A Digital Power Quality Monitoring Equipment Designed for Digital Substation

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Abstract. Taking into account both current status and development trend of digital substation, this paper proposed a design of a new multi-channelled digital power quality monitoring equipment with high compatibility. The overall functional structure, hardware architecture, software architecture, interface architecture and some key techniques such as IEC 61850 modelling of transient event and harmonic measurement method under the condition of non-synchronous sampling are described in this paper.

Keywords. Digital substation; IEC 61850; monitoring equipment; power quality.

1. Introduction

Digital substation based on IEC 61850 model has become the trend of smart grid. Digital substation will also be affected by non-linear load, wind power, power grid operation mode, etc., thus power quality issues such as harmonic voltage/current, voltage/current unbalance, transient voltage events will also affect the reliability of digital substation. Power quality management is of great importance in digital substation.

However, the standard and the design of merging units, transformers and other devices in digital substation didn’t take power quality monitoring into account in the first place. Thus there is a series of problems and technical difficulties of power quality monitoring in digital substation. In order to solve the problem, relevant researches have been promoted and certain solutions have been achieved, including power quality testing arithmetic research, IEC 618150 function and data model of power quality monitoring equipment, digital power quality monitoring equipment and monitoring system, etc.

Considering the necessity of power quality monitoring and management, as well as the development of digital substation, the sampling rate of digital transformers, merging units and other devices in digital substation will be increased in order to satisfy the requirement of power quality monitoring. Considering the current situation of digital substation, a high performance and compatibility digital power quality monitoring equipment with various sampling rate is designed in this paper, which is compatible with both digital and traditional transformers.

2. Framework of the Digital Power Quality Monitoring Equipment

Digital power quality monitoring equipment collect sampled signal mainly from merging units. The sampling rate of merging units is mainly at 80 bits per cycle in the digital substation. The sampling rate of some merging units can reach up to 200 bits per cycle. Most merging units can generate standard sampling signal corresponded with IEC 61850-9-2 standard. Besides, in some power grid, both
digital/photoelectric transformers and traditional transformers are installed in substations. For example, in Guangdong power grid, digital/photoelectric transformers are mainly used for substations with voltage level at 110kV and above, while in the substations with voltage level below 110kV, traditional transformers are mainly installed.

According to the situation, the digital power quality monitoring equipment for digital substation needs to meet the requirement below:

(1) Power quality monitoring function
The relevant technic index of power quality monitoring in digital substation is often beyond the standard of ordinary power quality monitoring equipment, including the six monitoring index in GB/T 19862-2005. The measurement algorithm should satisfy the requirements of in IEC 61000-4-30: testing and measurement techniques – power quality measurement methods, IEC 61000-4-7: testing and measurement techniques – general guide on harmonics and interharmonics measurements an instrumentation, for power supply systems and equipment connected thereto, IEC 61000-4-15: testing and measurement techniques – flicker meter – functional and design specifications, etc.

(2) Standard model and interface
The data model should be satisfied with IEC 61850 model. The digital equipment would collect digital current and voltage signal corresponded with IEC 61850-9-1/2 standard from process layer in digital substation, while would communicate with background system in primary station with IEC 61850-8 model.

(3) High stability and reliability
Self-adjusting and remote adjusting of the digital monitoring equipment is supported in the digital equipment so as to maintain the real-time performance and accuracy after long time operation in substations.

(4) High compatibility
The digital monitoring equipment is compatible with sampling signal with various sampling rate, including 80 bit per cycle, 200 bit per cycle, and 512 bit per cycle. The efficiency and data quality can be assured in data transforming and data processing under sampling rate at 512 bit per cycle.

(5) Multi-channel access
Multi-channeled power quality monitoring of digital substation is supported with the digital monitoring equipment. The access of both digital/photoelectric transformers and traditional transformers are supported.

The framework of the digital power quality monitoring equipment is shown in Fig. 1.

\[ \text{Figure 1. Framework of digital power quality monitoring equipment} \]
3. The Design of the Digital Power Quality Monitoring Equipment

3.1. Development platform

Most of power quality monitoring equipment, especially multi-channeled monitoring equipment, use Windows operation system and its data collecting card as control center. Windows system is a time-sharing system. The system will calculate each process’s priority automatically. Users cannot control the priority of each process. Thus Windows operation system is mainly used in scientific calculation or other fields which does not require high real-time performance. However, power quality monitoring equipment need to collect signal continuously in a long period. Besides, transient event monitoring and collecting need higher real-time performance. Thus, power quality monitoring equipment based on industrial computer may cause sampling and calculating errors.

Compared with time-sharing operation system, real-time operation system is more fitted with processing controlling, data collecting and communicating. There are some common Real-time operation systems such as VxWorks, Linux, WindowsCE, etc. After some research and experiment, VxWorks operation system is used as the develop platform for the digital power quality monitoring equipment. VxWorks operation system is with high reliability and real-time performance, thus is often used in the field which requires high real-time performance, such as communication, military, aviation, etc.

3.2. Hardware design

In order to meet the requirement of multi-channel access, especially the access of both traditional and digital/photoelectrical transformers, the hardware framework of the digital power quality monitoring equipment is adopted with modular design, which is shown in Fig 2. Each sampling module supports the access of up to 4 channels. Each channel monitors three-phase current and voltage signals. Both traditional and digital transformers are supported with different design of sampling modules. Different types and numbers of sampling module can be installed according to different conditions.

![Figure 2. Hardware framework of the digital power quality monitoring equipment](image)

As for the internal structure, multi-CPU and multi-DSP modules are designed for data processing. The internal structure of the equipment is shown in Fig 3.
The scheme requires high performance of PowerPC and DSP. Each OMAPL needs to process 4 channels’ power quality data. Each DSP needs to receive large quantity of data. PowerPC needs to process up to 16 channels’ data, and transform these data with IEC 61850 model.

In order to solve the problem, an appropriate software design can reduce the load of each module, which is described below.

3.3. Software design
The digital power quality monitoring equipment is based on multi-CPU framework. Each CPU has its own function and task.

PowerPC is set as principal CPU, which is for configuration management, data analyze and storage, human-computer interaction, and external communication of the equipment. Principal CPU and subordinate CPU are connected with internal Ethernet.

OMAPL is for the calculation, statistic of power quality index, and data interchanging with PowerPC. The power quality arithmetic module is composed with basic measuring module, harmonic measuring module, flicker measuring module, and transient voltage measuring module, etc.

DSP is for signal sent from merging units decoding based on IEC 61850-9-2. If the data sent from merging units are the original data with sampling rate at 512 bit per cycle, then each channel will receive data flow of 24 Mb/s. DSP is for data pre-processing and send the data to power quality arithmetic module through FIFO.

The DSP program module includes decoding module and communicating module. Decoding module receives data from ISO/IEC 8802-3 link layer directly and decodes data. Communicating module transform decoded data to processing module through FIFO. The framework of data collecting and preprocessing module is shown in Fig 4.
3.4. Protocol scheme design

The digital monitoring equipment communicate with merging units through fiber Ethernet by IEC 61850-9-2 model. As for the traditional transformers in digital or traditional substations, analog signals can be transferred to IEC 61850-9-2 signals by external data collecting card.

The digital monitoring equipment communicate with monitoring system with MMS communication protocol defined in IEC 61850 standard. For real-time data, non-cache report is used for data communicating; for statistical data, cache report and log file is used for data communicating; for waveform data, COMTRADE file is used for data communicating.

4. The Key Technique Research and Test

4.1. Transient signal sampling model with IEC 61850

The IEC 61850 module of power quality monitoring equipment has been consummated. However, the realization of transient IEC 61850 model in power quality monitoring equipment is with difficulty. The main problem is the definition and processing mechanism of multi-channel events. For example, if a voltage dip event happened in several channels, or the duration of voltage dip events are overlapped, there is a doubt whether a single event or multiple event should be recorded.

For this issue, through researching IEC 61000-4-30 thoroughly and discussing with several power quality experts, the processing mechanism of multi-channeled events is settled and actualized in the digital power quality monitoring equipment.

1) In multi-phase power system, a multi-channeled event starts at a voltage transient event happens in one channel or several channels, and ends at all voltage values return to normal. Voltage transient events include voltage dip, voltage swell and voltage short interruption.

2) Multi-channeled events are recorded as occurrence time, total amplitude and total duration. The amplitude and duration of each channel will also be recorded.

3) Occurrence time of multi-channeled event is the time when the voltage value exceeds the limited value.

4) Total characteristic amplitude of multi-channeled event is the largest characteristic amplitude of all channels.

5) Total duration of multi-channeled event begins at the start of a transient voltage event, and ends at all transient voltage events end.

6) For each transient event in each channel, a COMTRADE file will be generated, which includes the characteristic value, wave data and other information.

4.2. Harmonic measurement arithmetic under asynchronous condition

Headings are organizational devices that guide the reader through your paper. There are two types: component headings and text headings.

Digital/photoelectric transformer samples signal with fixed sampling rate. However, the frequency in power system is not fixed. Therefore, the output signal of merging unit is not the original signal. If
analyzed with fast Fourier transform (FFT) arithmetic, the precision will not meet the requirement of power quality monitoring.

Some experts have noticed the problem and proposed some improved method and arithmetic. However, some method still has its own disadvantage. For example, interpolation method can solve barrier problem, but cannot improve the precision caused by spectrum leakage. An advanced DFT arithmetic can improve the precision problem caused by spectrum leakage, however, this method needs large computation. In a word, a method based on appropriate window function and optimal interpolation method is the key to solve the problems mentioned above for harmonic monitoring in digital substation.

In order to solve the problem, a Rife-Vincent window interpolation FFT arithmetic is proposed in this paper. The process of the method is shown in Fig 5. Both theoretical analysis and simulation experiment show that this method is with noise suppressing capability and detection ability. The testing result is shown in Table I.

![Diagram of Harmonic Measuring Arithmetic Progress](image-url)

**Figure 5.** Harmonic measuring arithmetic progress

### Table 1. Result of Harmonic Test

| Harmonic | Harmonic Voltage | Harmonic Current |
|----------|------------------|-----------------|
|          | Testing value (kV) | Error (%Un) | Testing value (kV) | Error (%Un) |
| 3        | 4.619            | -0.02         | 9.975              | 0.00        |
| 5        | 4.621            | 0.02          | 9.994              | 0.00        |
| 7        | 4.621            | 0.02          | 9.995              | 0.00        |
| 11       | 4.622            | 0.04          | 10.002             | 0.00        |
| 13       | 4.618            | -0.04         | 9.991              | 0.00        |
| 25       | 4.629            | -0.19         | 10.034             | 0.00        |
| 50       | 4.626            | 0.13          | 10.056             | 0.01        |
5. Conclusion
In order to meet the requirement of digital substation and power quality management, a digital power quality monitoring equipment with high performance and reliability is proposed in this paper. The equipment is designed with Works platform and advanced framework, which is to assure the stability and reliability. Multi-CPU and multi-DSP are used to increase the efficiency of data processing. Extendable and replaceable hardware design will assure the compatibility of the equipment. IEC 61850 standard model is used to assure the standardization of data model and communication interface. The digital power quality monitoring equipment proposed in this paper has been used in some digital substations. The function and performance are satisfied with

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