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Reliability of Substation Protection System Based on IEC61850*

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Abstract: Although the new technology of protection and automation system of substation based on IEC61850 standard has developed rapidly in China, reliability measures depending on this technology need to be further researched. By taking advantage of convenient information sharing, two kinds of new schemes, shared backup protection unit (SBPU) and signal backup (SB), have been proposed to solve the failure problem of protective devices and current/voltage transducers respectively, and the working principle of these two schemes are also described. Furthermore, the key technologies of on-line diagnosis of protective devices' failure and on-line status diagnosis of optical or electronic current/voltage transducers to realize the two schemes are proposed.
Keywords: IEC61850; reliability measures; shared backup protection unit (SBPU); signal backup

Although the wide use of microcomputer relaying and integrated substation automation system in China has improved operation reliability, there are still many problems in substation protection system, for example, the complex insulation of conventional transducer, electromagnetism saturation[1], electromagnetism resonance, lack of uniform information model of intelligent electronic device (IED) and other devices[2]. These problems have limited further development of substation protection system.

IEC61850 standard[3] has been accelerating the development of substation's protection & automation technologies; moreover, the new style of current and voltage transducer based on electro-optical technology, fiber-optical net communication, high-speed Ethernet and primary device's intelligent technology have laid the base for the implementation of new-style digital substation's protection & automation system. Therefore, the technology superiority including information sharing, equipment interconnection and intelligent operation will certainly make deep changes in power system's protection and control[4].

At present, the new substation based on IEC61850 protocol (called digital substation in China) has been accepted in China; however, there are still some problems as follows.

(1) Although optical or electronic transducers have been used to acquire current and voltage signals required by protection automation devices, the function of substation protection system has not been improved.

(2) The higher reliability of the new equipment and system has not been proved in the new digital substation. There are still some anxieties about new current/voltage transducer in their stabilities.

In the course of constructing and implementing the new protection and automation system of substation based on IEC61850, we should take advantage of new technology to get higher reliability than the integrated microcomputer protection & automatic system. So it is necessary to study the method of improving the reliability of the new kind of protection & automation system of substation. On the basis of analysis of traditional protection system, two kinds of reliable schemes, shared back-up protection unit and signal back-up based on information sharing, have been proposed.

1 Characteristics of substation protection system based on IEC61850

The main characteristics of substation protection &

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automation system based on IEC61850 (digital substation in China) are as follows.

1.1 Digitization of data acquisition

The major mark of digital substation is adopting a digital electrical measurement system [5−7] , such as optical current transducer (OCT) , optical voltage transducer (OVT) and electronic current transducer (ECT), electronic voltage transducer (EVT), to acquire electric parameters of power system, which can accomplish effective isolation between the primary system and the secondary system, enlarge the dynamic measurement range of electric parameters and improve the precision. Thus, it lays basis for converting device redundancy of conventional substation into information redundancy as well as the integrated application of information.

1.2 Compaction of system structure

Ref.[2] shows that the digital electrical measurement system with small capacity and light weight can be incorporated into the intelligent switchgear system, and the design idea of electronics mechanism integration of substation can be achieved.

1.3 Standardization of system information model

As shown in Ref.[3], a uniform standard model for information exchange in the substation has been established according to IEC61850, which has much significance as follows: (1) Interoperability of intelligent devices; (2) Information sharing in the substation devices; (3) Simplicity of maintenance, configuration and implementation.

1.4 Data communication by networks

In the digital substation, a new type of low-powered and digital current/voltage transducer has been used instead of the conventional current/voltage transducer, and the new one can change high voltage and current to digital signals directly. Data interacts through high-speed network among devices in substation, and the secondary equipments no longer have those A/D and I/O interfaces. What is more, the devices with conventional function can be changed into logical function modules, that is to say, data and resource sharing can be truly achieved by adopting the standard Ethernet technology.

1.5 Integrated application of the information

In the conventional substation, devices used to monitor, control, protect, record fault, and measure are almost of single function and independent, and there are some disadvantages, such as redundant hardware configuration, information which cannot be shared and high investment cost. But in the digital substation, we can integrate information and optimize the functions of original secondary system, and can also avoid those problems mentioned above efficiently.

1.6 Condition-based equipment repairing

In the digital substation, we can obtain efficient running status data of power grid, fault and operation information of various IED devices and monitor the operation state of these devices including signal loops. There are almost no functional units which are not monitored, and there is no blind area for picking equipment state features. So equipment maintenance strategy can be changed from regular maintenance of conventional substation to state maintenance as a result of improving the system's availability greatly.

1.7 Intelligent control of devices

The new high-voltage breaker system adopting microcomputer, power electronic technology and new-type sensor can control accurately the trip and switching angle, execute local function independently and make devices self-checking and so on .

The characteristics mentioned above are the potential superiorities of digital substation. However, these superiorities have not been fully utilized up to the present. Now the new device is only used to complete the old function, and the technical indices especially the reliability indices of system have not been broken through.

2 Reliability of the protection in the digital substations

2.1 Analysis of relay failure

As shown in Fig.1, when failure occurs in F, according to the action principle of protection, relay CB_1 should work to clear the fault. If relay CB_1 fails to operate, protection CB_2 will operate to remove all loads on Bus 3, which is not expected to occur.

If one of the relaying devices fails to work correctly, the fault will lead to the following consequences: delaying to cut off the fault and more loads' losing the

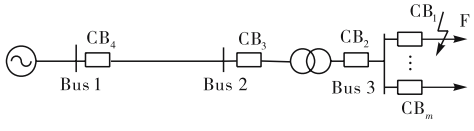

Fig.1 Configuration of protection system

power. The former will lead some electrical devices to suffer a longer time of failure impact which will certainly shorten the service life. The latter will enlarge the range of outage and affect the reliability of the power supply. Thus, how to solve this problem should be our major research work in the course of establishing a new protection & automation system of substation.

2.2 New method of making higher reliability of substation protection system based on information sharing

Fig.2 shows that each set of microcomputer protection is equipped with hardware interface which only conveys analog signals of current/voltage transducers to protection units .The double structure is the main measure taken to improve the protection reliability [8,9].

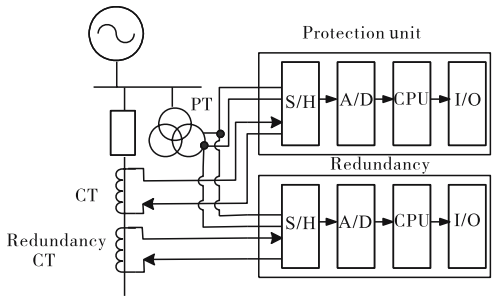

Fig.2 Double structure of microcomputer protection unit

In transmission lines and transducers of 220 kV and above voltage in China, a double structure is adopted to avoid refusing operation of protective devices, while in substations of 110 kV and below voltage, there is no hardware redundancy taken in every loop owing to the high cost.

Thus, we propose two redundant methods based on information sharing and rapid network switch to improve reliability in the new-style protection and automation system based on IEC61850 standard. These two measures complete the back-up of all protective devices and current/voltage transducers at a lower cost of hardware and software, so they can make the system achieve higher reliability economically. One measure is to use shared back-up protection unit to solve the problem of protective devices' disable operation in the substation. The other one is called software back-up method, which is based on changing data flow and need not add hardware to solve the problem of losing information source due to sensor's failure in the substation.

2.2.1 Shared back-up protection unit

Fig.3 shows the structure of substation protection system with shared back-up protection unit (SBPU).

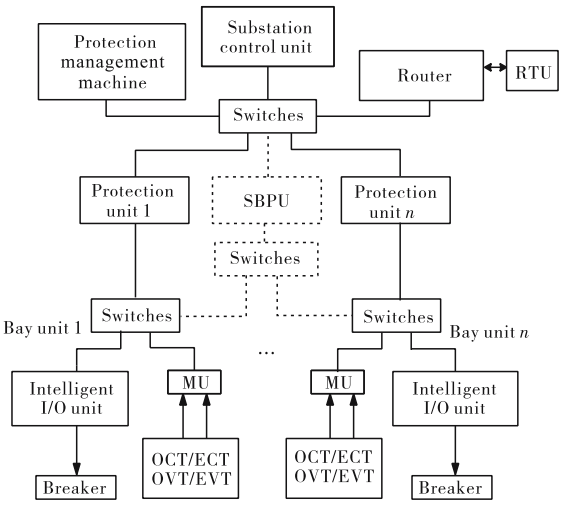

Fig.3 Schematic diagram of SBPU

When all protective devices are well, SBPU does not gather any data. But when some faults of these protection units have been detected by protection management machine (PMM) , SBPU will be woken, and the information on faulted protection unit including unit number and set values will be sent to SBPU from PMM. At this time, the protection function of the faulted protection unit will be replaced by SBPU which can start to collect data and work automatically. Consequently, the protection function is restored on-line without outage.

Fig. 4 shows the process of starting the SBPU. In this figure, DS means detection signals; AS, active signals; MS, measured signals.

We can find the advantages of this scheme:

(1) Hardware redundancy completed without double layout for every protection device will improve the system's reliability;

(2) The protection function can be continued without load outage when some protection unit goes wrong;

(3) It is cheaper and easier to complete because data of every bay can be conveyed to SBPU only though optical fiber.

When some optical or electronic current/voltage transducer becomes out of action, the protection device cannot get correct data. So the protection function will be lost. Unfortunately, the SBPU proposed above also cannot resolve this problem. It is necessary to figure out another scheme.

2.2.2 Signal back-up for failure of signal loop

When one of optical or electronic current/voltage transducers fails to work or is disconnected due to some unknown reason, we hope the protective function of this

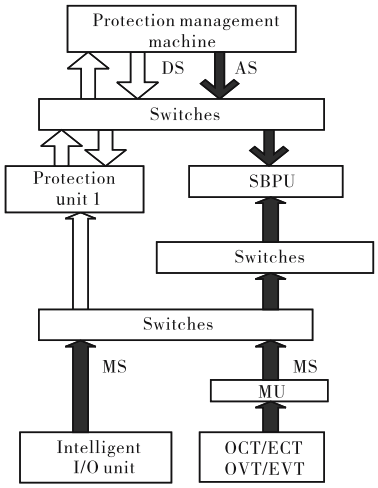

Fig.4 Signal-flow chart using SBPU

transmission line or other power equipment can be kept for the security of power system. Although we can use two sets of instrument transducers and two sets of protection devices in the 220 kV and above voltage power system, the two sets of instrument transducers are still likely to fail at the same time.

In the digital substation based on network connection, we can use the signal back-up (SB) method to maintain protective function.

Take the network shown in Fig.5 for example, according to Kirchhoff' s current law,

$$\boldsymbol{i}_1 + \boldsymbol{i}_2 + \boldsymbol{i}_3 = 0 \tag{1}$$

Thus, the current values in one loop can be calculated according to the current values of other loops. It means that when one of OCT or ECT fails, we can acquire indirectly the current value of the faulted loop.

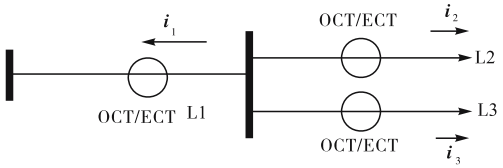

Fig.5 Example of power network

When abnormality or failure of OCT or ECT in L2 is detected by local protection, this protection unit P2 can request protection unit P1 and P3 to transmit the current of L2 and L3 to it. The relevant loops' sampled current values are used to calculate the current value of L2 so that the protection unit P2 continues working correctly. Fig.6 shows the signal flow in the module of SB.

Suppose that the protection P2 has the impedance protective function, and the measured impedance under usual conditions is

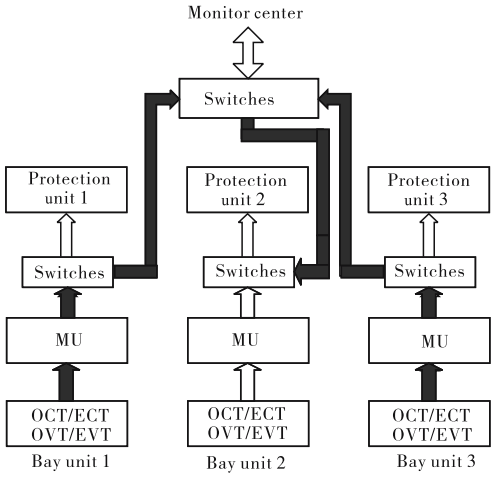

Fig 6 Signal flow with the SB

$$z_{2m} = \dot{U} / I_2 \tag{2}$$

When OCT or ECT of this loop fails, the current of L2 is replaced by L1 and L3.The measured impedance is

$$z_{2m}^{'} = \frac{\dot{U}}{-(\dot{I}_1 + \dot{I}_3)} \tag{3}$$

From above analysis, it is known that SB method can achieve back-up function only by invoking some special software functions and changing the information-transmitted mode without adding any hardware.

The structure diagram of the digital substation including SB function is shown in Fig.7, which adopts merging bus introduced in Refs. [10,11].

3 Key technologies to realize SBPU and SB

To fulfill the back-up functions proposed above in digital substation, the following problems must be solved.

(1) Data-acquired mode of SBPU

There are two modes to connect SBPU with other bay units, which are connections based on IEC61850-9-1 protocol and IEC61850-9-2 protocol included in Ref.[3].

(2) On-line status diagnosis of optical or electronic current/voltage transducers

Diagnosis of failure status of electrical measuring devices (OCT/ECT and OVT/EVT) is the key to SB.

(3) On-line diagnosis of protective devices' failure

How to know the failure of protective devices is the key to attaining SBPU when protective devices fail to work. However, it is a very complicated job to detect the protective devices' failure and there has been little progress in this field at present. But several aspects as fol-

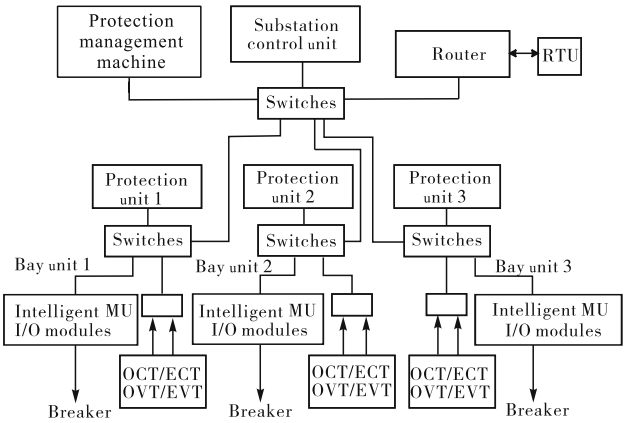

Fig.7 Digital substation structure only with SB

lows are worthy to study.

(i) Detection of signal interruption

When protection management machine cannot receive the response of protective devices, failure signal will be given, and when protection devices fail to receive the signal from OCT/ECT or OPT/EPT, the failure of input signal must occur.

(ii) Self-check of protection devices

It has been known that the microcomputer relay has strong self-check functions. When protection manage machine receives the lethal failure signal of protection unit, failure signal will be given.

(iii) Accuracy comparison of signal processing

To test the capability of signal processing of protection devices, it is a good method to send a set of pre-designed data from protection management machine to a protection device periodically, then call the result data from this protection unit and compare the amplitude and phase given by pre-designed data with the protection unit. If there is a big difference between these data, we can conclude that this protection unit fails.

4 Conclusions

By making use of information sharing and high speed data network in digital substation, the two kinds of back-up schemes, SBPU and SB, have been proposed. The main results are as follows.

(1) The scheme of shared back-up protection unit can be used to solve the problem when a protection device happens to fail. The advantage is that the amount of backup units is minimized. So the system's structure is simplified and the reliability is higher.

(2) For the signal loop's interruption or abnormality caused by failure of optical/electronic current/voltage transducers, the real-time data from relevant loops can be used to calculate the current of disabled loop. This scheme can hold the protection function of fault loop without adding any hardware.

References

[1] Chen Jianyu, Meng Xianmin, Zhang Zhenqi. Influence of the current transducer saturation on relay unit and its countermeasures in medium voltage power systems [J]. *Automation of Electric Power Systems*, 2000, 24(6): 54-56(in Chinese).

[2] Gao Xiang, Zhang Peichao. Main features and key technologies of digital substation [J]. *Power System Technology*, 2006, 30(23): 67-71(in Chinese).

[3] IEC61850 — Communication Networks and Systems in Substations [EB/OL]. http://domino.iec.ch/ webstore/webstore.nsf/ searchview/? SearchView=&Search Order=4&SearchWV=TRUE&SearchMax=1000& 61850&submit=OK.

[4] Lu Guogang, Liu Ji, Zhang Changyin. The technology development of substation digitization [J]. *Power System Technology*, 2006, 30(Supplement): 499-504(in Chinese).

[5] Zeng Qingyu. Application of digital electro-optical measurement technology in power system and analysis of its benefit [J]. *Power System Technology*, 2001, 25(5): 6-9(in Chinese).

[6] Zeng Qingyu. Principle and technology of digital electro-optic measurement for power system [J]. *Power System Technology*, 2001, 25(4): 1-5(in Chinese).

[7] Chatrefou D , Montillet G F. A series of implementation of optical sensors in high voltage substations [C]. In: *Proceedings of Transmission and Distribution Conference and Exposition.* 2003 IEEE PES. Vol.2. 2003. 792-797.

[8] Wang C, Xu Z, Zheng S. Reliability analysis of protective relays in fault information processing system in China [C]. In: *Proceedings of Power Engineering Society General Meeting*. 2006 IEEE, 2006.

[9] Ding M, Wang G, Li X. Reliability analysis of digital relay [C]. In: *Proceedings of the Eighth IEEE International Conference on Developments in Power System Protection*. Vol.1. 2004. 268-271.

[10] Gross R, Herrmann H J, Katschinski U. Substation control and protection systems for novel sensors [C]. In: *Proceedings of CIGRE Session.* Paris ,2000.

[11] Andersson L, Brunner C, Engler F. Substation automation based on IEC61850 with new process-close technologies [C]. In: *Power Technology Conference Proceedings.* 2003 IEEE Bologna. Vol.2. 2003.