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Automatic Detection System of New Energy Vehicle Charging Pile Based on Image Recognition

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***Abstract* –In this paper, the active electric energy value of the charging pile and its change time scale are obtained through the image recognition algorithm, and the low-pass filter algorithm is used to filter out the time scale jitter. By calculating the active electric energy value (*Ex*) of the charging pile in the time scale interval and the standard electric energy value (*Eb)* in the same interval, the active electric energy error is calculated according to the electric energy comparison method. Compared with the traditional energy comparison method, the verification time is related to the minimum quantitative value of active electric energy, The verification time of this method is only related to the jitter of time scale and the quantization error of camera, which can greatly improve the verification efficiency of low-power charging pile.**

***Keywords* –image recognition, the charging pile, the jitter of time scale**

I. INTRODUCTION

The important basis for trade settlement of charging piles is active electric energy[1]. Most of the charging piles in stock have no pulse detection output of hardware, and only the accuracy of active electric energy can be measured by electric energy comparison method, This method must meet the requirements of "the standard meter shall operate synchronously with the tested charging pile, and the ratio (%) of the electric energy value represented by the last word (or minimum Division) of the tested charger display to the accumulated shall not be greater than 1/10 of the grade index of the tested charger"[2]. Since the resolution of the active electric energy value of the charging pile is mostly 0.01 degrees, in order to meet the requirements, the minimum cumulative electric energy will reach 10kWh, resulting in very slow measuring speed. Under small working current, it takes more than 30min for a single test point. The regulation also requires that "the average value of two errors is taken as the verification result", then the verification time will be doubled; The verification time of other items in the regulation is about 10min[3][4]. In addition, the on-site operation seriously restricts the work efficiency and cannot complete the verification task. The detection technology based on image recognition algorithm adopted in this paper can ensure that a point can be verified within 17min regardless of the detection current, which greatly improves the verification efficiency of charging pile under small current[5][6].

II. TECHNICAL SCHEME

In order to solve the problem of slow measuring speed, the image recognition technology is used to read the active electric energy of the charging pile. Combined with the filtering algorithm, the full-automatic and rapid verification of the charging pile can be realized, the work efficiency can be improved and the human error can be reduced. It can be applied to the laboratory, on-site detection and the factory detection of the charging pile equipment.

The active energy value displayed by the camera on the charging pile is obtained through the convolution neural network (CNN) algorithm, and the digital active energy value and change time scale value are obtained. The delay jitter is filtered through the low-pass filter algorithm, And reconstruct the time scale value of the active power value collected by the camera, calculate the standard power value (*Eb*) collected by the AD acquisition module in the interval from the $M + 1$ time scale value (M is the screen refresh rate) to the nth time scale value (n is the cut-off frequency of the filter), compare the power value (*Ex*) collected by the camera in the same time zone, and calculate the active power error according to the power comparison method.

As shown in *Figure 1*, the detection system is composed of USB camera, DSP processing motherboard, computer, USB to serial port, electric vehicle analog load, vehicle DC charging interface circuit simulator, current sensor, power module, proportional partial voltage resistance and AD acquisition module.

Among them, the USB camera can manually adjust the focal length, which can be well focused to the active power data. Its magnification is 20 ~ 220 times, continuously adjustable, and the frame rate is 45fps; DSP processing motherboard adopts DSP-BF609 EZ-KIT Lite of ADI, which meets the calculation performance and interface requirements of the system; The analog load of electric vehicle adopts equivalent resistance or electronic load or directly adopts rechargeable battery, and the resistance value of the load can be set through CAN bus; The electric vehicle charging interface circuit simulator adopts the charging pile control guidance detection device for simulation, or other equipment meeting the requirements of relevant standards can be used to simulate the communication and interoperability between electric vehicle and charging pile; The current sensor is used to convert the current signal into voltage signal for AD acquisition module to collect; The power module outputs customized power supplies of ±5V and ±3.3V, and the current output capacity is 2A; The proportional voltage dividing resistance is composed of 2kΩ, 0.01% precision resistance and 998kΩ, 0.01% precision resistance, and the transformation ratio is 500:1.

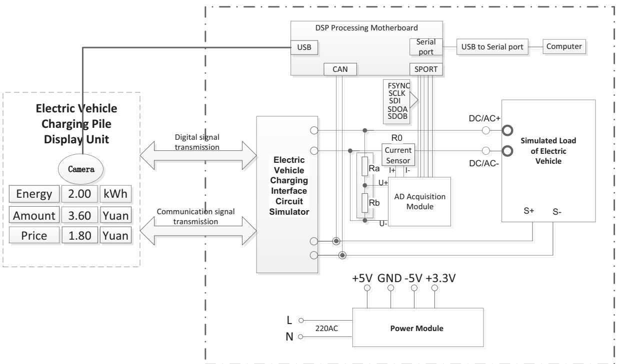

Fig. 1. Block diagram of detection system.

III. WORKING PRINCIPLE

The proportional voltage divider reduces the voltage signal by 500 times, and the current sensor converts the current signal into a voltage signal and inputs it to the AD acquisition module. The AD acquisition module continuously collects the signal values of voltage and current channels at a sampling rate of 1ksps, calculates the current standard electric energy value EBI according to equation 1, and saves the corresponding time scale value T_{bi} (unit: Second).

$$Eb_{\mathrm{i}} = \sum_{m=1}^{i} \frac{U_m \times I_m \times T_s}{3600 \times 1000} \quad (1)$$

T_{s}: refers to the sampling time interval. The sampling rate of the system is 1ksps, so the sampling interval is 0.001 seconds; U_{m}: sampling value of voltage, unit: V; I_{m}: sampling value of current, unit: A; *I*: Is the current sampling point; *m*: Is a historical sampling point.

At the same time, continuously receive the image signal, analyze the electric degree value of active electric energy (*Ex*) through CNN algorithm, and save the corresponding time scale value (T_{n}'), after passing through the low-pass filter, reconstruct the time scale value (T_{n}'') according to formula 10.The low-pass filter M = 20th order, the cut-off frequency is 0.01fs (Fs sampling rate which is the time interval for the camera to read the change value of electric energy each time), Through the reconstructed time scale value *Ex* of the electric energy value of the tested electric energy meter in the corresponding interval of $T_{M+1}''$to T_{n}'', and the standard electric energy meter value *Eb* of the corresponding time period of AD acquisition module, calculate the active electric energy error of the charged pile according to formula 4. The calculation of standard electric energy meter *Eb* (referring to the electric energy calculated by AD acquisition module according to Formula 1) is shown in formula 2.

$$Eb = Eb_{m2} - Eb_{m1} \quad (2)$$

Eb_{m1} is the electric energy value Ex_{M+1} of the standard electric energy meter at the corresponding time of the tested charging pile; Eb_{m2} is the electric energy value Ex_n of the standard electric energy meter at the corresponding time of the tested charging pile.

The electric energy value of the tested charging pile in this time period is

$$Ex = Ex_n - Ex_{M+1} \quad (3)$$

So as to calculate the error value of active electric energy γ by

$$\gamma = \frac{Ex - Eb}{Eb} \times 100\% \quad (4)$$

IV. PRINCIPLE OF IMAGE RECOGNITION

Image recognition only involves the recognition of numbers 0 ~ 9. In order to simplify the design, as shown in *Figure 2*, we only need to manually frame the individual, tenth and percentile images of active electric energy through the mouse, and then classify them according to 0 ~ 9 respectively. Since the maximum electric value tested by the charging pile based on image recognition does not exceed 9.99kwh, generally 1.00 kwh can meet the requirements of test accuracy.

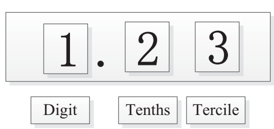

Fig. 2. Image analysis diagram.

Manually framing three numbers can greatly reduce the boundary recognition of the image. After framing, the data matrix (U8 RGB_Digit $[m_1][n_1][3]$,U8 RGB_Tenths$[m_2][n_2][3]$,U8 RGB_Tercile $[m_3][n_3][3]$,

m_1,m_2 and m_3 are the total pixels of the row of the image intercepted by the mouse, and n_1,n_2 and n_3 are the total pixels of the column of the image framed by the mouse) of three digital images can be obtained by reading the images of three numbers, RGB pixels are stored in the array, and the color pixels are converted into gray pixels (U8 Gray_Digit[m1][n1], U8 Gray_Tenths[m2][n2]、 U8 Gray_Tercile [m3][n3]) through RGB to gray function, which coexists in the digital matrix, True color image is m × n × 3 numerical array, grayscale image is m × n numerical array, evenly extract the three digital pixel matrices into 28 × 28 digital matrices, the purpose is to match the existing MNIST dataset, the extracted array is U8 Mnist_Digit[28][28],U8 Mnist_Tenths[28][28], U8_UnitTercile[28][28]. As the background color of the active electric energy of the charging pile and electric value of the electric degree value displayed are basically fixed in two colors, according to this known information, we can store the gray level of 28 × 28 digital matrices are further binarized, if the gray value of and 4 edges and corners which is within ± 50 is 0, otherwise the gray value is 1,as shown in formula 5. Then, the numerical classification of individual Digit, tenth and Tercile is recognized by CNN, and the electric energy value recognized by the current image is obtained according to equation 6.

$$f(v)=\begin{cases}0 & \mathrm{Mod}(v+256-vb)\leq 50\\ 1 & \mathrm{Mod}(v+256-vb)>50\end{cases} \quad (5)$$

vb is the average gray value of the four corners, and *v* is the gray value of the current pixel color.

$$Ex_i = \mathrm{Digit}\times 1+\mathrm{Tenths}\times 0.1+\mathrm{Tercile}\times 0.01 \quad (6)$$

The frame rate of the camera is 45Hz, so there will be one frame of image every 22ms. If the image value of this frame is different from that of the previous frame (the first frame is directly stored), store the current electrical value Ex_i and the current time scale T_i', as shown in *Figure 3*, the charging pile interface displays electric energy and time scale.

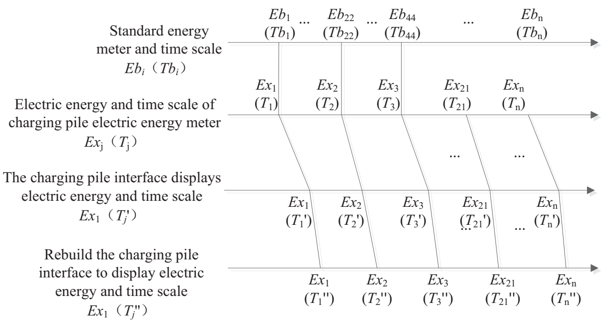

Fig. 3. Principle of time synchronization between electric energy and time scale.

CNN needs to use MNIST data set for training before use. It can also binarize MNIST data set according to the middle value of gray level for training. The program will save the learned parameters and can be used directly without training next time. There are 70000 pictures in MNIST dataset, including 60000 for training CNN and 10000 for testing CNN. Each picture is a 28 ×28 Handwritten digital pictures of 0 ~ 9 pixels. Each sample is a 28 × 28 pixel gray handwritten digital picture with white characters on black background.

V. TIME SCALE JITTER PROCESSING

The camera can obtain a time scale with a time standard accuracy of 22ms. Because the charging pile displays the electric energy by acquiring the data of the metering module in the pile, the inconsistent communication time of the read data will cause the time scale of image recognition to shake, as shown in *Figure 4*. The time interval of electric energy measurement of the metering module in the tested charging pile is even, but the time scale displayed on the charging pile interface is uneven. Therefore, the detection time of the charging pile must be prolonged to obtain sufficient accuracy, Assuming that the maximum jitter of the time scale is 0.5s, and just the last jitter time scale is 0.5s, In this way, according to the system control error of 0.1%, the detection time is 0.5s×1000=500s. Since the power output of the charging pile is very stable and the power calculation is shown in formula 7, the difference between each active electric energy value and the last active electric energy value is taken as the input, If $\Delta T_i = Tx_i - Tx_{i-1} > 0$, formula 7 can be rewritten into formula 8. A low-pass filter is designed to conduct low-pass filtering for the function Δ T, filter out the time scale jitter, so as to restore to the time scale of the metering module in the tested charging pile, and reduce the influence of jitter by 10 times or less. As shown in *Figure 4* and *Figure 5*.

$$P_i=\begin{cases}\dfrac{Ex_i-Ex_{i-1}}{Tx_i-Tx_{i-1}} & i>0\\ \dfrac{Ex_0-0}{Tx_0-0} & i=0\end{cases} \quad (7)$$

$$\Delta T_i=\begin{cases}\dfrac{Ex_i-Ex_{i-1}}{P_i} & i>0\\ \dfrac{Ex_0-0}{P_0} & i=0\end{cases} \quad (8)$$

ΔT_i adopts FIR finite impulse filter, and its difference equation is shown in formula 9.

$$\mathrm{y}(n)=\sum_{k=0}^{M} b_k x(n-k) \quad (9)$$

y(*n*) is the output value of the filter; *x*(*n*-*k*) is the input value of the filter; *M*: Is the order of the filter: 20; *b*: Is the filter coefficient.

The coefficient of filter is the key of FIR filter. Various filters can be generated by modifying the coefficient. The order of filtering is designed as M = 20, and the cut-off frequency is set to the sampling rate of

0.01. The filter coefficient is obtained by fir1 of MATLAB: Set $M = 20$, W_n=0.02% (W_n corresponds to half of the sampling frequency), b=fir1(M，W_n,，'low'), The filter coefficient of B is b=[0.0070,0.0090,0.0149,0.0243, 0.0361,0.0494, 0.0627,0.0749,0.0845,0.0908, .09290,0.0908, 0.0845,0.0749,0.0627,0.0494,0.0361,0.0243, 0.0149,0.0090,0.0070]. The input data of FIR filter is $\Delta T_j'$, as shown in *Figure 4*, and the output data of FIR filter is $\Delta T_j''$, as shown in *Figure 5*. Since the phase shift of FIR filter is m / 2 = 10, as shown in Figure 5, the first 10 numbers are invalid.

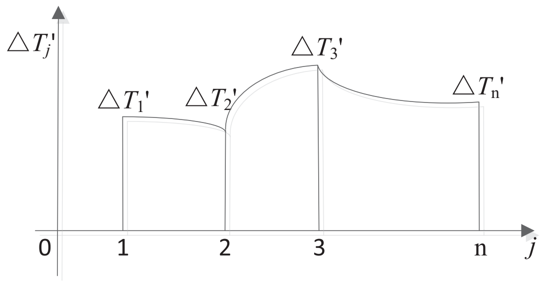

Fig. 4. Camera reading time scale interval.

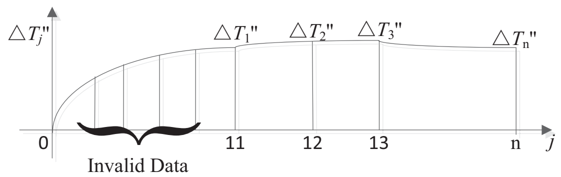

Fig. 5. Time scale interval after filter.

As shown in *Figure 3*, reconstructing the time scale of the charging pile display interface according to the output result of the filter is actually filtering out the reading delay jitter and restoring the real time scale close to the metering module in the tested charging pile, as shown in formula 10.

$$T_n'' = \sum_{k=2}^{n} \Delta T_{n+M/2}'' + T_1' \quad (10)$$

$$T_1'' = T_1' \text{且} n>1$$

The filter output is delayed by M/2 points. After T_n' passes through the low-pass filter, the purpose is to reduce the impact of time scale jitter on the measurement error. The time scale interval of T_n'' 'after filtering is closer to the real time scale T_n of the metering module in the charging pile. M sampling points are required to completely restore the FIR filter. In this system, the start of intercepting data starts from T_{11}' and the corresponding filter output is T_{M+1}''.

VI. PRINCIPLE OF ELECTRIC ENERGY CALIBRATION

As shown in *Figure 6*, search the time scale Tb_{m1} closest to T_{M+1}'' in the time scale Tb[0,m] of the standard electric energy meter, the retrieval method is to find the number of I with $Tb_i - T_{M+1}''$ as the minimum value, and the number is $m1$. Then search the time scale Tb_{m2} closest to T_n'' in the time scale Tb[0,m] of the standard electric energy meter. The search method is to find the number of i with $Tb_i - T_n''$ as the minimum value, and the number is $m2$. The value of n is related to the charging power of the charging pile. The value algorithm is that the test time is greater than 100 seconds, that is, assuming that the time jitter after filtering is less than 0.1 seconds and the additional error is less than 0.1%. According to the requirements of the regulations, it can only reach the additional error of 0.1%. The time resolution of Tb_i is 1ms, and the time resolution of the electric energy meter of the charged pile is 22ms. Relative to the operation error of 0.1s, it can be ignored. In this way, in the same time interval, the electric degree value of the standard electric energy meter is calculated according to equation 2, the electric degree value of the electric energy meter of the tested charging pile is calculated according to equation 3, and the active electric energy error value calculated by comparing the standard and the tested electric energy meter value is calculated according to equation 4.

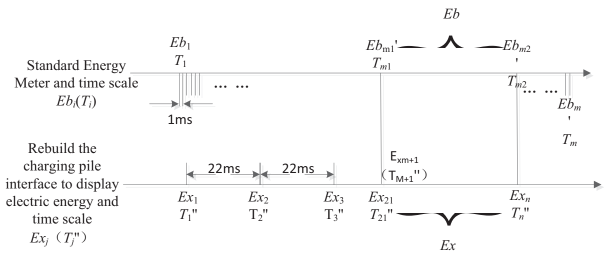

Fig. 6. Acquisition of electric energy and time scale.

VII. TEST RESULTS AND ANALYSIS

As shown in *Figure 7*, the field test is carried out according to the method in this paper.

The traditional electric energy comparison method and the method based on image recognition are measured respectively. The test time takes the level 1 charging pile as an example. The duration of one-time verification of an error verification point (for the stock pile with the current resolution of 0.01 degrees) is shown in the table below. According to the requirements of the verification regulation, the measurement is carried out when the output current of the charging pile is Imin, 0.5imax and IMAX respectively. The comparison results are shown in Table 1, Table 2 and Table 3:

Fig. 7. Field test picture.

Table 1. Comparison of verification time of DC charging pile.

Output Power	Electric Energy Comparison Method	Image Recognition Method
570 V 5 A(I_{min})	210 min	16.7 min
570 V 120 A($0.5I_{max}$)	8.7 min	16.7 min
570 V 250 A(I_{max})	4.2 min	16.7 min
Total Time	222.9min	50.1 min

Table 2. Comparison of verification time of Single-phase AC charging pile.

Output Power	Electric Energy Comparison Method	Image Recognition Method
220 V 0.5 A(I_{min})	2727 min	16.7 min
220 V 16 A($0.5I_{max}$)	85 min	16.7 min
220 V 32 A(I_{max})	43 min	16.7 min
Total Time	2885 min	50.1 min

Table 3. Comparison of verification time of Three-phase AC charging pile.

Output Power	Electric Energy Comparison Method	Image Recognition Method
220 V 1 A(I_{min})	909 min	16.7 min
220 V 32 A($0.5I_{max}$)	28.4 min	16.7 min
220 V 63 A(I_{max})	14.4 min	16.7 min
Total Time	951.8 min	50.1 min

The experimental data show that through the error verification of charging pile based on image recognition, The efficiency of off-board charger is increased by 4.5 times, the efficiency of single-phase AC charging pile is increased by 57 times, and the efficiency of three-phase AC charging pile is increased by 19 times. For the verification of low power output points of AC charging pile or DC charging pile, the time advantage is obvious, so this method is recommended for verification. When the output power of DC charging pile is large, there is no obvious efficiency advantage, but the total verification time is significantly shortened and the efficiency is significantly improved.

VIII. CONCLUSION

By designing a low-pass filter with a cut-off frequency of 0.01fs (sampling rate), the random time jitter returned by the DC electric energy meter is effectively filtered, the detection time scale is reconstructed, the random time jitter is reduced, and the rapid detection of active electric energy of the charging pile is realized.

The charging pile error verification based on image recognition does not change the verification method of the national metrological verification regulation, nor does it violate the principle of making the system error meet 1 / 10 of the grade index and ignoring the influence of the system error. Its verification time is greatly shortened and the efficiency of charging pile verification is greatly improved.

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