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Shared-network scheme of SMV and GOOSE in smart substation

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Abstract The network structure of the smart substation in common use was introduced, and the technical problems of the shared-network of sampled measured value (SMV) and generic object oriented substation event (GOOSE) were analyzed, such as the processing ability of network device and the intelligent device, the data real-time property and the network reliability, the effects to the substation in the condition of network fault, etc. On this basis, the feasibility of the shared-network of SMV and GOOSE was discussed, the implement scheme was presented, and eventually the solution of the shared-network of SMV and GOOSE was put forward, which based on the applications of the message priority control, restricting the switch number, virtual local area network (VLAN) and GARP multicast registration protocol (GMRP) classification flow control, flow rate limiting, etc. In the test-bed, the cases of shared-network and separate-network of SMV and GOOSE were compared and analyzed, and the result was valuable for reference.

Keywords Smart substation, Sampled measured value (SMV), Generic object oriented substation event (GOOSE), Shared-network, GARP multicast registration protocol (GMRP), Virtual local area network (VLAN)

1 Introduction

The promulgation and promotion of IEC 61850 standards has laid a foundation for the development of smart substation system. It's generally considered that, the system structure of smart substation consists of station level, bay level and process level [1]. Between station level and bay level is manufacturing message specification (MMS) network, and between bay level and process level is process level network, which includes sampled measured value (SMV) network and generic object oriented substation event (GOOSE) network [2]. Generally, for the sake that protection device detects the faults and abnormal work status of power system correctly and quickly, isolates faulty elements reliably, and ensures the reliable operation of smart substation, SMV network and GOOSE network are physically separated at present [3], and process level network may be divided into multiple physical networks according to voltage grade [4], so as to ensure interference-free analog signal transmission, GOOSE tripping and GOOSE binary acquisition, reduce network flow, and raise real-time property and reliability. However, in this way, the devices on bay level need to provide at least 3 groups of Ethernet interfaces, with one group for MMS network, one for SMV network, and one for GOOSE network, and the substation network will become complicated. In addition, for busbar protection and transformer protection devices, etc. which needs to exchange messages among multiple bays, separated-network of SMV and GOOSE has brought many troubles. With shared-network of SMV and GOOSE [5], related devices may make the best of the information of the whole substation to simplify network structure and enhance efficiency. Also, along with the application of IEEE 1588, synchronization network is eliminated, and the whole substation communication network will be finally unified [6].

The shared-network of SMV and GOOSE has a big network load [7], so Gigabit LAN may be adopted. Considering network redundancy mechanism, priority division, network flow, fault recovery, processing capacity of CPU

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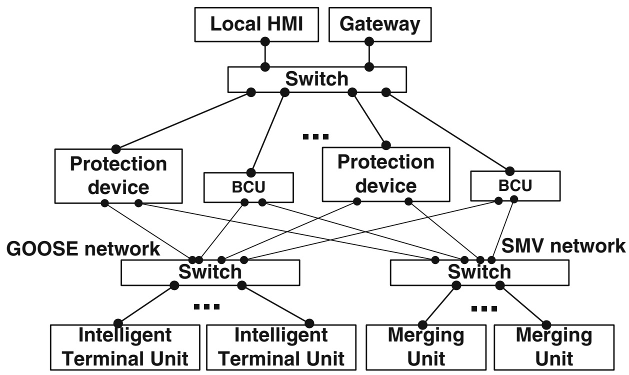

Fig. 1 Communication network of smart substation

and network card of devices on bay level and process level, and application demand, the shared-network scheme of SMV and GOOSE is researched in this paper.

2 Network structure of present smart substation

Generally, MMS network and process level network are separated physically at present. Where, MMS network adopts double-star or double-ring network [8]. The information of the whole substation are needed for bay level interlock, so in general, MMS network is used for GOOSE service of bay level interlocking; process level network usually adopts double-star network, with SMV network and GOOSE network separated, and may be divided into multiple physical networks according to voltage grade, and its basic structure is as shown in Fig. 1.

In the system structure as shown in Fig. 1, SMV network is applied to the analog signal transmission between merging unit and protection, BCU on bay level, while GOOSE network is mainly applied to the transmission of binary messages like the tripping, on-off status, and switching, etc. of the devices on process level. Due to the high importance of these messages, SMV network and GOOSE network shall be of high dependability; MMS network is applied to the message exchange between devices on station level and bay level, such as monitoring and control messages of devices on bay level, the requirement on dependability is low, but that on the message quantity is relatively high. Separating MMS network from process level network, and separating SMV network from GOOSE network may ensure that SMV network and GOOSE network are free of interaction and the interference of MMS network, reduce data flow, relieve the load of switches, and raise the information transmission efficiency; meanwhile, when one of the networks is in fault, it can reduce the fault scope and raise the dependability, and this is also the main reason for separation of MMS network and process level network at present.

3 Main issues for shared-network of SMV and GOOSE

The shared-network of SMV and GOOSE is mainly confronted with four problems:

1) The effects of network load on the intelligent devices and switches connected to network. When the whole network load reaches a certain order of magnitude, intelligent devices connected to the network will be heavily impacted due to the restriction of their own network card and CPU property [9], while switch is subject to limited influences thanks to its strong processing capacity. In smart substation, multicast transmission is adopted for data of SMV and GOOSE. Switch broadcasts and transmits target messages in the whole network, and all devices connected to the network will receive such messages. The message quantity of SMV and GOOSE is inversely proportional to the scale of substation, and the increase of SMV and GOOSE messages will obviously affect the network performance of the whole substation.
2) Processing capacity of devices on bay level. For shared-network of SMV and GOOSE, the data flow will be probably 8 Mbps for each bay. For busbar protection and transformer protection, devices of multiple bays are connected, so the data flow is very big, and it's an important issue that whether the network card and CPU of busbar protection and transformer protection can afford to process them.
3) Time property of data, namely whether messages of high priority level can be transmitted in time. Both the binary acquisition and transmission of trip signal from protection devices are realized by means of GOOSE [10]. In condition of shared-network of SMV and GOOSE, network load is relatively big, the time property of GOOSE is a key factor which determines whether the shared-network of MMS and GOOSE is successful.
4) Effects of network fault. In case of network fault, the protection and BCU on bay level will lose the capability of sampling and tripping due to shared-network of SMV and GOOSE, and this is also a problem which must be solved.

4 Feasibility of shared-network of SMV and GOOSE

4.1 Network load

In smart substation, multicast transmission is adopted for SMV and GOOSE messages. Namely, switch will broadcast and transmit SMV and GOOSE messages, and all intelligent devices will receive related messages, which will be filtered by network card and then be transmitted to application module, thus the network load of SMV and GOOSE will have influences on the intelligent devices in the whole network. In present smart substation, the SMV flow and GOOSE flow of one bay do not exceed 8 Mbps and 0.1 Mbps respectively. For a substation with 30 bays, the load of process level network in the whole substation won't exceed 240 Mbps. If Gigabit LAN is adopted, the load of process level network won't exceed 25%. This flow is relatively small for switch, but not so for intelligent devices like protection devices and BCU, etc., and the load of process level network needs to be reduced by proper means. Process level messages may be isolated in one bay through virtual local area network (VLAN), static multicast management or GARP multicast registration protocol (GMRP), in order to control the flow of process level data. By proper means, the influences of process level data on intelligent devices may be greatly lowered, and the shared-network of SMV and GOOSE will be possible.

4.2 Processing capacity of devices on bay level

The information of at most 4 bays shall be connected to transformer protection. Assuming 8 Mbps data flow each bay, the data flow for transformer protection will be around 32 Mbps. If Gigabit LAN card and independent CPU are adopted, the transformer protection can afford to process such data flow.

As to busbar protection, multiple bays shall be connected, generally more than 10 bays. It is feasible that multiple CPU boards are adopted, and the bays are grouped with one group to one CPU board.

4.3 Real-time property

The store-and-forward time delay of process level messages through 1 switch does not exceed 10 μs generally. Here, 10 switches are considered, hence the time delay is 100 μs at most. The processing time of network card of intelligent devices won't exceed 100 μs, the time of application processing won't exceed 1 ms, and it usually takes no more than 2 ms to send, receive and process a process-level message. In the transmission link of process level messages, the processing time of network card and that of application modules of intelligent devices are basically fixed, and the store-and-forward time delay of switch is closely linked with its performance. The store-and-forward time delay of the present Gigabit switch can be less than 1 μs in case of full load. So for shared-network of SMV and GOOSE, the real-time property of process level data is guaranteed in the way of isolating process level data by bay through VLAN or GMRP technology, and reducing the load of the whole network.

4.4 Process level network fault

For shared-network of SMV and GOOSE, network fault will induce the simultaneous invalidity of sampling and tripping, and the consequence is very serious. There are mainly two solutions to this problem, namely 1) adopting double-network redundancy, and 2) limiting the connected ports of switch. The possibility is extremely low that the two networks are in fault simultaneously. In addition, after the connected ports of switch are limited, the influence scope of faults may be minimized even if the two networks are in fault simultaneously.

5 Implementation scheme for shared-network of SMV and GOOSE

5.1 Application of priority technology

In shared-network of SMV and GOOSE, there will be four types of data in process level network, namely tripping data, blocking and interlocking data between protection devices, binary data, and analog data. These data are all of high importance, but at different importance degrees. When the substation is in fault, the messages in process level network will be greatly increased, and the network will possibly be jammed. In such case, IEEE 802.1p priority technology is applied to differentiate priority levels of the above mentioned four types of data, in order to ensure a reliable and quick transmission of the most important data in the worst condition. The priority sequence from high to low is: tripping data, blocking and interlocking data between protection devices, binary data, and analog data.

5.2 Limit on connected ports of switch

In smart substation, line bay has the most switch ports. Generally, one line bay includes 1 merging unit, 1 intelligent terminal unit, 2 line protection devices and 1 BCU. Five switch ports is enough for one bay, but a switch generally has 16 ports, which are enough for 3 bays. When a switch used for 3 bays is faulty, all the 3 bays will lose their protection, measuring and control functions. The solution is to limit the connected ports of a switch for only one bay. In this way, the failure of one switch will only affect one bay.

5.3 Application of flow classification control

5.3.1 Application of VLAN

VLAN is used to limit the scope of message dissemination [11]. In smart substation, most messages exchange is

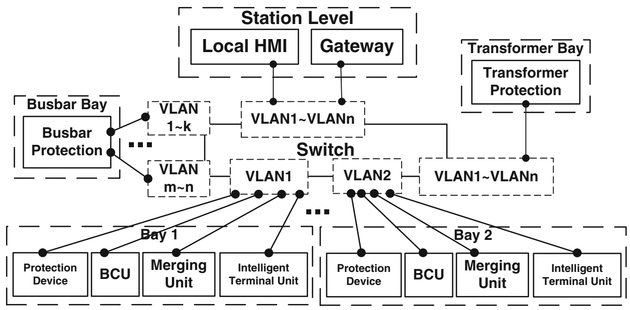

Fig. 2 Scheme based on VLAN

completed within the same bay, so the devices of each bay, including BCU, protection device, merging unit and intelligent terminal unit, belong to a same VLAN [12]; devices on station level, such as gateway or HMI, need to exchange messages with devices of all bays, so they belong to all VLANs; transformer protection needs to exchange messages with the devices of the bays governed, thus it belongs to the VLAN in the scope governed; busbar protection exchanges messages with different bay groups through different CPU boards, thus it belongs to multiple VLAN groups. In this way, it is possible to minimize the interference of messages between different bays, as shown in Fig. 2.

5.3.2 Application of static multicast management or GMRP

Both GOOSE and SMV messages are multicast messages, so the static multicast management or GMRP can be adopted to manage them. Static multicast management and GMRP works in similar pattern, both of which are achieved by maintaining the internal filtering database (FDB) in the switch, and the final filtering work is done by switching chip according to the FDB.

There are differences between them. The FDB of static multicast management FDB need to pre-configure to the switch, according to the forwarding rules, thus it is called "static". When configuring, each switch must have known the forwarding ports of every multicast address in this switch. While the FDB of GMRP is automatically generated by the switch through the interchange of protocol management messages, accordingly, GMRP is a "dynamic" protocol, which learns FDB dynamically and don't need to configure the forwarding strategies. GMRP can also dynamically respond to the changing of the network structure. But when using GMRP, it is required to support GMRP protocol by all terminal devices and switches.

When static multicast management or GMRP is applied, the division result of multicast group is the same as that of VLAN, as shown in Fig. 3.

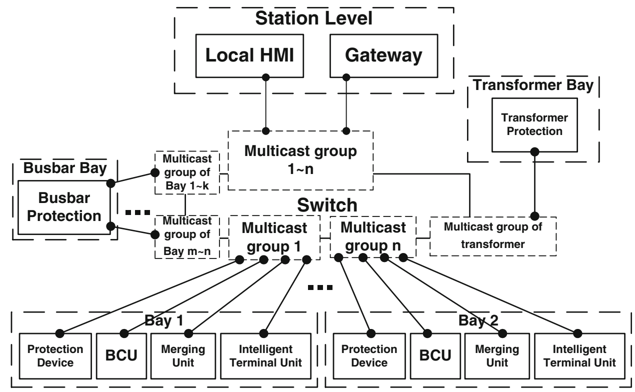

Fig. 3 Scheme based on GMRP

5.4 Application of flow rate limiting

The application of flow rate limiting technology can increase the ability of resisting risks in shared-network of GOOSE and SMV. As we know, if not using flow rate limiting, when there is a storm or some devices anomalously generating a lot of messages and suddenly sent to the network, all of the devices will be affected. When the flow rate exceeds the switch port bandwidth, the switch will randomly drop messages; even the port bandwidth is not exceeded, the other terminal devices will have unnecessary shocks. The flow rate limiting technology can be used in the switch to eliminate such cases. Currently, there are three ways that can be used to limit the flow rate .

5.4.1 Port based flow rate limiting

The maximum rate of each port in the switch can be set to prevent a sudden injection from some ports. The maximum threshold of the flow rate should be set a bit more than the normal maximum flow rate, leaving the safety margin.

When setting, it's only required to set ingress direction threshold, and the egress direction flow rate don't need to be controlled, because the storm must be derived from the ingress direction. In addition, it's only required to set flow rate threshold of edge ports (i.e. the switch ports directly connecting to IED equipment), and don't need to set link up port. Because the link up port is definitely not the source of the storm, and the maximum flow rate of the link up port is difficult to calculate.

5.4.2 Protocol type based flow rate limiting

Some switch supports the protocol type based flow rate limiting, which is more accurate.

Common flow rate limiting only supports setting a total threshold for all message flows. When the total flow rate

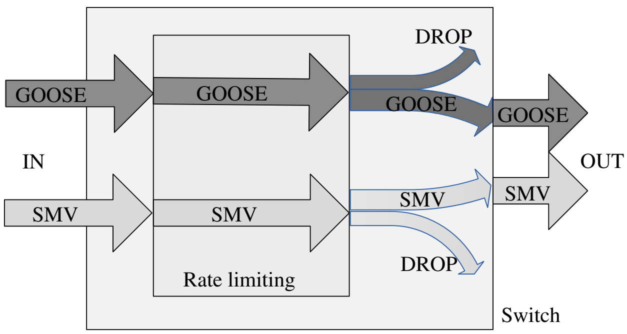

Fig. 4 Common flow rate limiting

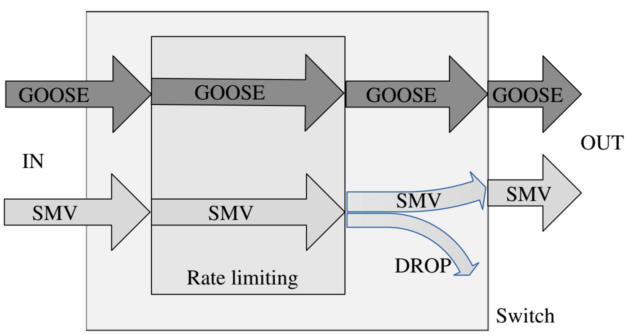

Fig. 5 Protocol type based flow rate limiting

exceeds the threshold, all kinds of messages will be dropped randomly, as shown in Fig. 4.

Protocol type based flow rate limiting supports setting different thresholds for all types of message flows. When any type of message flow rate exceeds its threshold, only this kind of messages will be dropped. As shown in Fig. 5, when SMV flow generates anomalous rate and exceeds its threshold, only SMV messages will be dropped, which has no influences on GOOSE message flow transmission.

Usually, the maximum threshold of for each SMV flow can be set to 10 Mbps, and the threshold of each GOOSE flow can be set to 2 Mbps in application.

5.4.3 MAC address based flow rate limiting

Some switch supports the MAC address based flow rate limiting technology, which can accurately limit the rate of any MAC address flow.

This technology is similar to protocol type based flow rate limiting. When a device produces abnormal flow rate, and exceeds its threshold, only the certain MAC flow will be dropped, which has no influences on the message flow transmission of other devices.

Usually, the threshold is set according to the destination MAC (ie, the multicast address of GOOSE or SMV) of a flow, and the threshold of for each SMV MAC can be set to 10 Mbps, and the threshold of each GOOSE MAC can be set to 2 Mbps in application.

6 Experimental comparison of separated-network and shared-network of SMV and GOOSE

The separated-network and shared-network of SMV and GOOSE are compared by means of experiment. Experimental conditions: the PCS-9881 Gigabit switch from NR Electric Co., Ltd is applied. Meanwhile, using the flow classification control technology to reduce unnecessary flow rate, making the flow rate to be control in the post-affordable range. 32 computers are used to simulate the merging units and intelligent terminal units of 32 bays, and 32 computers are used to simulate the protection devices of 32 bays; each merging unit sends 200 bytes of SMV message every 250 μs, each intelligent terminal unit sends 1,024 bytes of GOOSE message every 1 ms, and the network load is proximately 150 Mbps. The experiment result shows that, whether in condition of separated-network and shared-network of SMV and GOOSE, the maximum transmission time delay of SMV and GOOSE messages is 10 μs and no package is lost. Thus, the shared-network of SMV and GOOSE is feasible.

7 Conclusion

In smart substation, the shared-network of SMV and GOOSE may save communication network resources and cost, simplify the system structure and maintenance of smart substation, especially for LV substations. However, for shared-network of SMV and GOOSE, the data flow will be very big, especially for busbar protection and transformer protection, where the information of multiple bays are needed. In such case, Gigabit LAN card and CPU with quicker data processing are required. It's necessary to absorb experiences from practical operation and experimental inspection, solve the problems encountered, and make the technology become mature gradually. Currently, the shared-network scheme of SMV and GOOSE has been applied in lots of low-voltage smart substation, which is instructive for the construction of smart substations in the future.

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