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Design of DC measurement traceability system of charging pile by considering internet of things and fuzzy clustering

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Abstract: In order to effectively overcome the problems of low tracing efficiency and large tracing error in the traditional DC charging traceability system for charging piles, this paper designs a new DC traceability traceability system for charging piles considering the internet of things and fuzzy clustering. The network is established through ZigBee wireless communication technology. The hardware part of the system mainly includes a wireless communication module, a radio frequency matching module and a communication interface module to solve the problem of low transmission rate of measurement information. The software part uses the fuzzy clustering algorithm to perform real-time frequency division detection on the specified integer harmonics and fundamental current to realise the DC metering source of the charging pile. Simulation experiment results show that the designed system has higher traceability efficiency and lower traceability error, and the highest traceability efficiency can reach 98%.

Keywords: internet of things; fuzzy clustering; DC charging pile; measurement traceability; system design; ZigBee wireless communication technology.

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1 Introduction

In recent years, the use of electric vehicles has a great growth, but there are also some problems in the practical application process, such as more charging times and higher communication costs. These problems increase the charging cost seriously, resulting in the loss of users' rights and interests. The definition of the internet of things mainly includes all the current technologies combined with internet and computer technology. The increasingly developed internet of things technology provides a complete framework for wireless communication platform for DC metering traceability system of charging piles (Gu et al., 2016; Chen et al., 2016; Li et al., 2016), enhances the association between different subsystems, strengthens the ability of administrators to master the system, and improves the real-time operation performance of the system. However, the existing DC measurement traceability system of charging pile has the problems of low efficiency and error of traceability results, which is difficult to meet the demand of DC measurement traceability. Therefore, it is of great practical significance to design an effective DC measurement system of charging pile (Liu et al., 2019a; Shi et al., 2019).

Relevant experts focus on this aspect, and Zhang et al. (2019a) proposes a DC measurement traceability system based on side chain technology. The system uses Ethereum smart contract to build the supply management process of the traceability system and realise information sharing. Using side chain technology, the capacity of Ethereum is expanded and the capacity of traceability information is improved. However, this method has the problem of large traceability error. In Fan et al. (2019), a DC metering traceability system of charging pile based on sparse fault evolution discriminant analysis is proposed. It is considered that the metering traceability is affected by variable fault disturbance. Therefore, the system first analyses the relationship between fault variable and fault transmission, and locates metering fault and traceability fault. The sparse evolution discriminant analysis method is applied to awesome fault variables to realise DC measurement and tracing of electric pile. But the traceability efficiency of the system is low. Zhang et al. (2019b) proposes a DC metering traceability system for charging pile based on SSH framework. The system uses SSH framework to divide the view layer and control layer of the system, and realises the analysis of logic layer and data persistence layer. Finally, the RFID technology and RSA encryption algorithm are used to encrypt the DC metering data of the charging pile to complete the design of the traceability system. However, the measurement error of the system is high.

Aiming at the problems of low traceability efficiency and large traceability error in the above system, a DC metering traceability system for charging piles considering internet of things and fuzzy clustering is proposed. The overall design of the system is:

- System hardware design, system hardware design is based on the principles of stability, simplified structure and extensible interface. System hardware mainly includes identity authentication module, control module, intelligent instrument collection module, ZigBee wireless communication module, RF transceiver Matching module, coordinator and upper serial port module.

- System software design, using fuzzy clustering algorithm to cluster the fundamental DC, get the equivalent clustering coefficient of the RC compensation network, and draw the frequency response curve before and after RC compensation, design the charging pile DC overall verification device diagram.
- Experimental verification, using the basic error of device electrical energy, traceability efficiency, and traceability error as experimental comparison indicators, and comparing the designed system with Zhang et al. (2019a, 2019b) and Fan et al. (2019).

Through the above scheme, the design of the DC measurement system of the charging pile is realised.

2 Design of DC measurement traceability system for charging piles

In order to improve the effective utilisation rate of the DC power of the charging pile and improve the safety of the charging pile, a DC measurement traceability system for the charging pile is designed. The design principles of the system include security principles, advanced principles, maintainability principles, and openness principles.

2.1 Hardware design

In order to improve the shared transfer performance between system hardware, the system hardware is designed by applying internet of things technology. The system hardware design needs to follow the following principles, namely: the principle of stability, the principle of simplified structure, and the principle of interface scalability. The most remarkable feature of the internet of things is the ability to realise the perception function and recognition function between different objects. It focuses on the sharing and transmission of perceived information through the following technologies:

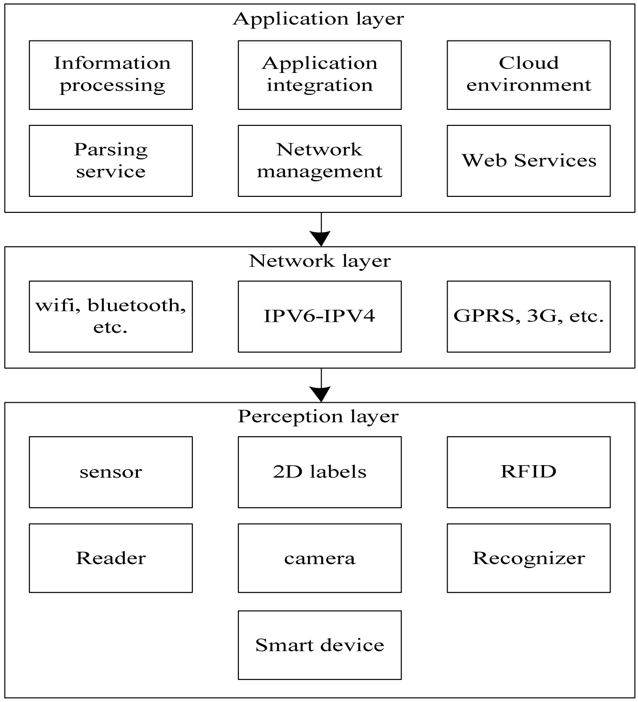
- RFID technology
- embedded technology
- sensor technology, etc.

At the same time, the internet of things can further realise transparent and intelligent management and monitoring through different sensing devices and complete information collection and transmission.

The IoT architecture can be divided into three different levels, as shown in Figure 1, the three levels are:

- perception layer
- network layer
- application layer.

Figure 1 Architecture of internet of things



At present, the more popular transmission data protocols in wireless network include WiFi technology, ultra bandwidth communication technology, infrared technology, etc. Different protocols include their own application fields. Currently, the more widely used wireless communication technologies are as follows:

(1) WiFi Technology:

It is the core representative of WLAN. Within the set range, users can communicate and connect with wired platform or wireless network.

(2) Ultra bandwidth communication technology:

This technology mainly outputs the data in the system by nanosecond to microsecond nonsinusoidal narrow pulse. It is a new type of carrier-free communication technology.

(3) Infrared technology:

This technology mainly uses infrared data which cannot be observed by human eyes for data transmission in the system. In the process of data transmission, the angle between the transmitter and the receiver must be less than 30 degrees.

(4) Bluetooth technology:

It is mainly through FHSS spread spectrum technology to complete the connection between different devices.

(5) ZigBee technology:

The whole work can be divided into three different frequency bands, including a total of 16 channels, and the transmission rate is 250kpds.

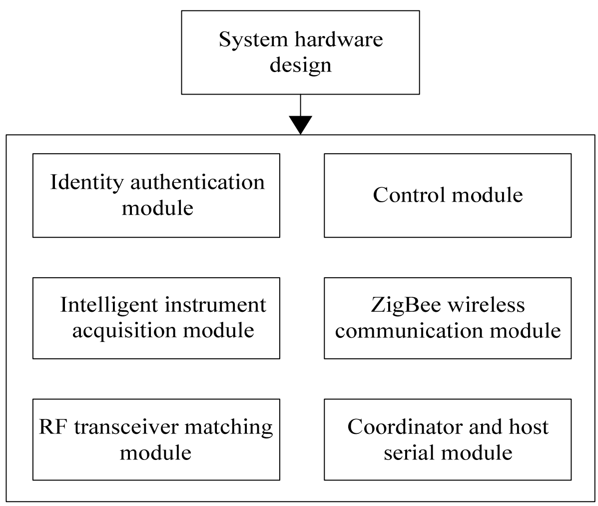
Charging piles are usually installed outdoors, usually unattended, so self-service card swiping is the best choice.

As the core part, the whole system is information collection, which plays a very important role in user identification and electric parameter monitoring of charge pile.

In the process of normal operation, the quality of different components in the DC measurement traceability system of charging pile needs to be guaranteed, among which the selection of all components must be industrial grade. In the process of hardware design, it needs to know the function target of the whole system in detail. In addition, the selection of system core chips is also very important. It is necessary to select chips suitable for the system to ensure the stable operation of the system.

Combined with the internet of things technology, the following hardware part of the system is designed, and the specific structure diagram is shown in Figure 2.

Figure 2 Hardware structure diagram of DC measurement traceability system of charging pile



In order to improve the efficiency of the traceability system, the following hardware modules are designed to significantly improve the transmission rate of measurement data of DC charging pile, and fundamentally solve the problem of low traceability efficiency of the traceability system. The hardware part of the system mainly includes the following modules, which are detailed as follows:

(1) Authentication module:

The IC card reader is mainly used for user identification. The module is mainly composed of the following two parts, namely:

- RF module
- terminal node.

The power supply voltage of the card reader shall be set in the range of 9~15V, and the voltage of the external power supply shall be set as 12V.

(2) Control module:

In order to ensure the stable operation of the system, the system will select the relay as the control unit, which belongs to the electrical control device. When the input value in the system reaches the set change requirements, the controlled value needs to be converted (Gao, 2017; Liu et al., 2016; Xue et al., 2016).

In the hardware design of the system, relay is the most direct and simple control channel, and it is also the realisation of the most basic functions of the whole system. In the process of practical application, the durability of the device itself needs to be considered comprehensively. At the same time, in the process of selecting devices, we need to select the best relay to ensure the stable operation of the system (Zhao et al., 2016a; Wang and Wen, 2016).

(3) Intelligent instrument acquisition module:

In the process of the module design, the electric pile parameters are selected by the multi-functional electric side instrument, which is mainly responsible for the selection of the electric parameters in the three-phase system.

Among them, the AC side is mainly composed of the following two parts, respectively:

- Electric energy measurement;
- Signal acquisition.

  The current part is mainly measured by current transformer (Han et al., 2016; Zhao et al., 2016b), and the AC energy is displayed by AC intelligent number.

- ZigBee wireless communication module:

  The core of the module is the microprocessor, which determines the data processing ability and operating efficiency of the system. At the same time, the module can also realise the establishment and maintenance of the network.

- RF transceiver matching module:

  This module has a great influence on the system, it can complete the conversion between RF balance and imbalance, and also can complete the matching of antenna anti-group (Zhao et al., 2016c; Li and Wang, 2016).

- Coordinator and upper serial port module:

  The module is in the full function node of the system, and only one coordinator can be included in the whole system.

Through the combined application of the above-mentioned modules, the collection and transmission efficiency of the DC charging pile measurement data can be greatly improved, thereby improving the traceability efficiency of the entire traceability system.

2.2 DC measurement traceability method of charging pile based on fuzzy clustering

Traditional methods will lead to large errors in the measurement results. In order to ensure the accuracy of the measurement results, this paper uses a fuzzy clustering algorithm to perform real-time frequency division detection on the specified integer harmonics and fundamental current to reduce the measurement error and improve the traceability system Accuracy. The software part of the system mainly uses the fuzzy clustering algorithm to analyse the harmonics and reactive current of the power grid.

Fuzzy clustering is one of the main technologies of unsupervised machine learning. It is a method of analysing important data by using fuzzy theory, and describes the uncertainty of data by clustering samples. Fuzzy clustering algorithm originated from pattern clustering theory, which is an analysis method to establish fuzzy similarity relationship based on the characteristics and similarity between data, and then cluster the data. The fuzzy clustering algorithm constructs a fuzzy partition matrix, calculates different degrees of similar membership, determines the distance in each cluster, and thus completes the clustering analysis of the data.

In the case of large load change and large amplitude change of current waveform, the current mileage needs to be set as 1A, in this case, the corresponding parameters need to be considered. For wide dynamic range signal processing, there are generally two situations:

- basic cost considerations;
- conversion between different schemes.

In the actual operation process, in order to determine the different sampling point values, feedback control must be introduced (He et al., 2016; Liu and Wan, 2016), but the increase of the whole link will lead to the system response delay, and the impact load also has a very complex frequent conversion characteristics, so the system delay will lead to the formation of mileage switching error, resulting in inaccurate final measurement results.

In order to detect the power meter with dynamic distortion load, a power amplifier is needed (Du and Wu, 2016; Du and Wu, 2016). In the system, the main use mode of power source is analogue power amplifier. It can effectively avoid the useless harmonic accumulation brought by modulation signal, and at the same time, it can minimise the uncertain factors of harmonic. Combined with data predistortion technology and standard table feedback, the actual output harmonic and theoretical harmonic waveform are compared, and the ideal harmonic value is output.

Ignoring the DC feedback, the fuzzy clustering algorithm is used to cluster the fundamental DC without RC compensation feedback, and the following formula can be obtained:

$$\tilde{V}_i = \tilde{I}_1 F_{ac} + \tilde{I}_2 K_1 \tag{1}$$

In the above formula, F_{ac} stands for fuzzy clustering coefficient; K_1 is the ratio of T_1.

Let $\tilde{U}_1$ represent the first input voltage; $\tilde{I}_2$ represents the converted current value; z' represents the converted load; Z_1 represents primary winding impedance; Z_2 represents the secondary winding impedance (Liu and Zheng, 2016; Liu et al., 2019b), and the values of which are usually small. In order to operate simply, the calculation of the two is omitted in this paper, where:

$$\tilde{I}_2' = \frac{\tilde{I}_2}{K_2} \tag{2}$$

$$I_0 = \tilde{I}_2' \frac{Z'}{Z_m} \tag{3}$$

In the above formula, K_2 represents the ratio of converter T_2; $\tilde{I}_2'$ represents secondary current; I_0 represents the excitation current.

By substituting the above two formulas into formula (1), the following formula can be obtained:

$$\tilde{V}_i = \left[\frac{F_{ac}}{K_2} \left(\frac{Z'}{Z_m} + 1 \right) + K_1 \right] \tilde{I}_2 \tag{4}$$

$$\frac{\tilde{I}_2}{\tilde{V}_i} = \frac{1}{\dfrac{K_2 F_{ac} Z'}{Z_m} + K_2 F_{ac} + K_1} \tag{5}$$

Using fuzzy clustering algorithm, it can accurately deduce the calculation formula of Z_m:

$$Z_m = \frac{\frac{f}{50}}{\left(\frac{f}{50}\right)^{1.3}} Z_{m50} \tag{6}$$

In the above formula, f stands for frequency; Z_{m50} represents the impedance value at 50 Hz.

By substituting formula (6) into formula (5), the following formula can be obtained:

$$\frac{\tilde{I}_2}{\tilde{V}_i} = \frac{1}{\left[\dfrac{K_2 Z_m \left(\frac{f}{50}\right)^{1.3}}{Z_{m50 \frac{f}{50}}} + K_2 \right] F_{ac} + K_1} \tag{7}$$

Where

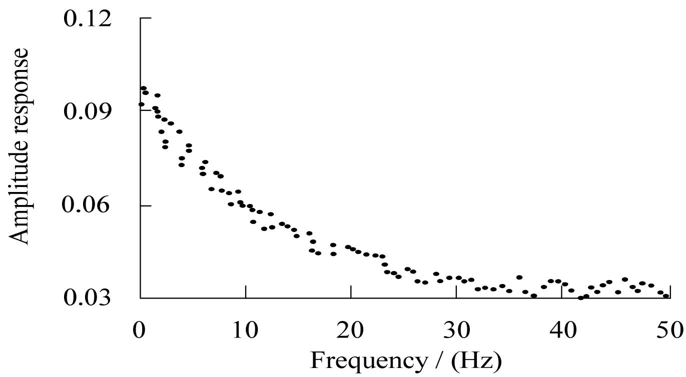
$$\delta = 50 K_2 Z_m \left(\frac{f}{50} \right)^{1.3} + K_2 Z_{m50} \tag{8}$$

The equivalent clustering coefficient of RC compensation network can be expressed in the following forms:

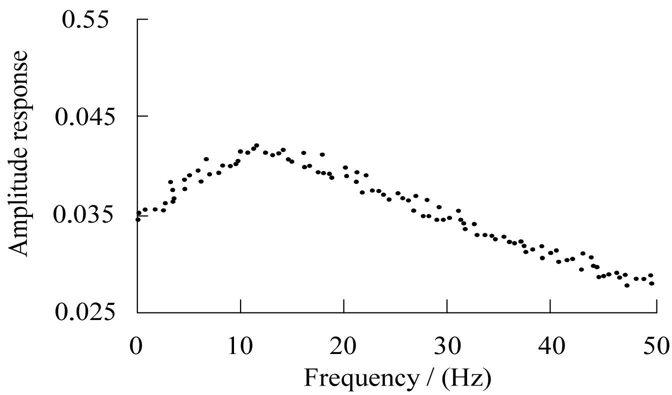
$$F_{rc} = \frac{R_1}{j2\pi fRC} \tag{9}$$

In the above formula, R_1 represents the sampling resistance value; C represents the compensation capacitance value; R represents the resistance value.

Figure 3 Change of frequency response curve (a) before and (b) after RC compensation

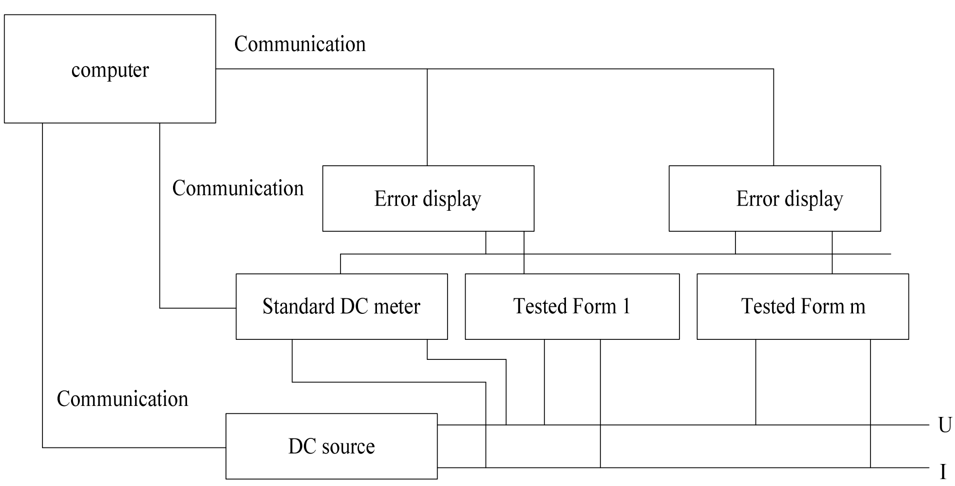


(a)



(b)

Figure 4 Overall verification diagram of DC device of charging pile



After clustering by RC network compensation (Ding et al., 2016; Ha et al., 2019), integer harmonic and fundamental current can be expressed in the following forms:

$$\tilde{V}_i = \tilde{I}_1 F_{ac} + \tilde{I}_2 K_1 + \tilde{I}_1 F_{ac} + \tilde{I}_2 F_{rc} \tag{10}$$

The frequency response curves before and after RC compensation is shown in Figure 3.

In order to effectively detect the DC electric energy meter used in electric vehicles, this paper has established a 0.05-level DC electric energy meter overall verification device. The DC overall verification device for charging piles is given in detail using Figure 4.

Through the above software design, the effective and accurate traceability of the DC measurement of the charging pile is completed.

3 Simulation experiment

In order to verify the comprehensive effectiveness of the designed DC metering traceability system of charging piles considering the internet of things and fuzzy clustering, simulation experiments are needed. Because electricity measurement will be affected by the environment of the inspected unit, it is necessary to conduct experimental tests for electricity measurement in different environments. The experimental hardware environment is: Windows10 operating system, core processor ARM Cotrex-MO+ 32-bit processor, speed 50MHz, experimental data size is 10GB.

The experimental scheme is set as follows: the basic error of the electrical energy of the device, the traceability efficiency, and the traceability error are used as experimental comparison indicators, and the designed system is compared with Zhang et al. (2019a, 2019b) and Fan et al. (2019) systems for verification.

- *Basic error of device power*: The basic error of device power refers to the relative error of device power in different systems under different harmonic orders and harmonic power factors. The lower the error, the higher the traceability stability of the system.
- *Traceability efficiency*: Traceability efficiency refers to the time spent by different systems when tracing the same measurement data. The shorter the time, the higher the traceability efficiency.
- *Source tracing error*: Source tracing error refers to the situation where three types of systems have erroneous source tracing under different frequency bands and different interferences. The lower the source tracing error, the higher the accuracy of the source tracing, which can ensure the validity of the measurement data.

3.1 Comparison of basic electric energy error of the device

In order to fully verify the effectiveness of the designed system in this paper, three traditional DC measurement traceability systems of charging piles are selected as the comparison system. The specific comparison results are shown in Tables 1–4:

Comprehensive analysis of the above experimental data shows that the basic error of the device electric energy of the designed system is the lowest among the four charging pile DC metering traceability systems, which fully demonstrates the effectiveness and superiority of the designed system. Because the designed system uses fuzzy clustering algorithm to calculate the specified integer harmonic and fundamental current more accurately, so it has a lower basic error of electric energy device.

Table 1 Basic error of electric energy of the designed system

Number of harmonic (times)	*Harmonic power factor*	*Relative error*/(%)			
		Phase A	*Phase B*	*Phase C*	*Three-phase*
4	4.0	0.0041	0.0027	–0.0017	–0.0038
	2.0	–0.0052	–0.0028	0.0054	–0.0049
	–4.0	–0.0022	–0.0035	0.0064	–0.0020
14	4.0	0.0041	0.0052	0.0021	–0.0011
	2.0	–0.0047	0.0061	0.0037	0.0022
	–4.0	0.0014	0.0028	0.0030	–0.0018
24	4.0	0.0041	0.0012	0.0019	0.007
	2.0	0.0079	0.007	0.0063	0.0080
	–4.0	0.0023	0.0014	0.0043	0.0069
34	4.0	0.0025	–0.0045	0.0047	–0.0074
	2.0	–0.0010	–0.0018	–0.0025	0.0051
	–4.0	0.0026	–0.0009	0.0010	0.0031

Table 2 Basic error of electric energy of devices in Zhang et al. (2019a)

Number of harmonic (times)	*Harmonic power factor*	*Relative error/(%)*			
		Phase A	*Phase B*	*Phase C*	*Three-phase*
4	4.0	–0.0089	0.0097	0.0095	0.0039
	2.0	0.0097	–0.0084	0.0055	0.0046
	–4.0	0.0077	–0.0098	0.0044	0.0084
14	4.0	0.0048	0.0075	0.0064	0.0076
	2.0	0.0069	–0.0084	–0.0087	0.0045
	–4.0	0.0095	0.0048	–0.0095	–0.0098
24	4.0	0.0086	–0.0065	–0.0056	–0.0065
	2.0	0.0079	0.0044	–0.0072	–0.0077
	–4.0	0.0055	0.0077	0.0041	–0.0086
34	4.0	0.0084	0.0087	0.0061	–0.0085
	2.0	0.0048	0.0085	0.0025	0.0055
	–4.0	0.0068	0.0078	0.0036	0.0092

Table 3 Basic error of electric energy of devices in Zhang et al. (2019b)

Number of harmonic (times)	*Harmonic power factor*	*Relative error/(%)*			
		Phase A	*Phase B*	*Phase C*	*Three-phase*
4	4.0	0.0101	0.0082	0.0092	–0.0062
	2.0	0.0082	0.0090	0.0094	–0.0081
	–4.0	–0.0092	0.0042	0.002	–0.0093
14	4.0	–0.0081	0.0077	0.0082	–0.004
	2.0	0.0095	0.0034	0.0041	–0.0097
	–4.0	–0.0056	–0.0086	0.0087	–0.0044
24	4.0	–0.0095	–0.0095	0.0080	0.0071
	2.0	–0.0079	0.0088	0.0051	–0.0045
	–4.0	0.0086	–0.0077	0.0072	0.0062
34	4.0	0.0095	0.0078	0.0081	0.0051
	2.0	0.0071	0.0067	0.0080	0.0081
	–4.0	0.0098	0.0088	0.0083	0.0088

Table 4 Basic error of electric energy of devices in Fan et al. (2019)

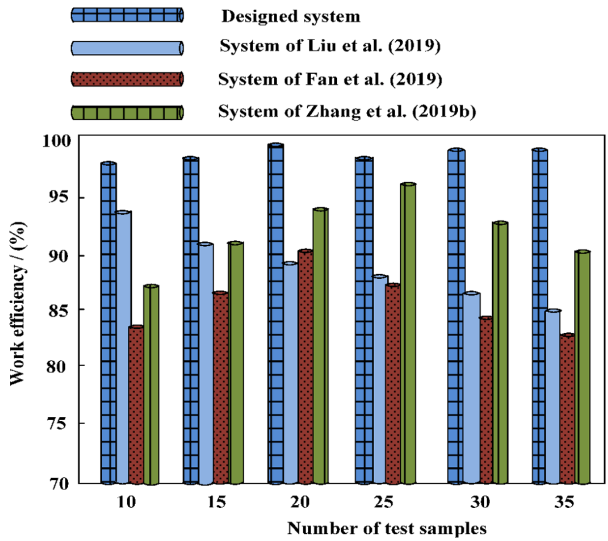
Number of harmonic (times)	*Harmonic power factor*	*Relative error/(%)*			
		Phase A	*Phase B*	*Phase C*	*Three-phase*
4	4.0	–0.0102	0.0081	0.0087	–0.0078
	2.0	–0.0121	0.0078	0.0091	–0.0089
	–4.0	–0.0159	–0.0081	0.0092	–0.0064
14	4.0	0.0095	–0.0099	–0.0095	–0.0095
	2.0	–0.0075	–0.0085	0.0078	–0.0067
	–4.0	0.0088	0.0084	–0.0082	–0.0094
24	4.0	0.0069	–0.0111	0.0079	0.0061
	2.0	0.0055	–0.0082	–0.0091	–0.0085
	–4.0	0.0078	0.0133	–0.0101	–0.0102
34	4.0	0.0045	–0.0157	–0.0122	–0.0112
	2.0	0.0045	0.0128	0.0130	–0.0091
	–4.0	0.0085	0.0149	0.0098	–0.0130

3.2 Traceability efficiency comparison

The following is the working efficiency comparison of four different DC measurement traceability systems of charging piles, and the specific comparison results are as shown in Figure 5.

Analysis of the experimental data in Figure 5 shows that the designed system has higher work efficiency than the other three systems. The designed system uses ZigBee wireless communication technology to build a transmission network. Through wireless communication module, RF matching module, etc., the transmission rate of measurement information is greatly improved, so as to improve the overall traceability efficiency.

Figure 5 Comparison results of work efficiency of different systems (see online version for colours)



3.3 Traceability error comparison

On the basis of the above experiments, the absolute error changes of each system under different interference degrees are compared as shown in Table 5.

Table 5 Absolute error changes under different interference degrees

		Absolute error/(%)			
Interference degree/(%)	*Frequency band*/(MHz)	*The presented system*	*Designed system in Zhang et al. (2019a)*	*Designed system in Fan et al. (2019)*	*Designed system in Zhang et al. (2019b)*
3	0.30~1.0	0.012	0.012	0.020	0.034
5	1.0~8.0	0.008	0.015	0.025	0.039
7	8.0~13.0	0.006	0.016	0.031	0.045
9	13.0~18.0	0.007	0.017	0.036	0.049
11	18.0~25.0	0.004	0.020	0.040	0.053
13	25.0~32.0	0.002	0.024	0.045	0.057
15	32.0~38.0	0.003	0.027	0.047	0.061
17	38.0~45.0	0.002	0.031	0.051	0.066
19	45.0~52.0	0.004	0.035	0.057	0.070
21	52.0~60.0	0.001	0.038	0.060	0.075
23	60.0~66.0	0.001	0.041	0.065	0.081
25	66.0~75.0	0.002	0.043	0.068	0.088
27	75.0~81.0	0.001	0.045	0.072	0.094
29	81.0~88.8	0.003	0.048	0.0077	0.099

Comprehensive analysis of the experimental data in Table 5 shows that with the increase of interference, the absolute error of each system is also changing, and the absolute error of the designed system is obviously lower, which fully verifies the superiority of the designed system. The software part of the designed system uses fuzzy clustering algorithm to detect the harmonic and fundamental current by frequency division, which can obtain more accurate detection results, so the traceability result error is small.

4 Conclusions

Aiming at a series of problems existing in the traditional charging pile DC metering traceability system, combined with the internet of things and fuzzy clustering algorithm, a new charging pile DC metering traceability system is designed, which proves the following conclusions from both theoretical and experimental aspects. This system has higher traceability efficiency and lower traceability error when performing DC measurement traceability of charging piles. Specifically, compared with the system based on the side chain technology, the traceability efficiency of the designed system is significantly improved, and the maximum traceability efficiency can reach 99%; compared with the system based on the SSH framework, the traceability error is greatly reduced, and the minimum traceability error is only 0.001. Therefore, it is fully proved that the proposed traceability system considering the internet of things and fuzzy clustering algorithm can better meet the requirements of the DC metering traceability of the charging pile, and has a broad application prospect. The operating cost of the designed system is still relatively high at this stage, and follow-up research will focus on this aspect.

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