anti-interference ability of traditional pilot frequency estimation algorithm in power line communication (PLC). This method builds up a new channel model of complex field signals in PLC. The complete response model was established by using transmitting terminal's pilot signal as input sample data, pilot signal's frequency response as output sample data, and pre-setting mean square error (MSE) and diffusion constant. Computer simulations show that compared with the traditional algorithm the channel estimation was more accurate and had lower MSE and bit error rate (BER).*

***Keywords:*** *power line communication, orthogonal frequency division multiplexing, channel estimation, complex radical basis function algorithm*

## 1. Introduction

Power line communication is a new developing science and technology in recent years; It uses the existing power line as a communication medium for data transmission. It makes full use of the electric facilities, takes full advantages of power resources, and makes electric power communication industry develop a lot. PLC has quick construction speed and less investment characteristics. While the distribution network is not designed specifically for communication, it is not an ideal transmission medium. Besides the transmission channel attenuation, and due to the presence of multipath reflection signals would be selective attenuation and intersymbol interference, channel characteristic performance as a time-varying frequency selective attenuation channel [1-2]. Orthogonal frequency division multiplexing (OFDM) technology can be a strong resistance to multipath, achieving to a high transmission data speed and effectively dealing with the poor channel environment in the low-voltage power [3-5]. However the data still under the influence of channel fading, reasonable compensation should be made at the receiving end [6-7]. At the receiving end to makes the signal equilibrium it needs to be aware of the frequency domain of the channel frequency transmission characteristics. Accurate estimate of the channel model becomes the key technology of the whole system performance.

As now, the estimation based on pilot channel used rather widely as mentioned in the literature [8-10]. Firstly, calculating the frequency response in the pilot position power line channel and through interpolation and smoothing algorithms determines all the channel response. However, this method calculated through interpolation has a high bit error rate problem.

Radial basis function (RBF) neural network is a new kind of three-layer feedforward neural network, it can realize the non-linear relationship mapping, in theory it can

ISSN: 1738-9968 IJHIT

approximate arbitrary function. As now, The applications of RFB network in real number domain is a lot, but literatures about applying RBF network in complex domain is still very limited.

In this paper a neural network algorithm based on the complex radial basis function (CRBF) is proposed to solve the problem of power line communication channel estimation.

CRBF neural network algorithm was conducted on the basis of the RBF neural network algorithm dimension transformation. The input and output of neural network turn into plural form. The benefits of such changes mathematical expression is output data contained in a group with plural weighted linear combination of the data. And ordinary real radial basis function (RBF) neural network algorithm's input and output data could be seen as special cases of complex radial basis function neural network algorithm, namely for the weight of the input and output values are real numbers. Because a hidden node response can be seen as a form of the generalized potential function, it will show in the application channel balance a hidden node actually realized the conditional probability density function for a given channel status. As a result, the RBF evolved into CRBF neural network algorithm gives better solution to the hidden nodes of neural network response, handling of the channel estimation is more accurate.

By the literature [12], in a certain period for high-speed communication power line channel can be seen as a smooth random channel, the least squares method to calculate the frequency response of pilot frequency points was used. Then by using the pilot signal at the receiving end and the corresponding frequency response as sample data and training the neural network, after inputting data signal the channel response can be obtained. Simulation test shows that compared with traditional algorithm the proposed algorithm can reduce the influence of noise to a certain extent, at the same time, improving the efficiency of transmission and reducing the channel estimation's MSE and BER than the old way.

## 2. OFDM System Model

With the development of science and technology, the orthogonal frequency division multiplexing technology is put forward to meet people's raising requirement for the quality of mobile communication. In the 1970s, the basic theory of OFDM technology was consolidated by S.B.W Einstein who proposed a new multicarrier modulation method using Fourier transform technique. And then L. J. Cimini solved the problem of the orthogonal frequency division multiplexing (OFDM) technology applied in wireless communication, which made OFDM get rapid development in the field of information and communication. This technique mainly uses the multi-carrier modulation technology, first, the data bits to be transmitted is decomposed into several low rate of child data bits, then, these decomposed data bits are transmitted in parallel on orthogonal subcarrier channel. The technology has been widely used in ADSL, WLAN, and other wireless communication system; it not only has reduced the mutual interference between the carrier channels, but also has greatly improved the spectrum efficiency. In addition, OFDM is easy to be combined with technologies of space-time coding, spatial diversity, suppress interference and smart antenna to improve the reliability of information transmission.

Based on the OFDM pilot frequency the channel estimation process is shown as Figure 1, after mapping and desterilizing bit stream to k parallel bit streams, we can get x(n) through IFFT by inserting pilot frequency signal. The process of using the IFFT implementation of OFDM can be described as follow,

$$x(n) = \frac{1}{N} \sum_{k=0}^{N-1} X(k) exp(j2\pi nk/N) \tag{1}$$

 

Where X(k) is the modulated plural data; k=0,1,…,N-1, k is the subcarrier serial number, N is the subcarrier number; n=0,1,…,N-1.

At the receiving end, the kth subcarrier's output is

$$Y(k) = X(k)H(k) + W(k) \quad (2)$$

Where X(k) represents sending end and W(k) represents receiving end of the *k*th subcarrier modulating signal. It is the *k*th subcarrier's channel transfer function in form of Gaussian white noise's frequency domain.

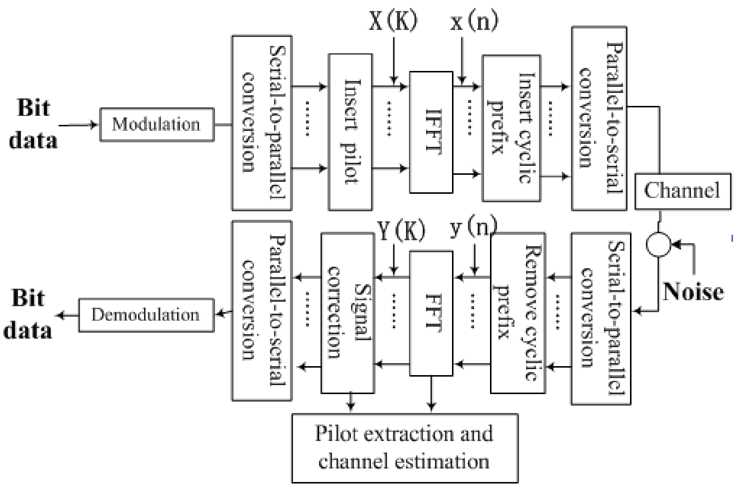


**Figure 1. Transmission diagram of Pilot method of OFDM system**

QPSK modulation is photograph Shift Keying (Quadrature Phase Shift Keying), it is one of the four Phase Keying. QPSK uses the four different phase of the carrier to represent the digital information. Because each kind of carrier phase represents two bits of information, so each quaternary element is also known as dual bit symbol. Expressed a and b as the two bit of information, the relationship between them and phase $\theta_k$ usually arranged according to gray code, their relations are shown in table 1, the vector diagram as shown in Figure 4. For data $I_k$、$Q_k$ after processing by the way A, the output form of waveform amplitude has three values:-1,+1,0. For data $I_k$ 、$Q_k$ after processing by the way B, the output form of waveform amplitude has two values:-0.707,+0.707

**Table 1. QPSK Modulation Way of Working**

| dual bit symbol | | $\vartheta_k$ | |
|---|---|---|---|
| a | b | WAY A | WAY B |
| 0 | 0 | 0° | 225° |
| 1 | 0 | 90° | 315° |
| 1 | 1 | 180° | 45° |
| 0 | 1 | 270° | 135° |

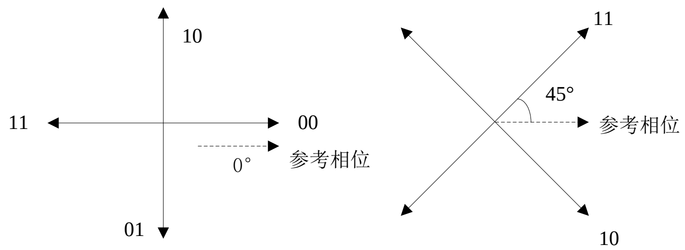


**Figure 2. QPSK Modulation Vector Diagram**

## 3. Traditional Pilot Frequency Estimation Algorithm

As to traditional pilot frequency estimation algorithm, it needs the estimated value of pilot channel points, the receiving symbols is:

$$Y_n = X_n H_n + W_n \tag{3}$$

Where $X_n$ is $n \times n$ order diagonal matrix of sending pilot signal, $Yn$ is the receiver signal, $Hn$ is the channel response needs to be estimated, $W_n$ is $n \times 1$ vector quantity as a gaussian white noise, n is the number of pilot. Set channel estimation at pilot frequency point as $\hat{\boldsymbol{H}}_{LS}$. Then under the least square principle the objective function is

$$\boldsymbol{J} = \left(Y_n - X_n \hat{H}_{LS}\right)^H \left(Y_n - X_n \hat{H}_{LS}\right) \tag{4}$$

Equation to *J*'s minimum

$$\frac{\partial \boldsymbol{J}}{\partial \hat{\boldsymbol{H}}_{LS}} = 0 \tag{5}$$

Then solve the channel estimation $\hat{\boldsymbol{H}}_{LS}$ of the pilot frequency point. After using the least squares method to obtain the channel estimation at the beginning of the pilot symbols, using linear interpolation algorithm to get the whole channel response, in the *k*th subcarrier it is:

$$\hat{H}(k) = \hat{H}(mL+1) = \hat{H}_{LS}(mL) + \frac{1}{L}\left\{\hat{H}_{LS}(m+1)L - \hat{H}_{LS}(mL)\right\} \tag{6}$$

Where mL<k<(m+1)L, 0<l<L, L is pilot symbol's interval, m is the relative location of the pilot frequency.

## 4. Channel Estimation based on Complex RBF Neural Network

### 4.1 The Data Processing of Plural RBF Neural Network

Through the constellation mapping, bits of data turns into complex signal with range amplitude and phase information so it is different from conventional RBF neural network. What we need is plural RBF neural network including input layer, hidden layer and output layer. Assuming we have total n pilot signal, sending the pilot signal $Y_n$ from the input end to hidden layer as sample data through complex radial basis function layer. In hidden layer the *i*th nerve cell will calculate the distance between pilot signal in input layer and its plural center vector. After entering the result into the radial basis function, we can get channel complete response $\hat{\boldsymbol{H}}$. Its basic structure is shown as Figure 2. $\varphi(x)$ is radial basis function given as Gaussian function:

$$\varphi(x) = exp\left(-x^2/\sigma^2\right) \tag{7}$$

The input signal vector is:

$$\boldsymbol{Y}(n) = \left[Y(1), Y(2), \ldots, Y(n)\right]. \tag{8}$$

The output signal is:

 

$$\boldsymbol{h}(P)=\sum_{i=0}^{n-1}\boldsymbol{w}_i\varphi\left(\left\|\boldsymbol{Y}(n)-\boldsymbol{c}_i\right\|\right)=\sum_{i=0}^{n-1}\boldsymbol{w}_i exp\left(\frac{\left\|\boldsymbol{Y}(n)-\boldsymbol{c}_i\right\|}{\sigma^2}\right)$$

$$\left\|\boldsymbol{Y}(n)-\boldsymbol{c}_i\right\|^2=\left(\boldsymbol{Y}(n)-\boldsymbol{c}_i\right)^H\left(\boldsymbol{Y}(n)-\boldsymbol{c}_i\right) \tag{9}$$

Where $H$ represents Hermitian transpose; $\boldsymbol{w}_i$ ( $1\le i\le N$ ) is the n connection weights of equalizer. $\boldsymbol{c}_i$ ( $1\le i\le N$ ) means $N$ plural n dimension vectors representing $N$ centers of equalizer. $\|\cdot\|$ represents Euclidean norm.

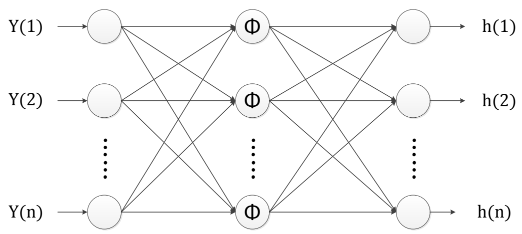


**Figure 3. Basic RBF Neural Network Structure**

Because $\boldsymbol{w}_i=\boldsymbol{w}_{R,i}+j\boldsymbol{w}_{I,i}$ , we can set output formula as[13]:

$$\boldsymbol{h}(n)=\sum_{i=0}^{n-1}\left\{\begin{matrix}\boldsymbol{w}_{R}\ \varphi_R\left(\left\|\boldsymbol{Y}(n)-\boldsymbol{c}\ \ \right\|\right)+\\ \boldsymbol{w}_{I,i}\left[j\varphi_I\left(\left\|\boldsymbol{Y}(n)-\boldsymbol{c}_{I,i}\right\|\right)\right]\end{matrix}\right\} \tag{10}$$

Then the whole network equals to the output signal that the real and the imaginary part are the input signal trained by the same RBF and multiply by corresponding real and imaginary part coefficient, the equivalent structure shown as Figure 3:

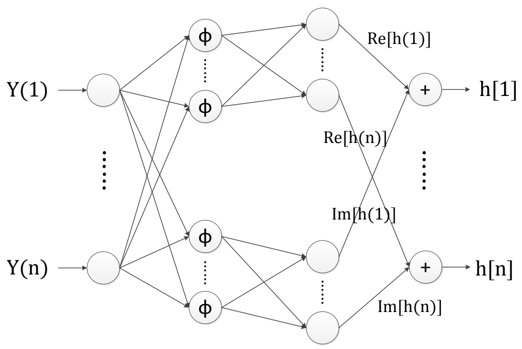


**Figure 4. Plural RBF Neural Network Structure**

### 4.2 CRBF Neural Network Training

CRBF neural network training means finding a series of network parameters including link weight $w_i$, radial basis function's plural center vector $c_i$ and diffusion constant $\sigma_i$, to make the output of the RBF neural network approximate expectation data as much as possible.

Using the stochastic gradient method proposed by I.Cha adaptively adjust all the parameters. The expectations output signal of neural network is $\hat{\boldsymbol{H}}_{LS}(n)$:

$$\hat{\boldsymbol{H}}_{LS}(n)=\left[\hat{H}(1),\hat{H}(2),\ldots\hat{H}(n)\right]^T \tag{11}$$

It bases on the signal trained by least square method at the beginning of the pilot. For the output signal is *h(n)*, the error signal between them is:

$$\boldsymbol{e}(n)=\hat{\boldsymbol{H}}_{LS}(n)-\boldsymbol{h}(n) \tag{12}$$

Define the MSE's cost function is:

 

$$J = E\left\{ \left| \boldsymbol{e}(n) \right|^2 \right\} \tag{13}$$

Then in the trained process the next weights of neural network, diffusion constant or plural center vector can be adjusted by the following equations [14, 15]:

$$w_{R,i}(x+1) = w_{R,i}(x) + \mu_w e_R(x) \varphi_{R,i}(x)$$

$$w_{I,i}(x+1) = w_{I,i}(x) + \mu_w e_I(x) \varphi_{I,i}(x)$$

$$\sigma_{R,i}(x+1) = \sigma_{R,i}(x) + \mu_\sigma \boldsymbol{e}_R(x) \boldsymbol{w}_{R,i}(x) \varphi_{R,i}(x) \left\| \boldsymbol{Y}(n) - \boldsymbol{c}_{R,i} \right\|^2 / \sigma_{R,i}(x)^3$$

$$\sigma_{I,i}(x+1) = \sigma_{I,i}(x) + \mu_\sigma \boldsymbol{e}_I(x) \boldsymbol{w}_{I,i}(x) \varphi_{I,i}(x) \left\| \boldsymbol{Y}(n) - \boldsymbol{c}_{R,i} \right\|^2 / \sigma_{I,i}(x)^3$$

$$\boldsymbol{c}_{R,i}(x+1) = c_{R,i}(x) + \mu_c \boldsymbol{e}_R(x) \boldsymbol{w}_{R,i}(x) \varphi_{R,i}(x) \left[ \boldsymbol{Y}(n) - \boldsymbol{c}_{R,i} \right] / \sigma_{R,i}(x)^2$$

$$\boldsymbol{c}_{I,i}(x+1) = c_{I,i}(x) + \mu_c \boldsymbol{e}_I(x) \boldsymbol{w}_{I,i}(x) \varphi_{I,i}(x) \left[ \boldsymbol{Y}(n) - \boldsymbol{c}_{I,i} \right] / \sigma_{I,i}(x)^2$$

Where $\mu_w$, $\mu_\sigma$, $\mu_c$ respectively represents learning efficiency, controlling and adjusting speed.

## 5. The Simulation Experiments and Analysis

Comparing the proposed algorithm with Pilot-based linear interpolation algorithm by MATLAB, we select 5~20KHz as modulation frequency band and white noise as interference which its average value is 0 and variance is 1, applying QPSK modulation method。 The number of OFDM sub-carriers is 100, IFFT length is 256, and applying comb pilot the pilot spacing is 7. In plural RBF networks, the number of hidden layer nodes is 20. 20 top input vectors are selected as initial value of centre vector, the initial mean square error value of the RBF real and imaginary is a small random number, and the initial value of the weight coefficient is a small random complex.

Define the MSE of channel estimation is:

$$MSE = E\left[ \left\| \boldsymbol{H} - \hat{\boldsymbol{H}} \right\|^2 \right] \tag{14}$$

Where $H$ is ideal channel response vector.

Figure 4 and Figure 5 respectively shows the comparing result of MSE and BER in different signal noise ratio（SNR） between using the proposed algorithm in this paper and using linear interpolation algorithm. It is obviously that Neural network algorithm’s estimation accuracy is 4~5db higher than linear interpolation algorithm under the same BER. The proposed algorithm in this paper has better performance when there is high SNR.

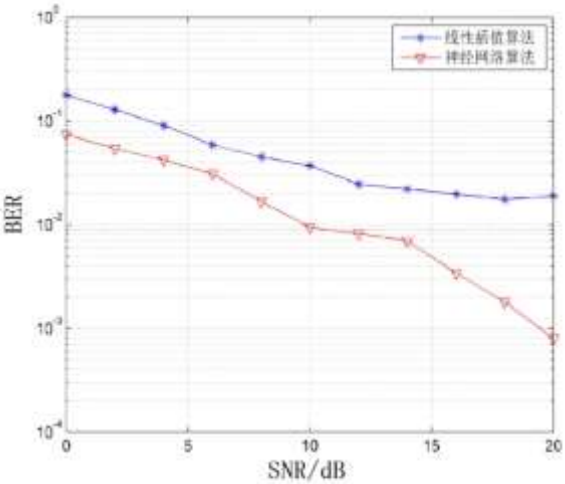


**Figure 5. Comparison Curve of BER**

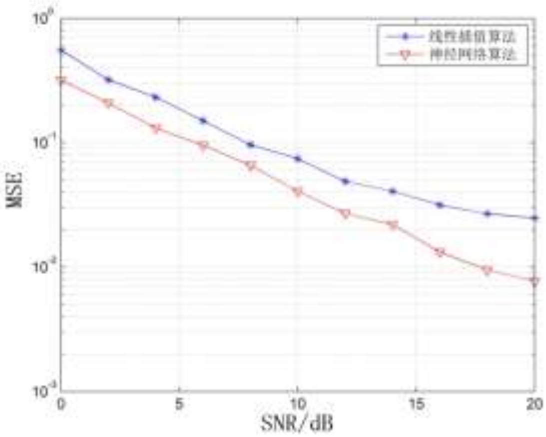


**Figure 6. Comparison Curve of MSE**

## 6. Conclusion

In this paper, a complex radial basis function neural network algorithm has been proposed to solve the problem of channel estimation in power line communication. Compared the estimation performance between the proposed algorithm and linear interpolation algorithm the simulation result shows this paper's algorithm has lower BER and MSE in the same SNR.

## Ackownledgement

This work was supported by the National Natural Science Foundation of China (6127302961273027), the Program for New Century Excellent Talents in University, China(NCET-12-0106) and the Basic Scientific Research Funding of Northeastern University(N130504004N130104001). The authors also gratefully acknowledge the helpful comments and suggestions of the reviewers, which have improved the presentation.

## References

[1] J. Anatory, M. M. Kissaka, and N. H. Mvungi, "Trends in telecommunication services provision: Power line network can provide alternative for access in developing countries," in Proc. IEEE Africon, Gaborone, Botswana, vol. 601, **(2004)**.
[2] Z. Baohui, L. Haitao and C. Changde, "Concept and key techniques of using power transmission lines as common platform for telephone, computer, television and power transmission networks", Proceedings of the CSEE, vol. 21, no. 60, **(2001)**.
[3] P. S. Henry, "Interference characteristics of broadband power line communication systems using aerial medium voltage wires", IEEE Communications Magazine, vol. 43, no. 92, **(2005)**.
[4] N. Pavlidou, A. J. H. Vinck and J. Yazdani, "Power line communications: state of the art and future trends", IEEE Communications Magazine, vol. 41, no. 34, **(2003)**.
[5] F. J. Canete, L. Diez, J. A. Cortes, *et al.*, Entrambasaguas, Broadband modeling of indoor power-line channels", IEEE Transactions on Consumer Electronics, vol. 48, no. 175, **(2002)**.
[6] L. Silva, J. J. Duque, R. Tinos and L. O. Murta Jr., "Reconstruction of Multivariate Signals Using Q-Gaussian Radial Basis Function Network", Computing in Cardiology, vol. 25, no. 465, **(2010)**.
[7] Y. H. Ma, P. L. So and E. Gunawan, "Performance analysis of OFDM systems for broadband power line communications under impulsive noise and multipath effects", IEEE Transactions on Power Delivery, vol. 20, no. 674, **(2005)**.
[8] Z. Jidong and Z. Baoyu, "Overview of pilot-aided channel estimation in OFDM", Jounal of China Institute of Communications, vol. 24, no. 118, **(2003)**.
[9] M. Morelli and U. Mengali, "A comparison of pilot-aided channel estimation methods for OFDM systems", IEEE Transactions on Signal Processing, vol. 49, no. 3065, **(2001)**.
[10] W. G. Jeon, I. K. K. H Pa and Y. S. CHO, "An Efficient Channel Estimation Technique for OFDM Systems With Transmitter Diversity", The 11th IEEE International Sympolsium on Personal, Indoor and Mobile Radio Communications, vol. 1246, **(2000)**.
[11] S. Q. Ding and C. Xiang, "From multilayer perceptrons to radial basis function networks: a comparative

 

study", Proceedings of the 2004 IEEE Conference on Cybernetics and Intelligent Systems, vol. 69, **(2004)**.
[12] G. Jingbo and W. Zanji, "Spread Spectrum Signal Transmission Over Low Voltage Distribution Networks and Realization Countermeasures of the Communication System", Proceedings of the CSEE, vol. 21, no. 78, **(2001)**.
[13] J. B. Xu, F. Liu and Y. M. Wang, "Adaptive equalizer based on complex radial basis functions networks", Acta Electronica Sinica, vol. 26, no. 59, **(1998)**.
[14] N. B. Karayiannis and Mary M. Randolph-Gips, "On the Construction and Training of Reformulated Radial Basis Function Neural Networks (Part Ⅰ)", IEEE Transactions On Neural Networks, vol. 14, no. 19, **(2003)**.
[15] "Lee-Ming Institute of Technology, Taipei County, Taiwan Depth From Defocus Using Radial Basis Function Networks (Part Ⅱ)", Signal Processing, vol. 36, no. 175, **(2006)**.
[16] D.-F. Yuan and X.-F. Song, "Turbo Code Performance over Rayleigh Fading Channel Using QPSK Modulation", 2002 IEEE Region 10 Conference on Computers, Communications, Control and Power Engineering, vol. 2, no. 1056, **(2002)**.
[17] S. R. Kim, J. G. Lee, H. Lee, B. S. Kang and J. W. Jeong, "A coherent dual-channel QPSK modulation for CDMA systems", Mobile Technology for the Human Race., IEEE 46th, vol. 3, no. 1848, **(1996)**.
[18] L. Xiaoli, L. C. Look, S. Zhongxiang, S. Aditya, Q. Cheng and S. Zhongliang, "New approach for QPSK modulation", VTC 2001 Spring, IEEE VTS 53rd, vol. 2, no. 1225, **(2001)**.
[19] A. V. Mikushin and A. M. Shingarev, "The Analysis of Parameters of Four-Item Phase Modulation QPSK", Electron Devices and Materials, vol. 206, **(2007)**.
[20] R. Yao, S. Yang, Q. Zhu and Z. Nie, "A QPSK modulation scheme based on four dimensional antenna arrays", Electromagnetics, Applications and Student Innovation (iWEM), vol. 1, **(2012)**.

## Authors

**Nan Wang**, She received the M.S. degrees in electrical engineering from Northeastern University, Shenyang, China, in 2014. Since 2014 she work in the electric power research institute of state grid Liaoning electric power Co.Ltd major in the smart power grid. Her research interests include grey theory, smart power grid, planning and scheduling of electrical power and manufacturing industry systems. She has 4 national patents and a software patents.

**Bo Hu**, He received the B.S. and M.S. degrees in computer and application from North China Electric Power University, Beijing, China, in 1995 and 2006, respectively, and the Ph.D. degree in power system and automation from the North China Electric Power University, Beijing, China, in 2013. He is a senior engineer in the State Grid Liaoning Electric Power Co.Ltd. He has participated in many important national technological projects and gotten great efforts, which made him honored the national science and technology progress award once and provincial and ministerial level 5 times. His research interests include complex networked systems including smart power grid, planning and scheduling of electrical power and electric power markets.

**Junyang Zhang**, She received the M.S degree from Tianjin University, mainly engaged in high voltage and intelligent substation technique.

 

**Jinsong Liu**, He is a senior engineer in the electric power research institute of state grid liaoning electric power Co. Ltd. He mainly engaged in power system operation and analysis, clean energy grid detection and assessment, the smart grid in the fields of research. He has participated and chaired in many important projects of power grid security and stability analysis, the static/dynamic reactive power compensation, voltage stability analysis, dc operation stability analysis, main transmission capacity, wind power given ability, wind turbines grid detection, power quality monitoring and evaluation, smart grid etc. He won the national science and technology progress award second prize once and provincial and ministerial level third prize once. He applied for 11 national patents, of which 6 items have been authorized.

**Xinyu Zhang**, He received the M.S degree in high professional electronic instrument and measurement technique from University of Electronic Science and Technology of China, mainly engaged in the generator excitation system technology improvement and the parameter testing. Form 2012 till now, he mainly engaged in the distribution automation, maintenance, fault repair service.

 