A multi-channel power input automatic switching system based on power quality analysis

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Abstract—A Multi-channel power input automatic switching system used for mobile vehicle equipment based on power quality analysis is proposed in this paper. The basic measurement principle of power quality analysis is introduced first, based on this principle, a hardware implementation of the power quality analysis unit is fulfilled, including function diagram, measurement sampling circuit, and communication interface circuit. A communication interface protocol is designed based on CAN bus used for interaction between the multi-channels of power supply input. Based on the power quality analysis unit, the multi-channel power input automatic switching system is proposed driven by the priority of input channel determined by sharing the data of the power quality between the multi-channel power supplies.

1. Introduction
Compared with the fixed places such as homes and offices using state grid power supply, mobile vehicle equipment requires at least two input channels of power supply, including grid power supply, diesel generator power and large-capacity battery pack inverter power according to paper [1]. The working environment of the mobile vehicle equipment is tough, the power resources are relatively scarce and unstable compared with the fixed place. With the development of power electronics, lots of high-voltage, large-capacity nonlinear loads get used in mobile vehicle equipment according to paper [2]. This will further aggravate the harmonic pollution of power quality. Power harmonic pollution will not only affect the efficiency of scarce power resources, but also have a huge impact on the components’ life of mobile equipment according to paper [3] and paper [4]. Therefore, it is necessary to measure the parameters of the multi-channel power supply used for vehicle equipment. By analyzing the power quality from the measured results, we can take certain compensation measures accordingly.

2. Power Quality Analysis
The AC distribution network has been widely used in the modern industry due to its advantages of convenient generation, distribution and high transmission efficiency. The theoretical basis of AC distribution network is sinusoidal alternating current.

2.1. Sinusoidal alternating current
The voltage of sinusoidal alternating current changes periodically according to the sine law. The mathematical expression of voltage is:

\[ u = U_m \sin(\omega t + \varphi) \]  \hspace{1cm} (1)

In the formula, \( U_m \) represents the amplitude of the voltage, \( \omega \) represents the angular frequency, and \( \varphi \) is the initial phase of the voltage. For single-phase AC voltage, the amplitude is more often expressed...
by the effective value $U$ in engineering, such as the common AC380V, AC220V. Therefore, the voltage is also expressed as:

$$u = \sqrt{2} U \sin(\omega t + \varphi)$$  \hspace{1cm} (2)$$

Besides voltage, current, frequency, power and harmonics and other parameters can also represent the quality of Power. Among them, power is one of the most important parameters since it relates to the industry economy directly. The related concepts include instantaneous power, active power, reactive power and apparent power.

For a passive single-port load network, the instantaneous power $p(t)$ can be derived from the product of the voltage $u(t)$ and the current $i(t)$ across the port. Assuming $\varphi$ represents the phase between the voltage $u(t)$ and the current $i(t)$, it can be expressed as

$$u(t) = \sqrt{2} U \sin(\omega t), \quad i(t) = \sqrt{2} I \sin(\omega t - \varphi),$$

such that the instantaneous power expressed as:

$$p(t) = u(t) \times i(t) = \sqrt{2} U \sin(\omega t) \times \sqrt{2} I \sin(\omega t - \varphi)$$

$$= U I \cos\varphi - U I \cos(2\omega t - \varphi)$$

$$= U I \cos\varphi \left[1 - \cos(2\omega t)\right] + U I \sin\varphi \sin(2\omega t)$$  \hspace{1cm} (3)

The active power $P$ refers to the average power in one cycle $T$ in the load network, which can be expressed as follows:

$$P = \frac{1}{T} \int_{0}^{T} p(t) dt$$

$$= \frac{1}{T} \int_{0}^{T} U I \cos\varphi - U I \cos(2\omega t - \varphi) dt$$

$$= U I \cos\varphi$$  \hspace{1cm} (5)$$

It can be seen that the active power is a constant, and has nothing to do with the time-based parameter. It physically represents the average power of the resistive loads in the entire load network, reflecting the rate of energy consume in the load network according to paper [5].

Inevitably, capacitive and inductive loads exist in any load network. As is known, these two kinds of loads do not consume energy themselves, but only store energy. The reactive power $Q$ is hence defined to represent them, which is the amplitude of the second part of Formula (4), $Q = U I \sin\varphi$. It reflects the maximum rate of energy exchange between the load network and the source according to paper [6].

Apparent power $S$ is defined as the product of the effective value of voltage and current at the load network, which expresses as $S = U I$, it is the maximum value of active power and reflects the capacity of the load network.

Power factor $\lambda$ is defined as the ratio of active power $P$ to apparent power $S$, namely:

$$\lambda = \frac{P}{S} = \cos\varphi$$  \hspace{1cm} (6)$$

It represents the share of active power in apparent power. The greater the power factor, the higher the utilization rate of electrical energy.

2.2. Harmonic energy

Ideally, sinusoidal alternating current theory can meet the needs of power quality analysis. While in physical power network, the occurrence of lots of nonlinear loads leads to the increasing harmonic components in the power grid. Compared with harmonic power, sinusoidal alternating current is also called fundamental power. According to paper [7], research on harmonic power has shown that the harmonic components derive from the fundamental wave power. It will feed back to the power grid and pollute the power grid quality. Harmonic power increases the cost burden of all users, since it can influence the accuracy of power meter. Lots of research in paper [8] have been done on harmonic power analysis. GB/T 14549-1993 puts forward corresponding requirements for the harmonic content rate and total harmonic distortion rate of the power grid.

The traditional analysis method of sinusoidal alternating current can only calculate the total harmonic power, but the active power of each harmonic cannot be given. Therefore, the analysis of harmonic
power is currently carried out by Fourier transform (FFT) analysis method combined with windowing and interpolation correction algorithm according to paper [9]. The active power and reactive power of harmonic energy can be expressed as \( P \) and \( Q \):

\[
P = \sum_{n=1}^{\infty} U_n I_n \cos \varphi_n,
Q = \sum_{n=1}^{\infty} U_n I_n \sin \varphi_n
\]

\( U_n \) and \( I_n \) represent the effective values of the h-order harmonic voltage and current respectively, and \( \varphi_n \) means the phase between the h-order harmonic voltage and current. The parameters used for harmonic power quality analysis involve harmonic content rate, harmonic content and total harmonic distortion rate. Take voltage as an example:

\[
HRU_h = \frac{U_h}{U_1} \times 100\% \quad (8)
\]

\[
U_H = \sqrt{\sum_{n=2}^{\infty} U_n^2} \quad (9)
\]

\[
THD = \frac{U_H}{U_1} \times 100\% \quad (10)
\]

\( HRU_h \) is the harmonic voltage content rate of the h order, \( U_H \) is the harmonic voltage content, and \( THD \) is the total harmonic distortion rate of the voltage.

3. Hardware Design of Power Quality Analysis Unit

Based on the above theory, a hardware of power quality analysis unit is designed to measure the parameters expressed in Section 2, which can be used for power abnormality monitor.

The functional block diagram of power quality analysis unit is shown in the Fig.1.

![Fig.1 The functional block diagram](image)

The power supply module provides power supply for the entire block. The voltage sampling module converts the AC input voltage of such as AC380 or AC220 into a small signal. And the current sampling module converts AC current into a small voltage signal by a transformer or a Hall component. Both of above signals are sent into measure engine and sampled through a high-precision analog-to-digital conversion unit (ADC), thus various types of parameters for power quality analysis can be calculated out. The action-output interface is used to control the access of the power supply channel. Through the parameter display interface, the needed power parameters are shown. The measurement results can be sent out using the communication protocol through the communication interface.

3.1. Power supply module

The power supply module includes three parts: AC-DC circuit, isolated power supply and power-drop detection circuit. The AC-DC circuit adopts the full-bridge rectification method, which rectifies the AC380 or AC220V input into a DC voltage, and then outputs the DC24V through a flyback switching circuit.
The isolated power supply converts output DC24V into DC5V using isolated methods, which guarantees the safety of human-computer interaction. The power-drop detection circuit is designed to ensure that when the input power supply is powered down, the backup domain register of the MCU used for unit is maintained through the back-up battery.

### 3.2. Voltage and current sampling

![Voltage Sampling Circuit](image1)

The voltage sampling circuit adopts a precise resistor bridge, which divides the input voltage of AC380V or 220V into a small signal at about 100mv.

![Current Sampling Circuit](image2)

Transformer or Hall component is adopted in the current sampling circuit, after which, the AC current is converted into a 40mv small-signal AC voltage through the bridge voltage equalizing circuit.

### 3.3. Measure engine unit

The measure engine unit is based on the RN7326 chip launched by RENERGY, which integrates ARM Cortex-M0 core, 256KB Flash, 48KB SRAM, 7-channel Σ-Δ ADC, 2-channel multiplexed SAR ADC,
and 5-channel multiplexed GP ADC, FFT calculation engine, 2 SPI interfaces, 2 UART interfaces and 31 multiplexed GPIO interfaces. The diagram is shown in Fig.5.

![Diagram of measure engine unit base on RN7326](image)

Fig.5 The hardware diagram of measure engine unit base on RN7326

By configuring the RN7326 peripheral control register, the corresponding pins are configured as 7-channel Σ-Δ ADCs. Among them, 4 channels are used for sampling three-phase voltage signals, and 3 channels are used for sampling phase current signals.

![Diagram of Σ-Δ ADC combine PGA used for sampling](image)

Fig.6 Σ-Δ ADC combine PGA used for sampling

As is known, the accuracy of sampled signal determines the performance of power quality analysis unit. The AC voltage and current parameters have a wide dynamic range. To achieve a high resolution, Σ-Δ ADC in Fig.6 is suitable for sampling this kind of larger dynamic range signal according to paper [10]. By combining the pre-low-noise programmable gain amplifier (PGA) and the post-digital processor, RN7326 can achieve a dynamic range of 8000:1 with a nonlinear error of <0.1%. The sampled signals are sent to the FFT calculation engine. Up to 41 orders of harmonics can be calculated, including the active power, reactive power, apparent power and other parameters. Based on the calculated results, RN7326 can also fulfill short-circuit detection, zero-crossing detection, over-voltage and over-current detection, voltage power-drop detection, phase sequence error detection, frequency abnormality detection, etc.

RN7326 drives the ferroelectric storage medium FRAM memory chip through the I2C interface to save power parameters, which can guarantee data integrity according to paper [11]. A solid-state relay is used to control the on-off of the AC contactor of the power supply circuit. And a buzzer and a light
are used for the sound and light alarm when FFT engine detects a parameter abnormality. An OLED screen is used to display power parameters through the SPI interface, which also drives the SPI to CAN interface chip for reporting data messages through CAN bus.

The power-drop detection circuit is used to monitor the external power supply. When RN7326 detects a powered down, the external interrupt event of the corresponding GPIO is triggered to notify the MCU core to save the context to prevent data loss. It will cut off the main power supply for protection and enter the low-power mode at the same time. The power-drop detection circuit sends out a trigger signal at the same time, to turn on the battery power supply through a switch circuit. The MCU then enters the alarm state, drives the buzzer to alarm, flashes the light and sends out an alarm message through SPI interface to notify users that there has been a power drop event.

4. Flow chart of Power Quality Analysis Unit

![Flow chart of power quality analysis unit](image)

The power quality analysis unit is designed with DIP switches, which can uniquely mark different power channels by dialing the DIP switches to different configurations. In this design, DIP switches are used to mark the priority of different power supply channel. A 3-bit DIP switch is set to support up to 8 channels, sequentially from 000 to 111, by which the priority represents high to low.

After powered on, each unit on line will get its own priority by reading the configuration of the DIP switch. It then sends out a handshake message to the bus to exchange its own priority to determine the channel topology of the system. The input channel with high priority is always switched to system first while the power quality parameter it fetched is active. When it detects a parameter abnormality, it will switch to another channel with a next-priority level one by one, and an alarm message will be sent to notify users to solve the problem in time. Flow chart can be seen in Fig.7.
5. Multi-channel Power Input Automatic switching system verification

To verify the effectiveness of power quality analysis unit, a power input automatic switching system with two AC380V power input channels is designed. The diagram is shown in Fig.6. The first channel uses the grid power of AC380V stated as AC380_IN1, while the other channel uses diesel generator stated as AC380_IN2. The AC380_IN1 channel is bypassed by an AC power regulator (Model.TDG2C2J-10KVA), which can modulate the AC380_IN1 parameters including aptitude, frequency, etc. An AC contactor is used for cutting off. The diagram is shown in Fig.8. In this case, the AC380_IN1 channel priority is set to 000 by DIP, and the AC380_IN2 channel priority is set to 001.

![Diagram of a two channel power input system based on power quality analysis unit](image.png)

Fig.8 A two channel power input system based on power quality analysis unit

The test result has shown that, either the first channel or the second channel is accessed to the system alone, the power quality parameters of the accessed channel can be displayed normally, and no alarm event occurs. The AC contactor in corresponding channel is active, and AC380_OUT port can measure a normal voltage output. When both of the two AC380V channels are accessed to the system at the same time, the OLED screen can show the parameters normally, and no alarm event occurs. The AC contactor of the AC380_IN1 input channel with high priority 000 is active, while the AC380_IN2 input channel with low priority 001 is negative. The system powers the loads uses the AC380_IN1 channel. At this point, we take the following actions to simulate the abnormality situation:

**Situation 1:** Disconnect the AC380_IN1 input channel. The result shows that after disconnection, the AC contactor of the AC380_IN1 channel gets cut-off immediately, while the AC contactor of the AC380_IN2 channel gets accessed subsequently. The OLED screen can then show the power quality parameters of the AC380_IN2 channel normally, while the AC380_IN1 channel power parameters get missed. An alarm event of beep and light occurs. Reconnect the AC380_IN1 channel again, the AC contactor of the AC380_IN2 channel gets cut-off soon, while the contactor of the AC380_IN1 channel is pulled in again. All parameters can be displayed normally, and the alarm event of beep and light gets cleared.

**Situation 2:** Modulate the frequency of the AC380_IN1 input channel gradually from the normal 50Hz to 49Hz through the AC power regulator. Since the lower threshold of frequency is set to -2%, the AC contactor of the AC380_IN1 channel gets cut-off immediately upon the frequency lowers to lower threshold 49Hz. The AC contactor of the AC380_IN2 channel gets accessed subsequently. The OLED screen can then show the power quality parameters of the AC380_IN2 channel normally, while the AC380_IN1 channel power parameters get highlighted. An alarm event of beep and light occurs. Modulate back the frequency of the AC380_IN1 gradually to 50Hz. The AC contactor of AC380_IN2 channel gets cut-off upon across the lower threshold of frequency, while the contactor of AC380_IN1 channel gets accessed in again. All parameters can be displayed normally, and the alarm event of beep and light gets cleared.

Other parameters of power quality can also be verified rightly by setting the control strategy in the program of the power quality analysis unit.
6. Conclusion
In this paper, a power quality analysis unit is proposed, it can monitor power parameters such as voltage, current, active power, total harmonic distortion rate, etc. A multi-channel power input automatic switching system consists of two channels of power quality analysis units is designed. Tests have shown that, this system measures power quality parameters correctly. And it switches to the other channel in time according to the designed control strategy when detecting a parameter abnormality. It can be used in the mobile vehicle equipment for power quality monitor.

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