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Special protection system to cope with the unavailability of sampling values from an entire substation

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ABSTRACT

A special protection system is proposed to respond to a challenge such as that a substation must be immediately taken out of service or only be protected by a remote backup protection without selectivity if the sampling system of this substation breaks down or the samplings are unavailable even though the GOOSE channel is functioning normally. After the special protection system perceives an abnormality of the sampling system of the substation, it first locates the rough fault region using a wide area measurement system based current differential protection scheme of the sound side of the lines connected to the substation with an abnormal sampling system. Then, a novel compensation voltage difference scheme is proposed to determine the faulty line within the recognized rough fault region. Combined with the zone I distance protection scheme, a comprehensive special protection scheme to address a serious sampling abnormality is proposed. Theoretical analysis and PSCAD and MATLAB based simulation studies show that the proposed scheme has the advantages of high reliability, sensitivity and capability of withstanding a fault resistance.

1. Introduction

With the development of the IEC61850 and the application of intelligent electronic devices, more than 2000 digital substations have been built and refurbished in China [1]. The deployment of the IEC61850–9-2 process bus increases the possibilities that new and refurbished substations will use Ethernet communication networks with free allocation of the protection and control functions [2]. The process bus technology utilizes the transmission of Sampled analogue Values (SVs) of currents and voltages according to IEC 61850–9-2 and trips by high-speed peer-to-peer communications of Generic Object Oriented Substation Event (GOOSE) messages according to IEC 61850–8-1 over Ethernet [3]. However, the prevalent application of Ethernet communication networks will introduce the risk of cyber security in a protection system, which is a tremendous threat that must be taken into account.

One of the most perilous threats is the Denial of Service (DoS) attack. The purpose of DoS attacks is to break down the network by sending aggressive traffic to the network, leading to network congestion, network peripheral (e.g. Ethernet switch) overloads, or even network paralysis. In addition, another user in the network can't receive services from the network services (e.g. protection relay) [4,5].

Because the same sampled value packet is not being transmitted repeatedly, unlike the GOOSE, the transmission of real-time, continuous and huge-flow SVs is difficult under network congestion, which will result in the unavailability of SVs of several nodes, and possibly all of the nodes within the substation, for long time periods [6–9]. Although the communication system availability was greatly increased by additional link redundancy in IEC61850 edition 2 [10], all the SVs within the substation will be unavailable under serious DoS attack. However, the GOOSE channel is with higher transmission priority and higher reliability, which is less affected by the DoS attack [7,11].

According to the existing protection procedures, if the SVs are unavailable, the protection relay generates the "sampled value failure alarm" and the related protection functions are inhibited [12,13]. The corresponding protected primary components should be intentionally taken out of service. Otherwise, they simply count on the remote backup protections to guarantee their security, which have problems such as poor cooperation and override tripping under faults and improper operation under heavily loaded-flow transfer, especially in the Ring Power Network. Meanwhile, the fault removal speed will be very slow [14–16].

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Researchers have studied how to take advantage of the abundant information in substations [17–19]. Based on the information sharing of SVs within substations, several simple laws among measurements are adopted to supplement the lost SVs, e.g., the sum of the incoming current is equal to the outgoing current of the same bus [18]; the solution is effective when the SVs of a single node are lost, but it is not enough to defend against the unavailability of SVs of an entire substation. An agent-based wide-area current differential protection system is proposed in [19], which extends the coverage of the current differential relay to a dynamic protection zone. However, the coverage of current differential relaying should be extended to the entire substation if the SVs of entire substation is lost, making the selectivity very unsatisfactory.

To solve this problem, a special protection system (SPS) is proposed. First, the rough fault region is located with a multi-terminal current differential protection scheme based on the current information coming from the sound sides of the lines connected to the target substation. Then, a novel protection criterion of high selectivity is designed. Combined with zone I distance protection, the fault can be identified as reliably as possible. Then, the circuit breaker on the sound side of the faulty line is tripped by the zone I distance protection locally or by the SPS remotely. In the meantime, the circuit breaker on the other side is tripped via the sound GOOSE channel by the above protections.

2. SPS strategy dealing with the unavailability of SVS of an entire substation

2.1. Basic solution architecture

Fig. 1 shows a simplified structure of regional substations, in which there exists N substations connecting to substation C. The information coming from these substations is shared using a wide-area communication network.

When the SV system in substation C breaks down, the substation-area protection and wide-area protection all cannot obtain the SV information of substation C. In this case, the traditional power system will face a difficult situation. An appropriate solution is the SPSs based on the architecture of the Protection Intelligent Center (PIC) proposed in [20]. Under the engineering practice condition where wide area information is reliable and available, PIC is adopted as a basic framework of SPS to cope with the above situations. Based on the PIC, the related information of the substations adjacent to this abnormal substation is obtained and improved protection algorithms can be developed. Additionally, the faulty region can minimized by transmitting the tripping signal via the sound GOOSE channel.

2.2. Rough location of the faulty region

Firstly, the abnormal substation is determined by perfect communication self-checking, the minimum extended protected area associated with this substation shown in Fig. 1 is automatically formed via the PIC and the corresponding SPS is formed as well. Any potential pick-up signal from local protection equipped on the sound side of the faulty line connected to the target substation can be detected in real-time. The multi-terminal current differential protection acting as the measuring element of the rough fault region is dynamically formed by taking advantage of SVs coming from the sound side of the lines connected to the target substation as long as a certain local protection starting signal is received.

Multi-terminal current differential protection criterion mentioned in section II is given by (1) [21]:

$$\left|\sum_{m=1}^{N} \dot{I}_m\right| > K_{set1}\left(\sum_{m=1}^{N} |\dot{I}_m|\right) \tag{1}$$

where $\dot{I}_m$ represents the current phasor coming from the sound side of

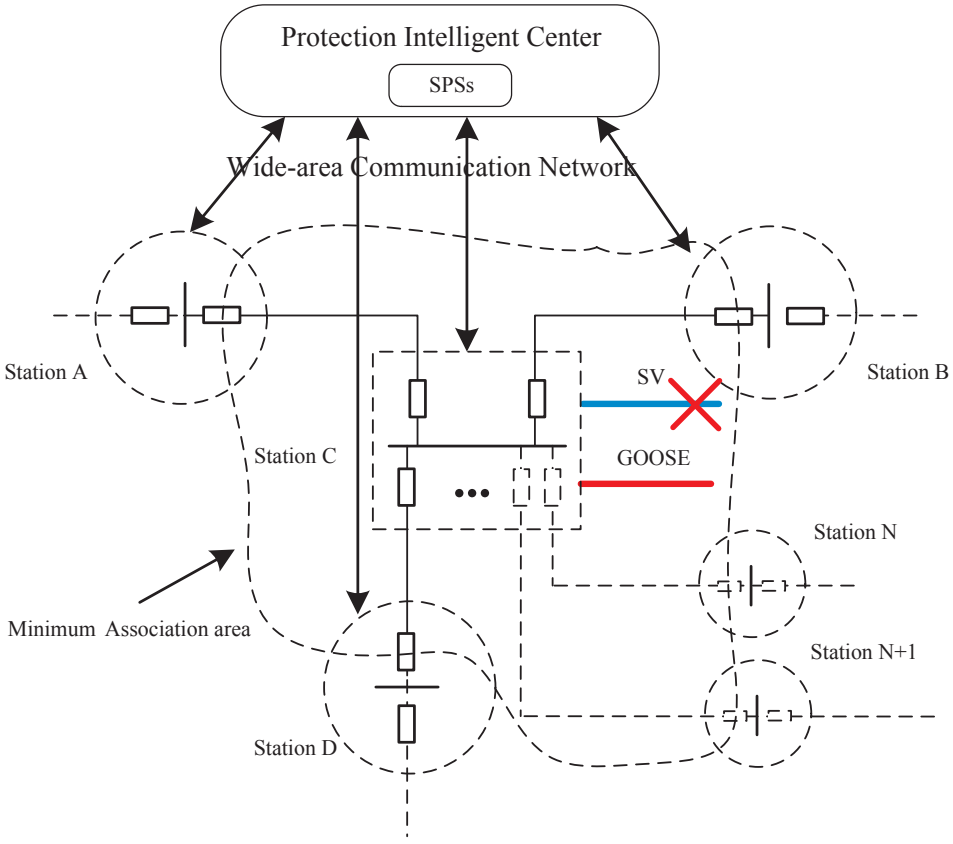

Fig. 1. Simplified diagram of regional substations.