Study on Unified Reference Source Phase-Check Technology Based on Synchronized Phasor Measurement

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Abstract. In the power system, the phase-check is a simple but very important work. The newly built, transformed and expanded power plant, transformer substation electrical equipment and power transmission lines before put into operation must be carried out phase-check test, in order to ensure voltage phase sequence and phase correct. At present, there are some limitations of traditional phase-check technology in China. In this paper, we study the method of unified reference source based on synchronized phasor measurement technology. Through the GPS time synchronization signal to realize synchronous sampling of source voltage signal in different regions, by comparing to the phase of a fixed reference source signal in the power network to determine the phase relationship between any two different power points, and thus to complete the work of phase-check. The unified reference source phase-check method based on the synchronized phasor measurement technique is simple, easy to operate, and has high efficiency, which has unique advantages. And wide area power grid phase-check can be realized.

1. Introduction
With the concept of the global energy Internet, As the development of power grid planning in 13th Five-Year, We should speed up the problems of UHV and distribution network and enhance the energy optimization and allocation capability. For this reason, The State Grid is expected to build the Eastern and Western synchronous networking projects by 2025. During the "13th Five-Year" period, it will accelerate the upgrading of synchronous power grid integration. The "Four AC Four DC" UHVDC projects that is integrated into the national air pollution control action plan will be completed in 2017. By 2020, the Eastern and Western UHV main network frame will be formed. The new transformation and upgrading of the agricultural power grid and the investment in the urban distribution network have a total of 128 billion 100 million yuan. The task of building and reforming the power grid is very heavy, High strength and large scale power grid construction will be through the "13th Five-Year" period[1].

The phase-check test must be done before power plants, substations and transmission lines are put into operation when they are built, reconstructed and expanded, in order to ensure that the three-phase phase sequence of the power equipment and the transmission line is the same and the phase is correct. The phase of the two three-phase power supply should be ensured for the three-phase AC power system which needs parallel or closed loop operation[2]. If the phase sequence is not consistent, the
generator will not be connected to the power grid. The forced integration of the power grid will cause serious damage to the power generation equipment. The phase-check test is a basic and important work in power system. Because of the new-build and expansion of substations every year, Power supply enterprises invest a lot of manpower and material resources in nuclear power. Therefore, it is a very meaningful thing to study how to improve the efficiency of the phase-check test, reduce the cost, and reduce the risk. The main limitations of traditional phase-check test mainly include the limitation of space distance for phase-check equipment, and simultaneity of signal sampling must be satisfied, and it also takes time to operate[3].

The aim of this paper is to improve the efficiency of phase-check test in substations, In view of the problems of low efficiency, complex operation and large limitation in traditional phase-check method, the technology and method of unified reference source phase-check based on synchronous phasor measurement technology are proposed. In order to improve the efficiency of phase-check and to simplify the operation process. At the same time, when the GPS unified clock is used, the phase-check method is not limited by the space distance of three-phase power, and it can solve the single power phase-check problem in substation well, so it has high popularization and application value.

2. Current methods, principles and limitations of phase-check

2.1 The Phase-check Method and Principle from Primary System
A phase-check from primary system is usually composed of two parts: a phase-check instrument hand-held terminal and a high voltage phase-check probe. As shown in Figure 1, the principle diagram of the phase-check from the high voltage primary system is shown. Wireless communication is usually used to transmit data between high voltage probe and phase-check instrument handheld terminal. Because the handheld terminal of the phase-check instrument requires high real-time sampling data, and the distance of data transmission is not the same in different wireless communication modes. Therefore, it is required that the distance between the high voltage probe 1 and the probe 2 of the phase-check meter should not be too far away, and should be within the range of the technical requirements of the phase-check instrument. Otherwise, the real time data sampling and the distance of data transmission will not be met.

The handheld terminal makes a comparison of the phase and amplitude of the data after transmitting the sampled data detected by the high voltage probe 1 and 2 to the handheld terminal, then the phase-check of 1 and 2 of the high voltage power supply is completed.

![Figure 1. The Principle Diagram of Phase-check from Primary System](image)

2.2 The Phase-check Method and Principle from Secondary System
The phase-check from secondary system generally uses the phase-check meter in the secondary side of the voltage transformer in substations. The principle diagram of the phase-check from secondary system is shown in Figure 2. The phase-check from secondary system is a kind of indirect phase-check method, and the correctness of the results of the phase-check is based on the correctness of the primary
and secondary side connection of the voltage transformer TV1 and the TV2. It is necessary to guarantee phase congruency about High and low voltage side voltage $U_A$ and $U_{A'}$, $U_A'$ and $U_{A''}$ of two voltage transformer. In this way, the accurate phase-check of the two power supply can be carried out indirectly.

The phase-check from secondary system usually uses two sets of test lines to simultaneously connect voltage transformers TV1 and TV2, then pass its secondary voltage to a phase-check instrument G. A phase-check instrument is used to do phase-check tests from secondary system on two power sources directly. Therefore, the phase-check method requires that the secondary lead terminal distance between TV1 and TV2 which is connected with the primary system cannot be too far away. Otherwise, the test towing line will be too long, the phase-check is very inconvenient, or the phase-check cannot be completed at all.

![Diagram of Phase-check from Secondary System](image)

**Figure 2. The Principle Diagram of Phase-check from Secondary System**

2.3 The Advantages and Limitations of Traditional Phase-check Method

There are some limitations in the analysis of the principle of traditional phase-check method and whether it is a method from primary system or that from secondary system.

(1) The signal of two power source that needed phase-check must be collected at the same time to keep the synchronization of the AC voltage signal sampling.

(2) The space distance between the two power sources needed phase-check is not too far away, and the phase-check of the wide area power grid cannot be realized.

(3) The phase-check tests need to be involved in more people, and the steps of the phase-check are complicated, the cost of human and material resources is high and the time consuming is long.

(4) There is a certain danger in the phase-check from primary system test. It is necessary to consider the coordination and cooperation between the experimental personnel and take corresponding safety precautions.

To sum up, it is known that the traditional phase-check method has many limitations, and it needs to be improved to improve the efficiency of phase-check.

3. Phase-check Method Based on Synchronous Phasor Measurement

In order to realize the wide area power grid phase-check, a phase-check scheme based on GPS synchronous phasor measurement technology is proposed. The principle diagram of this design idea is shown in figure 3. The power supply 1 and the power 2 are those which will be done phase-check. In order to ensure the phase sequence and phase relation between power source 1 and power source 2. A power point in the synchronous grid is introduced as a unified phase-check reference source for the whole power grid. At the power point, the sampling host computer with reference source voltage signal is installed. The sampling host computer has the function of the network communication and the synchronization of the synchronization pulse of the satellite GPS. The synchronous sampling of the reference source voltage signal can be carried out according to the GPS pulse signal. And the data
information is stored on the local hard disk and network server. At the same time, the voltage signal is sampled by the portable handheld phase-check instrument 1 and 2 for the two power supply 1 and 2, respectively. The handheld phase-check instrument 1 and 2 have the same functions as the reference source sampling host computer. At the same time, it can be used to sample the sampling data of the host sampling host and perform the function of comparison and analysis. Through the analysis of the sampling signal of the power point voltage, the voltage phasor relationship between 1 and 2 of the power points based on the unified reference source is obtained.

![Diagram](image)

**Figure 3.** The Principle Diagram of Phase-check Instrument Based on Unified Reference Source

As a result of high precision real-time signal with global positioning system (GPS), the synchronous sampling of the wide area power point of the power system can be realized, and there is a unified time standard for the voltage measured by each node, the corresponding time scales are added to the sampling data of voltage signals at different locations. The comparison and analysis of the voltage phase of different power supply points in the synchronous grid is realized. And finally the phase-check work of power point 1, 2 is achieved[4-7].

At present, GPS is used to build the whole network in the same time, 99.87% of the time synchronization error can be accurate to 1s. For the 50Hz power system, the phase error will be less than 0.018 degrees, providing an accuracy guarantee for phase-check work[8]. At the same time, high precision, high speed A/D converter and DSP digital signal processor can be used to solve the problem of synchronous sampling in wide area power grid.

4. The structure and hardware of Phase-check Instrument Based on Unified Reference Source

4.1 The Structure of the Hardware System of the Phase-check Instrument

The core equipment in the unified reference source phase-check instrument is the base source
sampling host computer and the portable phase-check terminal. They basically have the same function, and the hardware structure is basically the same. The schematic diagram of its hardware structure is shown in Figure 4. The core panel is composed mainly of a high-speed digital signal processor DSP+FPGA. It also has USB, RS485 data interface module, TCP/IP network, 4G wireless communication interface module, GPS timing and B code timing module, remote switch on and voltage sampling A/D conversion module, and display module, keyboard and man-machine interface module and other expansion modules. The GPS time module realizes the output of the time pulse signal, and then produces a high precision analog synchronous sampling clock after the processor’s own crystal oscillator completes the frequency division. A/D analog conversion module completes synchronous sampling of voltage signals based on synchronous sampling clock. Finally, the DSP digital signal processor is used to realize the accurate calculation and processing of the voltage quantity digital signal, and then output the nuclear phase result to the user through the human-machine interface device.

**Figure 4.** The Schematic Diagram of the Hardware Structure of a Unified Reference Source Phase-check Instrument

### 4.2 The Design of the Hardware Module of the Phase-check Instrument

The core device hardware of phase-check detector is mainly composed of DC power module, digital signal processor module, analog acquisition module, GPS timing module, display and keyboard man-machine interface module, as shown in figure 5. The DC power supply module provides power supply for signal conditioning circuits, analog to digital conversion circuits, and DSP digital signal processors. There are 4 power output, 5V, 24V, +12V, -12V, respectively. Voltage transformer, operational amplifier IC and 14 bit MAX1320 analog to digital converter and other components constitute a voltage signal sampling circuit, which completes the synchronous sampling of the power voltage signal to the digital quantity. The TMS320F206 DSP digital signal processor and FPGA integrated circuit can measure the voltage amplitude and phase angle based on the DFT algorithm, and calculate the voltage phase amount.
In order to verify the performance of the whole system and its core equipment, a phase-check test project is designed. Feasibility and superiority of phase-check scheme based on GPS synchronous phasor measurement is achieved.

A phase-check test was carried out about high and low voltage side power supply for a main transformer in an 110kV substation. The connection of main transformer winding in this substation adopts Yd-11 connection mode. Primary side voltage phasor delay secondary voltage side voltage phasor of about 30 degrees. The reference source sampling host computer sampling the voltage of high voltage side bus is installed at the high voltage bus bar of the substation. And the voltage is used as the reference source of the phase-check. The portable phase-check terminals 1 and 2 synchronously sample the high and low voltage side voltage of the main transformer, respectively. The voltage phase of the high and low voltage side of the main transformer based on the voltage of the high voltage side bus is obtained. The results are shown in Table 1.

**Table 1. Phase-check Result of Power Supply Voltage**

| Supply Voltage        | Phase | Amplitude(V) | Phase Angle(°) |
|-----------------------|-------|--------------|----------------|
| 110kV Bus Voltage     | Phase A | 57.84         | 0.0            |
|                       | Phase B | 57.75         | -120.0         |
|                       | Phase C | 57.79         | 120.0          |
| Main Transformer 110kV Side Voltage | Phase A | 57.83 | 0.0 |
|                       | Phase B | 57.79 | -120.0 |
|                       | Phase C | 57.69 | 120.0 |
| Main Transformer 10kV Side Voltage | Phase A | 57.80 | 29.85 |
|                       | Phase B | 57.72 | -120.0 |
|                       | Phase C | 57.76 | 120.0 |

The voltage recording of portable phase-check terminals 1 and 2 is shown as shown in Figure 6. The T1 and T2 in the diagram are absolute and relative time, respectively. The time difference between the left and right two scales from the graph (1.655ms) and it can be calculated that the phase angle difference between the primary voltage phase and the secondary voltage of the main transformer. It is about:

\[1.655\text{ms} \times 18 \text{ °/ms} = 29.79 \text{ °} \] (1)
Figure 6. Recorded Diagram from Unified Reference Source Phase-check Instrument

6. Conclusions

This paper applies the synchronous phasor measurement technology based on GPS to the power system. The power phase-check of the wide area power grid is realized. It can make the work of the power system phase-check easier and simpler, and meet the needs of a single power supply substation high-voltage phase-check work. It has made up many defects and shortcomings of the traditional phase-check, and greatly improved the efficiency of the phase-check of the professional and technical personnel of the power supply enterprises.

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