Research on CCHP System Grid Connection Interface Device Based on Elman Neural Network

Hongyan He, Rui Chen, Jianqiang Xu, Kai Ding, Xiaofan Zhu, Guoqi Zhou, Shengguo He, Zhiwei Huang, Shengyuan Xiao, Xiang Zhou, Laifeng Luo, Xiaomin Fang, Wenjian Peng and Xingjun Cui

CYG SUNRI CO., LTD, Shenzhen 518000, China
Corresponding author e-mail: hehy@sznari.com

Abstract. With the promotion of the concepts of "energy Internet" and "multi energy complementation", the combined cold heat and power (CCHP) system technology has been paid more and more attention by the energy power circles at home and abroad. CCHP system generates electricity through internal combustion engine, meanwhile, the waste heat discharged after power generation is supplied with heat and cooling to users through waste heat recovery equipment, so as to effectively improve the energy utilization rate. However, with the development of information and intelligence in the power grid, the threat of various network malicious attacks on the power industrial control terminal is growing. The traditional CCHP system grid connection interface device operating environment is open and vulnerable to network malicious attacks. In this paper, an interface device of CCHP based on Elman neural network algorithm is proposed. The technical problem to be solved is to be able to realize active defense against unknown attacks and improve the security and operation reliability of CCHP system.

1. Introduction
The CCHP system [1-4] is a cogeneration system based on the concept of energy cascade utilization, using natural gas as a primary energy source to generate three types of energy: cold, heat and electricity. It uses natural gas as fuel. The high-temperature flue gas obtained by burning small natural gas using small gas turbines, gas internal combustion engines, and micro-turbines is first used for power generation, and then uses waste heat for heating in winter; it is cooled by a refrigerator in summer; can provide domestic hot water, making full use of exhaust heat. CCHP system's energy utilization rate can be as high as 80%, which saves a lot of energy. Compared with the traditional centralized energy supply method, the combined cooling, heating, and power system not only has the advantages of high energy efficiency, clean and environmental protection, good safety, peak-cutting and valley-filling, and good economic benefits. It can also meet the end-user's diverse energy supply. Demand is an important development direction of the power industry and energy industry.

In recent years, CCHP system technology has received increasing attention from domestic and foreign energy and power industries. It has developed rapidly in domestic and foreign markets, and engineering application technology has become increasingly mature. On the one hand, because the end-user's energy demand is affected by comprehensive factors such as seasonal changes, building types, and power supply of the power grid, the CCHP system needs to accurately and timely connect the relevant status data of cold, heat, and electricity to the grid when it is connected to the grid. The interface device is uploaded to the higher-level dispatch center; but on the other hand, as the power grid gradually moves towards informationization and intelligence, power industrial control terminals are increasingly threatened by various network malicious attacks, and the current operating...
environment of grid-connected interface devices. It is open and vulnerable to various cyber attacks. These attacks will jeopardize the confidentiality, integrity and availability of information. It can be seen from the cases of major power outages initiated by network information security events and network attacks that interfere with the normal operation of the power grid in the world in recent years. Security loopholes in industrial control terminals have always existed, and power outages caused by network attacks have been on the rise in recent years. Therefore, for grid-connected interface devices that need to be connected to the grid, it is necessary to improve its active immunity [5-8] to avoid network attacks by invading the grid-connected interface devices to interfere with the normal operation of the power grid and destroy the entire cold, heat and power tri-generation system.

This paper studies a CCHP grid-connected interface device based on Elman neural network. The device's active identification function includes the following steps: First, collect the status data of the cold, heat and electricity, collect the characteristic data stream that can characterize whether the CCHP grid-connected interface device is under attack; second, input the characteristic data stream to the Elman neural network model Perform real-time detection in the middle, and then output the detection classification results. When the classification results contain feature data classified as a network attack, the status data is intercepted and an alarm is issued. Third, when the classification data flows are classified as normal in the classification results, the status data is dispatched to the superior Center for forwarding.

2. Elman Neural Network Training Model

The Elman neural network [9-12] model training process, as shown in figure 1, specifically includes:

(1) The sigmoid activation function is used to normalize each hidden element to become the probability value that they are in activation:

\[ f(x) = \frac{1}{1+e^{-x}} \]  

(1)

Where \( e \) is a constant with a value of 2.718, and \( x \) indicates that the value transmitted by the explicit layer is multiplied by the connection weight plus the deviation of the hidden layer; the value transmitted by the explicit layer is the sample data in the input sample, and the connection weight is neural. Links between the yuan;

(2) Calculate the probability that the hidden element is activated:

\[ P(h_j = 1 | v) = \delta(c_j + \sum_{i=1}^{m} w_{ij} v_i) \]  

(2)

Where \( P(h_j = 1 | v) \) refers to the probability of the hidden element being activated, \( h_j \) is the jth activated hidden element, \( v \) represents the initial display layer, \( v_i \) represents the i-th display element, and each of the i displays is The value of the sample data of the training samples in the training database, \( w_{ij} v_i \) is the weight of the connection between the explicit layer (input layer, inherited layer) and the hidden layer, \( m \) is the total number of explicit elements in the explicit layer, and \( n \) is The total number of hidden elements in the hidden layer, \( j \) is the j-th hidden element, \( c_j \) is the offset of the j-th hidden element, and the initial offset \( c \) of the hidden layer is 0; between the explicit layer and the hidden layer The connection weight is the connection between the explicit layer and the hidden layer, and the initialization of the connection weight \( w \) comes from a random number with a normal distribution \( N(0, 0.01) \);

(3) Calculate the probability that the explicit element is activated:

\[ P(v_i = 1 | h_0) = \delta(b_i + \sum_{j=1}^{n} W_{ij} h_j) \]  

(3)

Where \( P(v_i = 1 | h_0) \) is the probability that the display element is activated, \( V_i \) represents the i-th activated element after reconstruction, \( h_0 \) represents the hidden layer, \( h_i \) represents the j-th hidden element, \( W_{ij} v_i \) is the connection weight between the explicit layer and the hidden layer, \( n \) is the total number of hidden elements in the hidden layer, \( i \) is the i-th explicit element, and \( b \) is the offset of the explicit element, which is initialized to \( b_i = \log \frac{p_i}{1-p_i} \). Where \( p_i \) represents the proportion of samples in
the training sample whose i-th feature is activated, the feature is sample data in the sample, and the hidden layer represents the activated feature.

(4) Then calculate the probability that the hidden element is activated again with the reconstructed explicit element, and obtain a new hidden layer h', that is, use the value of the hidden element after activation in step (2) as the input value and the corresponding Multiply the connection weights, and then sum these products before adding the deviations. The result is the reconstructed value, which is the approximate value of the original input. Then use the formula in step (3) to calculate the probability of activation of the display element. Then, Map the reconstructed activation explicit cell value to the hidden cell;

Where \( P(h_j = 1|v') \) refers to the probability of the hidden element being activated, \( h'_j \) represents the j-th hidden element activated by the reconstruction layer after reconstruction, and \( v' \) represents the reconstruction Layer, \( v_i \) represents the i-th display element, the i-th display is the value of the reconstructed display element, \( W_{n \times m} \) is the connection weight between the display layer and the hidden layer, and \( m \) is the display The total number of hidden elements in the layer, \( n \) is the total number of hidden elements in the hidden layer, \( j \) is the j-th hidden element, and \( c_j \) is the offset of the j-th hidden element; the connection between the explicit layer and the hidden layer The weight is the connection between the explicit layer and the hidden layer.

(5) Update the offset weights. The update formula is:

\[
\Delta W = [P(h_0 = 1|v_0)v_0^T - P(h'_0 = 1|v')v'^T] \tag{4}
\]

\[
W_{\text{new}} = W + \alpha \Delta W \tag{5}
\]

\[
b_{\text{new}} = b_i + \alpha (v_i - v'_i) \tag{6}
\]

\[
c_{\text{new}} = c_j + \alpha [P(h_j = 1|v) - P(h'_j = 1|v')] \tag{7}
\]

Where \( \Delta W \) represents the difference (Error feedback) between the display element and the input value after reconstruction, \( \alpha \) is the learning efficiency value of 0.01, and \( W \) is the connection weight before the update (W's initialization comes from the normal distribution \( N(0, 0.01) \) random number), \( v_0 \) is the initial explicit layer assigned to the explicit element, \( v_0^T \) is the transpose of \( v_0 \), \( h_0 \) is the hidden layer activated after the explicit layer mapping, \( v' \) is the reconstruction The reconstructed explicit layer maps the value to the hidden layer, and the hidden layer is activated to obtain \( h' \); the initial visible layer is the sample data in the sample;

(6) After sufficient training of an initial manifestation is completed, determine the connection weight and offset of the training sample data;

(7) Repeat (1)-(6) until all the sample data are trained, and finally get the trained Elman neural network model.
3. CCHP Grid-connected Interface Device Based on Elman Neural Network

3.1. Introduction Of CHP Grid-connected System
As shown in Figure 2, the CCHP grid-connected system structure includes a CCHP control management unit, a CCHP grid-connected interface device [13-16], and a superior dispatch center. In the figure, the solid line is the energy line, the dotted line is the communication line, and the grid-connected interface device is a communication bridge that connects the upper-level dispatch center and the lower-level control management unit. The control management unit obtains electricity from the generator, refrigeration unit, heat exchanger, and domestic hot water. And cold and hot status data and according to the relevant remote adjustment, start and stop commands sent by the superior dispatch center via the grid-connected interface device, while the grid-connected interface device receives status data (such as gas turbine power, power generation capacity) sent by the control management unit, power quality, heat supply, cooling capacity information and grid connection point voltage, current, power and other data, among which gas turbine power, grid connection point voltage, current, power and other data are susceptible to cyber attacks) (control system, temperature monitoring device and grid connection point) collects voltage, current, active power and reactive power, gas turbine power, cooling capacity, heat and other information, and receives relevant remote signal data from the lower-level controller. Generator or higher-level dispatch center) in real time to convey information such as gas turbine power, power generation, power quality, heat supply, and cooling capacity, as well as Point voltage, current, power and other data.
Figure 2. CCHP grid connection system structure

3.2. Structure and Strategy of Grid Connection Interface Device

The CCHP system grid connection interface device based on Elman neural network includes measurement module, control module, attack detection module, power module, communication module, display module, output module, input module and memory. As shown in Figure 3.

Figure 3. Structure diagram of interface device

The attack detection module is respectively connected with the input module, the measurement module, the power module and the communication module, and the AD conversion module is used for AD conversion between the measurement module and the attack detection module;

The control module is respectively connected with the power module, the display module, the output module, the memory and the communication module;

The measurement module is used to measure some state data in CCHP system data stream, and then send it to attack detection module after AD conversion;

The control module is used to communicate with the upper layer and the lower layer through the communication module, receive the alarm sent by the attack detection module, and send the alarm to
the display module for display. The control module also sends the output signal to the output module; the output signal includes the output control common connection point switch, CCHP system intercooler, thermal load equipment switch, breaker switch command signal.

The attack detection module is respectively connected with the input module, the measurement module, the power module and the communication module, and the AD conversion module is used for AD conversion between the measurement module and the attack detection module;

The control module is respectively connected with the power module, the display module, the output module, the memory and the communication module;

The measurement module is used to measure some state data in CCHP system data stream, and then send it to attack detection module after AD conversion;

The control module is used to communicate with the upper layer and the lower layer through the communication module, receive the alarm sent by the attack detection module, and send the alarm to the display module for display. The control module also sends the output signal to the output module; the output signal includes the output control common connection point switch, CCHP system intercooler, thermal load equipment switch, breaker switch command signal;

Further, the control module is also used to send alarms and log records to the upper layer and / or to the memory for storage through the communication module.

Further, before the attack detection module inputs the characteristic data flow into the Elman neural network model for real-time detection and classification, it also needs to train the Elman neural network model, and the training is realized in the following ways:

(1) Input samples to Elman neural network model; the samples include positive samples and negative samples, positive samples are normal data that can indicate whether CCHP system grid connection interface device is attacked; negative samples are obtained after network attack on normal data in positive samples;

(2) The Elman neural network model was trained repeatedly.

Through the detection and analysis of the cold, hot and electricity related state data through Elman neural network, the abnormal data in the state data which is attacked by the network can be found through the active identification [16-20], and the corresponding alarm prompt can be sent after the classification according to the characteristics of the network attack, and the active immunity can be realized by intercepting the abnormal data.

The attacker further invades the superior dispatching center through the security vulnerability of the grid connection interface device, so as to improve the security and operation reliability of the CCHP system.

Schematic diagram of neural network model is shown in Figure 4.
4. Conclusions
With the development of information and intelligence in the power grid, the power industry control terminal is threatened more and more by various network malicious attacks. At present, the operation environment of the grid connection interface device is open and vulnerable to various network attacks. These attacks will endanger the confidentiality, integrity and availability of information. Therefore, for the grid connection interface devices that need to be incorporated into the power grid, it is urgent to improve their active immune ability, so as to avoid network attacks to interfere with the normal operation of the power grid and damage the whole CCHP system by invading the grid connection interface devices.

In view of the current network attack risk, this paper proposes an attack identification method based on Elman neural network and grid connection interface device, which can realize the active defense of unknown attacks, improve the security and operation reliability of CCHP system, and then improve the reliability and security of grid connection.

5. Acknowledgments
This work was by Supported by the National Key R&D Program of China (2018YFB0904900, 2018YFB0904903).

6. References
[1] Maghsoud Abdollahi Haghighi, Seyed Mehdi Pesteei, Ata Chitsaz, Javad Hosseinpour. Thermodynamic investigation of a new combined cooling, heating, and power (CCHP) system driven by parabolic trough solar collectors (PTSCs): A case study[J]. Applied Thermal Engineering,2019,163.
[2] Xiaofeng Zhang, Rong Zeng, Qiaolin Deng, Xiaosong Gu, Huaican Liu, Yecong He, Kang Mu, Xiaobo Liu, Hong Tian, Hongqiang Li. Energy, exergy and economic analysis of biomass and geothermal energy based CCHP system integrated with compressed air energy storage (CAES)[J]. Energy Conversion and Management,2019,199.
[3] Di Wu, Jifeng Zuo, Zhijian Liu, Zhonghe Han, Yulong Zhang, Qiaomei Wang, Peng Li. Thermodynamic analyses and optimization of a novel CCHP system integrated organic Rankine cycle and solar thermal utilization[J]. Energy Conversion and Management,2019,196
[4] Cui Qiong, Huang Lei, Shu Jie, Wang Hao, Wu Changhong. Research status of capacity allocation and optimal operation of multi energy complementary distributed energy system [J]. New energy progress, 2019,7 (03): 263-270.

[5] Wang Liyan. Exploration of active defense mode of network security [J]. Agricultural development and finance, 2019 (12): 87-88.

[6] Weng Yuexin. Research and design of a multi-level network security active defense system [J]. Network security technology and application, 2019 (12): 29-30

[7] Ge Jian. Active defense measures for information security in the era of industrial Internet [C]. Network application branch of China computer user association. Proceedings of the 23rd annual meeting of new network technology and application of China computer user association in 2019. Network application branch of China computer user association: Key Laboratory of Beijing Information Service Engineering, Beijing Union University, 2019:225-229.

[8] Li Dawei. Research on host security immune credible technology in the era of network security level protection 2.0 [C]. Proceedings of 2019 China network security level protection and key information infrastructure protection conference, the Third Research Institute of the Ministry of public security, Jiangsu Provincial Department of public security, Wuxi Municipal Public Security Bureau. Information network security, Beijing editorial board, 201 9:40-43

[9] Jichang Lu, Jiaping Liu, Yutong Zhao, Dedong He, Caiyun Han, Yongming Luo. The identification of active chromium species to enhance catalytic behaviors of alumina-based catalysts for sulfur-containing VOC abatement[J]. Journal of Hazardous Materials,2020,384.

[10] Wu Manman, Xu Jianxin, Wang Qin. Research on ceemd Elman neural network prediction based on data decomposition AQI [J]. China Environmental Science, 2019,39 (11): 4580-4588.

[11] Li Dexin, Lu Xiangyu, Wang Jiarui, Lin Qiyou, Zhang Xingsheng, Wu Shunfeng. Design and application of a new type of distributed power grid connection interface device [J]. Journal of electrical engineering, 2017,12 (06): 30-35

[12] Li Yun, Li Ping, Ma Lixin. Power prediction model of photovoltaic power generation based on FOA Elman neural network [J]. Electrical engineering, 2019 (12): 1-4 + 49

[13] Qian Yizhao, Chen Liang. Application of Elman neural network in power load forecasting [J]. Electrical technology, 2019 (14): 55-56

[14] Lin Qiyou, Zhang Xingsheng, Wu Shunfeng. Design and application of a new type of distributed power grid connection interface device [J]. Journal of electrical engineering, 2017,12 (06): 30-35

[15] Liu Jie, Liao Bilian, song Shaojian. Hybrid main circuit and control method of micro grid connection interface [J]. Guangxi electric power, 2017,40 (05): 1-6.

[16] Zhang Wei, Wang Fei, Ruan Yi, Zhao Chunjiang, Xu Dezhi. Grid connection interface system suitable for single-phase micro grid application [J]. Electric power automation equipment, 2014,34 (10): 33-39 + 47.

[17] Guo Changliang. Research on new energy distributed flexible networked control technology [D]. Northeast Electric Power University, 2015.

[18] Peng Jiayi, Fang Yong, Huang Cheng, Liu Liang, Jiang Zhengwei. Named entity recognition in information security based on deep active learning [J] Journal of Sichuan University (NATURAL SCIENCE EDITION), 2019,56 (03): 457-462.

[19] [Elisabeth F.P. Peterse, Steffie K. Naber, Corinne Daly, Aaron Pollett, Lawrence F. Paszat, Manon C.W. Spander, Melyssa Aronson, Robert Gryfe, Linda Rabeneck, Iris Lansdorp-Vogelaar, Nancy N. Baxter. Cost-effectiveness of Active Identification and Subsequent Colonoscopy Surveillance of Lynch Syndrome Cases[J]. Clinical Gastroenterology and Hepatology,2019.

[20] Shigeto Atsushi, Wada Atsushi, Kumazawa Kenji. Identification of the novel odor active compounds "p-methane lactones" responsible for the characteristic aroma of fresh peppermint leaf.[J]. Bioscience, biotechnology, and biochemistry,2020,84(2).