Line Current Differential Protection: Migration of the Protection Interface from SDH to MPLS Networks

Welcome dear friends of protection, control and electrical engineering. In our new guest post, Dr. Andreas Aichhorn from Sprecher Automation GmbH has the floor. This involves new concepts for adapting protection interface connections to the properties of Ethernet-based networks. Let's get started

1. Introduction

With the constantly growing demand for bandwidth, the technical and economic requirements for communication networks and the associated challenges are also increasing. Synchronously clocked communication networks, so-called SDH networks, were widespread used. These networks function on the principle of time division multiplexing, which is not capable to work bandwidth efficient. Consequently, SDH networks have been successively replaced by packet switched networks such as MPLS systems. The change in network technology also leads to a change in the transmission characteristics. For a proper migration, it is necessary to adapt the end devices to the characteristics of the network technology in order to realize the most reliable communication.

This change primarily affects the protection interface (PI) of the line current differential protection, since a function-defining deterministic propagation delay in the communication network was assumed up to now, which is no longer given if Ethernet-based networks are used.

This article describes the requirements of line current differential protection systems on the protection interface as well as the mechanisms of different communication technologies and their usage for the protection interface. For the special case of the protection interface in line current differential protection, the characteristics of a migration concept with legacy interfaces are examined in more detail. In summary, a concept for the use of communication technology according to the state of the art is presented, with which a reliable protection interface connection can be established via packet switched networks.

2. Requirement of the protection interface to the communication

The protection interface is used to transmit data that is required for the trigger criterion of the protection relay and is therefore highly relevant. The PI of a distance protection relay typically exchanges binary data, whereas line current differential protection relays exchange measured values in order to continuously calculate a current sum and thus the actual fault current in the system. For this reason, the communication requirements for line current differential protection systems are significantly stricter than for distance protection. Therefore, the request for line current differential protection on the protection interface is used as a reference in the following.

At line current differential protection systems, the measured current values are digitised at each device and transmitted to the remote station. These measured current values must be transmitted in such a way that they can be correctly assigned to the original point in time at the remote station. If the alignment of the measured values at the remote station is imprecise, the result of the calculated fault current will be distorted and this may lead to an incorrect reaction of the protective relay. Different concepts are used for the correct time alignment of the measured values at the respective remote station. In the past, synchronous, deterministic communication systems (e.g. SDH networks) were widely used. The properties of these communication systems are advantageous for the transmission and subsequently for the correct assignment of the measured values at the remote station.

If a packet switched network (e.g. Ethernet-based) is used instead of a synchronous, clocked network (SDH), the concept of the protection interface must be adapted to the changed transmission properties in order to be able to guarantee a correct and precise assignment of the measured values and thus a correct calculation of the fault current.

3. Communication technologies

As already mentioned in the previous chapter, a precise, reliable and a fast transmission of the measured values is a prerequisite for using the communication for the PI. A precise transmission of the measured values can be achieved either through a synchronous network or through an adapted concept considering the properties of the communication system.

The communication networks addressed here are so-called WANs (Wide Area Networks) and are used in geographically extended computer networks (i.e. WANs are not tied to a single location). In contrast, local networks are referred to as LAN (Local Area Network). Such networks are spatially limited and the extent is typically defined within a building. With reference to the power system domain, these definitions mean that the communication within a substation is referred to as LAN, e.g. for the IEC 61850 station bus. On the other hand, the protection interface, which establishes a connection between geographically separated substations, is established via a WAN.

Depending on the transmission mechanism, most of the communication technologies used in the WAN area are divided into Time Division Multiplexing Technology (TDM) and Packet Switched Networks (PSN). Synchronously clocked networks, such as SDH, function according to TDM technology. MPLS networks (Multi Protocol Label Switching) or Ethernet-based networks are working according the mechanism of packet switching and are therefore referred to as Packet Switched Networks (PSN).

3.1. TDM-based communication networks

Time Division Multiplexing (TDM) is a transmission mechanism, in which a time slot is assigned to each participating device. Hence, each device can transmit a pre-defined amount of data at a specific point in time. This means that a constant amount of bandwidth is assigned to each device (regardless of whether the reserved bandwidth is used or not). Figure 1 shows schematically the transmission mechanism of TDM. Networks with such a transmission mechanism are known as SDH (Synchronous Digital Hierarchy) or PDH (Plesiochronous Digital Hierarchy) networks.

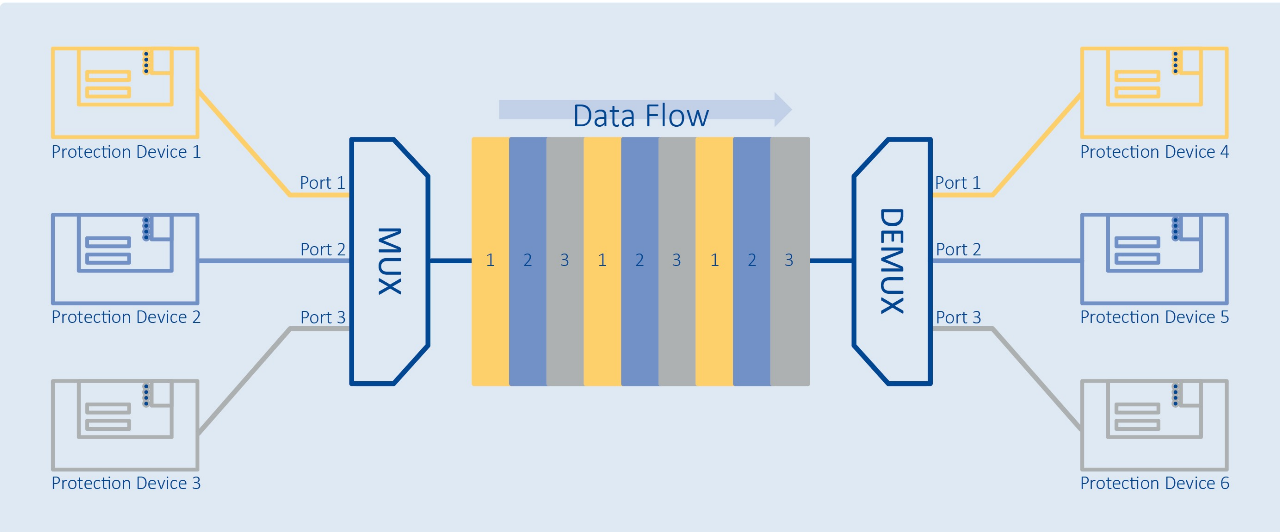

Figure 1: Transmission mechanism in TDM

In these networks, data is transmitted periodically and deterministically. This is a very important advantage of SDH in relation to the protection interface of line current differential protection systems. The main disadvantage of this technology is that the bandwidth cannot be used efficiently, since a large number of services do not send data at a fixed rate, but only on request. As a result, many time slots are not used and the effectiveness of the whole system is very low.

The use of a TDM-based communication system for the transmission of measured values has the essential advantage that these are always sent or received at a fixed point in time, so that the timing of the network can also be used as time information for the measured value. The implementation of the time synchronisation and the compensation of the signal delay are implementation-dependent. The deterministic transmission mechanism of the

TDM-based network, however, provides a good basis for the transmission of time-critical data.

3.2. PSN-based communication networks

A Packet Switched Network (PSN) transmits data in the form of packets (e.g. Ethernet-based networks). The size of each package is variable (within defined limits). Each participating device can send packets at any time. Network devices (such as switches or routers) forward these packets to the specified destination. If several packets arrive at a network device at the same time, these packets are stored in a memory and are processed according to the “first come – first served” principle. Each device sends data as needed, which means that the fluctuation of the load is not predictable. This is the basic mechanism of packet switching within a PSN. Figure 2 illustrates this transmission mechanism. An example of a communication network technology relying on PSN technology is MPLS.

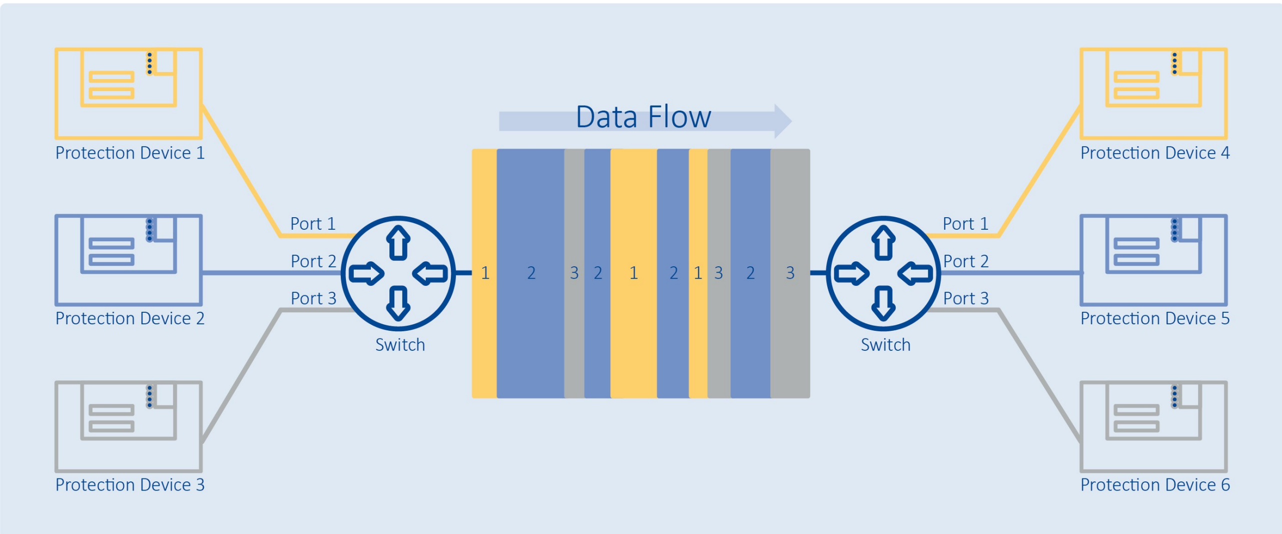

Figure 2: Transmission mechanism in PSN

This transmission mechanism enables bandwidth-efficient transmission of data, since only transmitted packets for the utilisation of the network are counted and not a fixed reserved timeslot of each participating device (cf. TDM technology). However, the mechanism of packet switching has the major disadvantage that a delay time fluctuation (also referred to as jitter) occurs. This jitter depends on the current network load, which is not predictable. Prioritisation of the transmitted packets could be a possibility for an optimised transmission of packets, whereas this service needs to be provided by each network device. This service optimises the propagation time but cannot fully compensate the occurring jitter. Exchanged packages are therefore subject to a propagation time fluctuation depending on the load.

It is therefore not advisable to connect a protection interface that is specially designed for SDH networks via Ethernet-based networks.

3.3. Development over time of the communication technologies used

The origin of TDM-based networks, such as SDH, goes back around 100 years. Harry Nyquist investigated telegraph speeds around 1920. In 1933, he determined the required sampling rate for the transmission of analogue speech patterns. Nyquist determined a rate of 8,000 samples per second to digitise speech (cf. [1]). On this basis, a transmission method was developed in which 8 bits are transmitted per time slot, resulting in the data rate of 64 kbit/s per channel, which is still known today. This is defined in the standards as bandwidth per time slot, for example in the ITU-T G.704 standard and also in the IEEE C37.94 interface standard for protection application.

Due to the diverse use of the SDH network (telephony, PC networks, protection interface, ...) there was a constant increase in the required bandwidth and consequently an expansion of the systems. The maximum sales of SDH-based systems were recorded in the year 2000, as described in the white paper by S. Perron [2]. After that, sales and thus also the expansion decreased. Through the Ethernet-based technology already established in the LAN area, packet switched networks with bandwidth-efficient data transmission have been further developed also for use as WAN. The Ethernet-based transmission thus successively replaces the SDH technology in order to meet the steadily increasing demands of the market, especially in terms of bandwidth. The packet switching mechanism is an economical and flexible system that can be used to implement various services and enables bandwidth-optimised transmission. In the WAN area, MPLS systems have been established.

The migration from SDH to packet-oriented, optical communication systems began around 2005 (cf. [2]). This reduced the number of available SDH networks. Nevertheless, the concepts of the protection interface in most protective devices available on the market have not been adapted to the communication properties of the packet switched networks that are now predominant. The use of a PI developed for SDH networks is only feasible via a packet switched network using additional services.

4. Use of Ethernet-based networks for the protection interface

In the following section (4.1), migration scenarios from SDH to Ethernet-based systems are explained, for which the properties of an SDH network are emulated via an Ethernet network. Subsequently, section 4.2 describes a concept that enables a native use of Ethernet for the protection interface.

4.1. Migration from SDH legacy interfaces

Due to the change from SDH to Ethernet-based communication systems, there was a high demand for an interface with the characteristics of an SDH network. Hence, services were developed that emulate the properties of an SDH connections via an Ethernet network. These services are called pseudowire connections. Known implementations are for example: SAToP (Service Aggregation over Packet) or CESoPSN (Circuit Emulation Service over Packet Switched Networks).

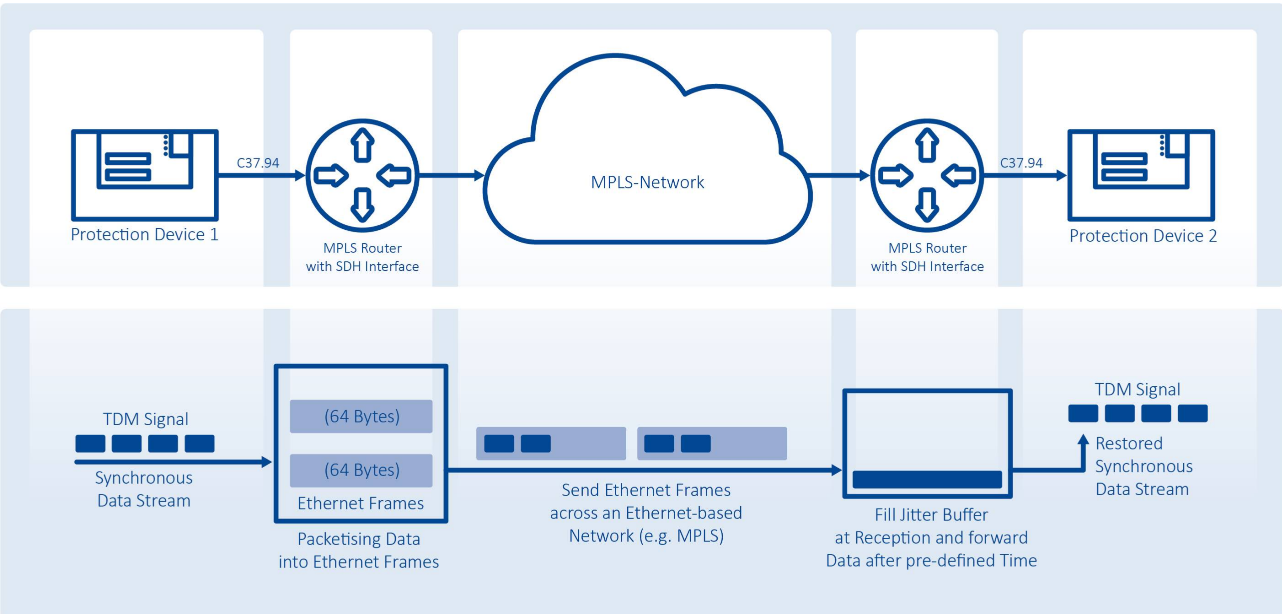

Figure 3: Communication of two protection devices with an SDH interface using a pseudowire connection

Figure 3 shows the principle mechanism of such pseudowire connections. Protection relays with a legacy SDH interface (e.g. C37.94) are connected to an MPLS network which support this legacy interface. For a better traceability of the mechanism, the data transmission is illustrated in one direction only (from protection relay 1 to relay 2). In practice, the data stream can be realized in both directions.

When data is sent out from a protection relay (relay 1 in Fig. 3), the data is first packetised and further transmitted via the network. At the network device where the data is leaving the network, a jitter buffer is placed which holds back the transmitted packets for the time of the maximum possible jitter. After a pre-defined time has elapsed, data is released and forwarded to protection relay 2 in the form of synchronous, clocked data. A deterministic transmission can be achieved by using a packet switched network (e.g. MPLS). However, this connection requires an increased time delay and/or increased bandwidth. Various publications on this topic describe evaluations of pseudowire connections via an MPLS network for the protection interface of line current differential protection systems. Results from a publication by S. Blair [3] clearly show the trade-off between increased time delay and bandwidth. With the setup used in this research, a time delay of 4.11 ms was measured at a required bandwidth of 2.32 Mbit/s. This parametrization was setup to optimised bandwidth. With an optimisation of the time delay, a value of 2.79 ms was reached at a required bandwidth of 8.26 Mbit/s. In this setup, an E1 frame was transmitted, which has a defined size of 2,048 kbit/s (the maximum usable net bandwidth using the protocol C37.94 is at 768 kbit/s). In comparison, the signal propagation time would be in the order of 50 µs if an MPLS network would be used natively. In practice, the resulting time delay depends on the expansion of the network (i.e. number of switches/routers and length of FO cables). This example illustrates the compromise that needs to be made for the migration for using an SDH interface via a packet switched network (e.g. as MPLS).

The simulation of the properties of an SDH network via a packet-oriented system is certainly useful for a migration process and a transition period. Nevertheless, new developments of end devices should consider native use of Ethernet in the overall concept of data exchange in order to obtain the most efficient holistic solution possible. The pseudowire connections are well-functioning solutions that work within their specification, but it should be kept in mind that this service has to be bought at a high price. Either an increased time delay or a significantly increased bandwidth must be accepted for.

These findings clearly illustrate that a pseudowire connection is definitely possible for a migration process, but only makes sense for migration due to the increased delay and/or bandwidth. The allocation of 8 Mbit/s for each protection interface will not be economically justifiable in the future either. So this approach should not be treated as the solution for the migration from SDH to MPLS networks. Rather, it is important to adapt the concept of the end devices (protection relays) to the characteristics of the packet switched network.

4.2. Adaptation of the overall concept for efficient use of Ethernet

For the protection interface, especially at the line current differential protection, the time delay behaviour of the data has an influence on the function of the protection device, which is why appropriate measures have to be taken to compensate for this influence. Using Ethernet-based communication, as already discussed in Section 3.2, jitter occurs during the transmission of data. Many current implementations of the protection interface on the protection device only transmit the measured value and require an exact time behaviour of the communication network. Therefore, direct transmission of the measured values via Ethernet-based communication networks would not be possible without additional measures.

Hence, the concept must be adapted so that a time stamp or counter value is also transmitted with each measured value. As a result, the measured value at the receiving device can be assigned exactly to the original point in time, so that the fault current in the system can accordingly be calculated correctly. Figure 4 shows the alignment of the measurement values schematically using the example at the time value t = 8 ms with a relating current value of i(8) = 50 A. In addition, the transmission of both, the time value and the current value, to the remote relay are also illustrated in this figure.

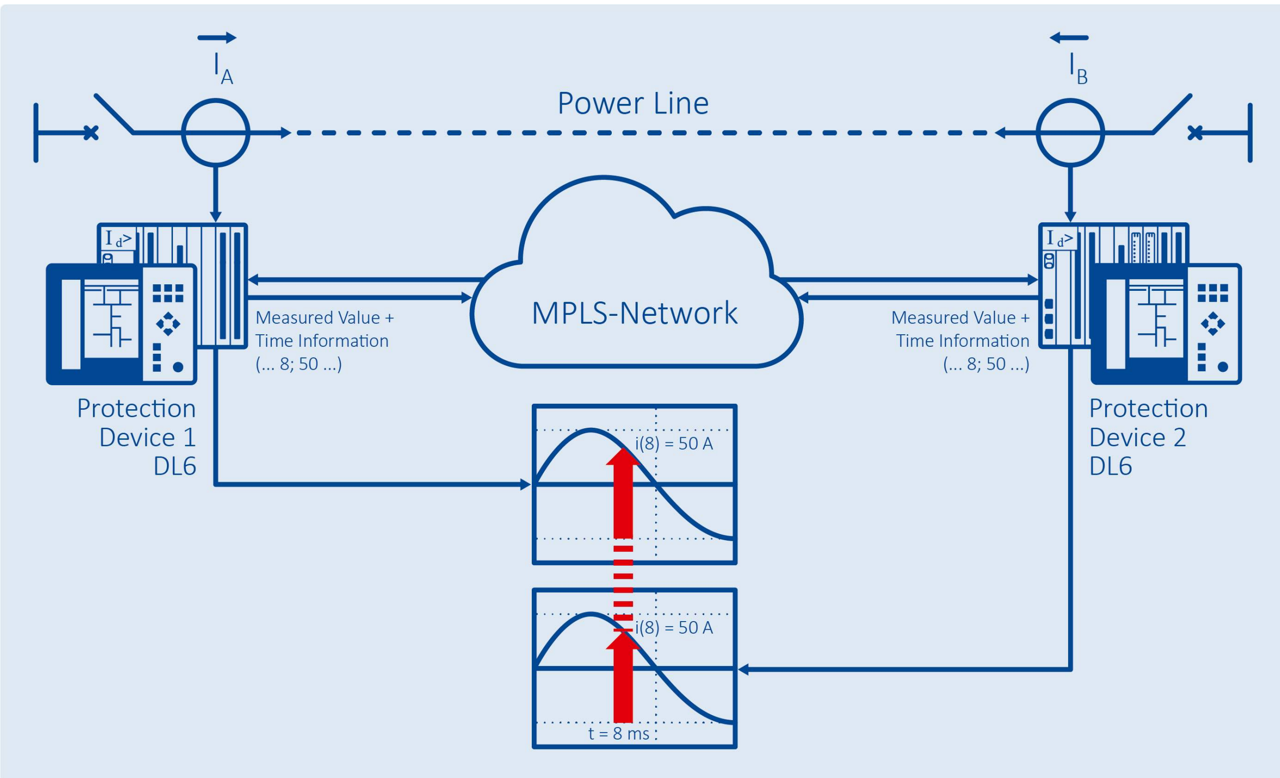

Figure 4: Concept of a line current differential protection via an MPLS network(exchange of measured values + time information)

The precise time synchronisation required for this method compensates for the jitter that occurs during transmission via the packet switched network, so that this does not affect the calculation result of the fault current. With this compensation, the measured values can be transmitted via packet-oriented networks without additional services. Such a concept has already been successfully implemented in process bus systems (in accordance to IEC 61850-9-2). In contrast to the process bus, the line differential protection system communicates between the end devices between substations. Hence, the required communication for line differential is a WAN and not a LAN. In a process bus system, PTP (Precision Time Protocol according to IEEE 1588) is mostly used for time synchronisation. PTP is designed for LAN and not for WAN applications, whereas it could be realized also via WAN. Each network device needs to support this service, which is not common for WAN network devices.

Known methods for providing precise time synchronisation are, for example, the already mentioned PTP protocol (acc. IEEE 1588), the use of GNSS (Global Navigation Satellite System) or proprietary mechanisms for the relative time synchronisation between the protection relays. When using PTP, each relevant network device must support the service in order to achieve the specified accuracy. GNSS require reception or a line of sight to the satellites in order to achieve sufficient accuracy.

The line differential protection from Sprecher Automation, SPRECON-E-P DL6, supports the direct use of an Ethernet network for the protection interface: The MPLS network can be connected natively without the need of an additional service or a pseudowire connection. The time synchronisation is implemented with a method patented by Sprecher Automation, which uses the communication channel for synchronisation. This method periodically measures the characteristics of the communication line. Based on these characteristics, a periodic time synchronization is performed in order to continuously correct clock deviations. According to the design guideline IEC 61850-90-1, the target for the time accuracy was set to 10 μs. The maximum deviation that occurred during a practical long-term test with this algorithm did not exceed 5 μs. The method works iteratively and thus adapts quickly to changed communication channels, for example when a route is changed in a network (e.g. re-routing at a failover).

5. Conclusion

For technical and economic reasons, it is necessary to replace SDH networks with Ethernet-based systems in order to meet the constantly growing demands on bandwidth. The pseudowire connections provided by the communication devices can be used with the accepted characteristics (increased bandwidth and time delay) for the migration of existing systems via Ethernet-based communication systems. To yield an efficient solution for the future, the concepts of the protection interface connection must be adapted to the properties of the Ethernet-based networks.

Literature

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