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PACS challenges for Packet Switched Networks

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SUMMARY

Protection, Automation and Controls Systems PACS are becoming a packet traffic generator with its IP native protocols challenging telecommunications networks for bandwidth and resilience of routes. The challenging situation appears because PACS keep unchanged their security, dependability, speed and reliability of their native TDM parameters.

On this paper we will analyze how critical parameters as Delay, Asymmetry, Time Stamp carrying capability and backup path switching time plays an important role in the fulfillment of maximum fault clearing time that guarantees the power system transient stability. Time analysis will be performed based on average data from some country specifics regulated transient stability time supported by field data and laboratory testing.

SDH and SONET (a TDM based technology) has >90% of current implemented telecommunications networks around the world. STM-16 is the maximum data rate supported by utility hardened multiplexers that comply with IEC 61850-5 and IEC 1613 standards, however the arising of IP based applications demanding higher bandwidth but keeping TDM typical times challenged the commercial IP platforms and protocols, converging on the Transport Profile suit of MPLS (MPLS-TP)

MPLS-TP technology becomes the more suitable technology for packet switching implementation on electrical utilities specially on providing reliable transport for critical services as well as supporting high bandwidth and fast communication for PMU/WMU traffic on energy stability systems.

Selective Backup Protection will be analyzed based on PMU measurements and Packet switched communications,

KEYWORDS

System Stability, PMU transport, PTP distribution, Latency, Symmetry, MPLS-TP, Selective Backup Protection

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Some utilities start to implement hybrid SDH+MPLS-TP platforms in order to have a transition between both technologies, carrying critical services as tele protection and differential protection signals on native SDH with IP SCADA non-critical traffic over MPLS-TP. The approach is very conservative and expensive considering that a correct evaluation of critical parameters to be served on the power transmission application would allow a direct replacement of SDH by MPLS-TP. For this, a deep understanding of the complementary functions of each technology must be evaluated. MPLS-TP arises as 100% replacement platform for SDH, emulating TDM circuits for critical services scarifying routing features required by IP traffic but preserving speed for PMU applications.

Delay: is usually associated with bandwidth; but we can notice that in case of TDM an E1 (2.048 Mbps) could provide the same delay to a single DS0 channel as if it was using a 64kbs G703.1 interface. In case of IP traffic, if not classified, delay can be affected due to bandwidth availability, not in case of MPLS-TP.

MPLS-TP has a key characteristic for protection and control applications, the forward and reverse paths go through the same nodes, that gives communication symmetry, and MPLS QoS, that gives higher priority to time-critical data (as stated in IEC61850-90-12) ensures a very good platform for such applications.

All these features aim to ensure a network latency, detailed in next figure, for a WAN performance classes.

WAN latency class	**IEC 61850-5 latency class**	**Latency**	**Use**
TL1000	TT1	≤1000 ms	All other messages
TL300	(TT2)	≤ 300 ms	Operator commands
TL100	TT3	≤ 100 ms	Slow automatic interactions
TL30	(TT4)	≤ 30 ms	Fast automatic interactions
TL10	TT5	≤ 10 ms	Teleprotection
TL3	TT6	≤ 3 ms	Differential protection
NOTE The measurement method is indicated in IEC 61850-5:2013. The abbreviation has been changed from IEC 61850-5 TT to TL in order to prevent confusion.			

Table 1. Latency classes for WAN extracted from IEC61850-90-12.

Figure 1 depicts a typical impedance protection scheme. Between two substations, a transmission line is subject to failure from external factors (strike, tower fall, phase to phase short circuit) or factors associated to the energy transmission by loads or generators (Overcurrent, SAGs, etc.). The protection principle is to insulate at the same time both sides of the transmission line in order to “protect” what is behind those ends (transformers, generators, loads).

As per IEC 60834-5 which defines the maximum times that teleprotection equipment (a device that allows the communication of distance protection relays) takes to clear a fault, also according to each country energy regulator we can infer that is required a fast communication channel.

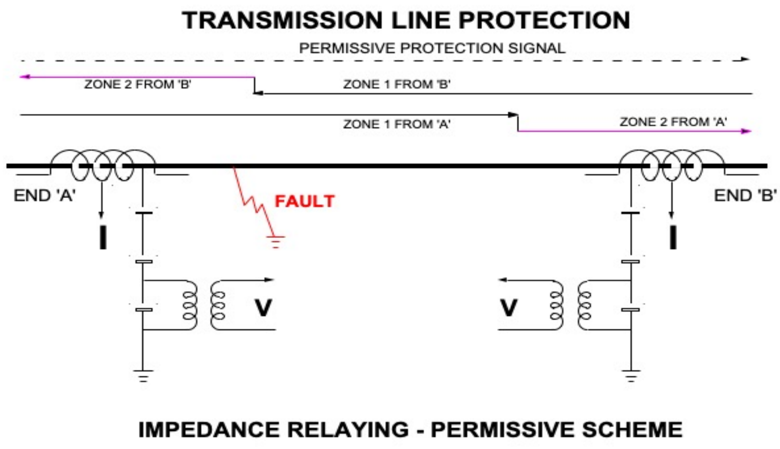

Figure 1. Permissive protection Scheme

“Based on the analysis performed to the MPLS-TP technology and the time response of the performed lab test, we consider this technology suitable for the Energy transport network as an optimized path of the progressive migration from the legacy TDM platform to the modern and reliable packet switched network.” [1]

Symmetry: relates to equal trajectory path of data, not important on pure IP based communications but critical for protection information especially where real time parameters processing is performed.

For the Differential Protection scheme as depicted on figure 2, the IED located at both ends of the power transmission line are in real time sharing the measured current input A vs Output B and vice versa. Same time measurements are compared, in case of 45 μs (1/60Hz/360^o) difference of Tx path compared to Rx path the phasor measurement comparison will be shifted 1^o, resulting most probably in a false differential comparison that could trigger protection.

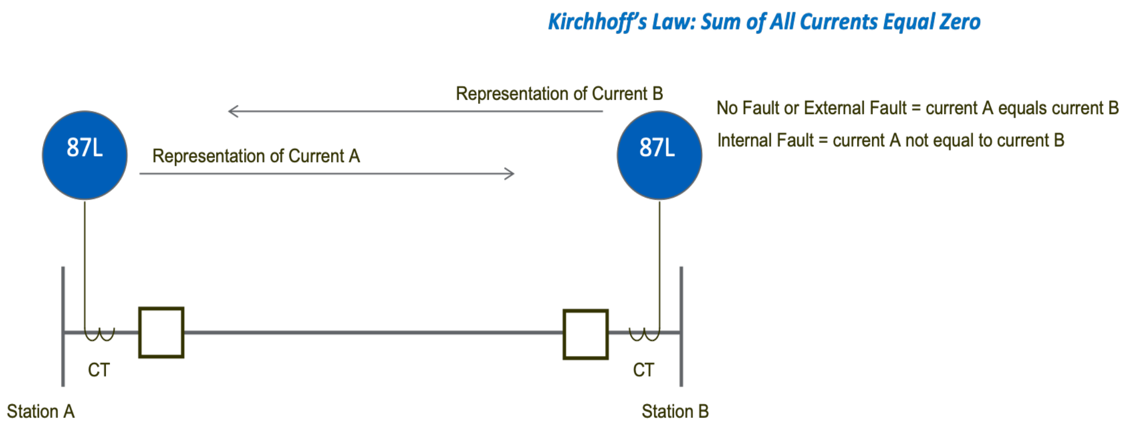

Fig 2. Differential protection scheme

MPLS-TP implements by default (not in case of MPLS) a symmetric path for main or alternate route, no extra resources for programming nor configuring is required beyond the initial manual setup.

Reliability: is associated with resilience and therefore with redundant or alternate communication path. In terms of communications the implementation refers to a backup path or route that must be operative in very short time to ensure that critical operative parameters of power transmission systems are supported.

On following image considering the stability time of 100 ms typical for 220KV transmission lines, a maximum of 20 ms is the time allowed for tele protection interface to operate, this time window includes the teleprotection itself and the Telecommunication equipment that provides such communication. Important to consider in case of packet networks, that path switching needs to be within such 20 ms window additional to the requirement of symmetry.

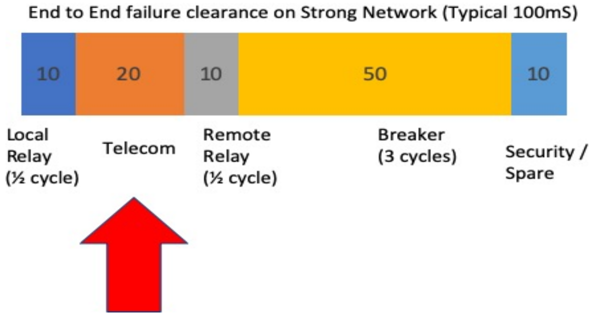

Figure 3. Typical Stability time for 220KV power transmission line

Path redundancy within the permissive time defined by the fault clearance/stability time, is a mandatory feature on packet networks. Is required a switching speed to allow the inherent telecom latency and teleprotection (algorithm processing) to be executed (around 10 ms). Some testing has been performed [3] to market available products based on MPLS-TP with switching times that meets the expected values.

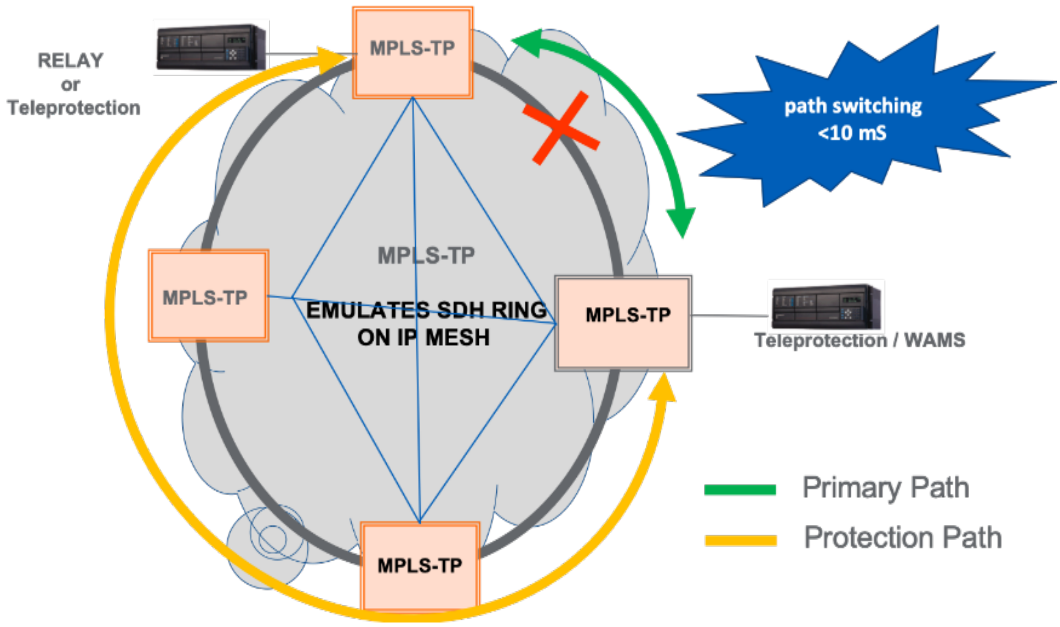

Figure 4: Path switching <10 ms

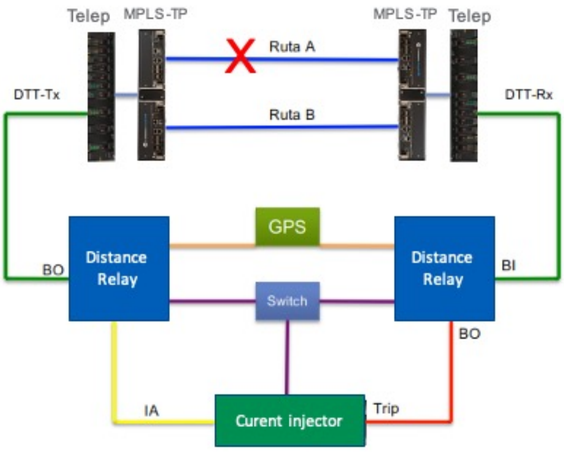

Figure 5: Test bed for path switching

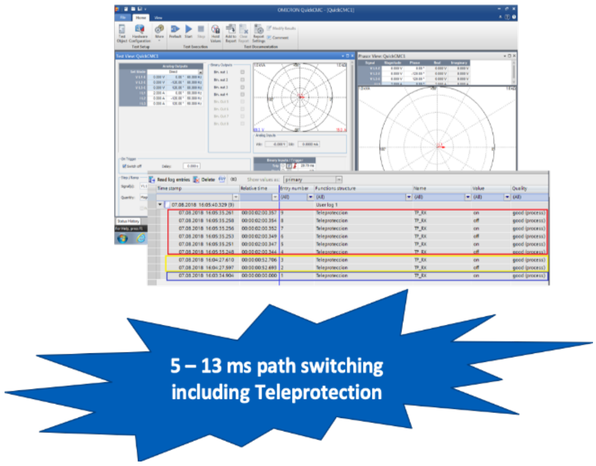

Fig 6. Path switching results

Time-Stamp: in a wide area applications a correct time-stamping is key to achieve certain applications, such as differential protection schemes or PMU based actuations, also is essential to use a common and reliable time reference.

The SNTP can have redundant capabilities but due to its accuracy limitations (order of ms) is out of the solution. IRIG-B has enough accuracy (µs) for the application but its redundancy is not supported by its protocol. The PTP synchronization has the advantage of redundancy given by its Best Master Clock (BMC) algorithm (multiple master clock) and its ethernet L2 capabilities additional to the accuracy (ns) provided by Global Navigation Satellite System (GNSS) constellation.

As an example of PTP distribution on a real system, figure 7 has for each substation a Phasor Measuring Units (PMU) to provide synchrophasor information with analog (voltage/current) and digital data (switchgear position). PTP is defined due to its high accuracy and per its IP nature, the use of ethernet platform for its distribution is mandatory (here is important to consider the symmetry, delay and reliability factors provided by MPLS-TP as previously discussed). For each substation is installed at least one PTP clock to synchronize all the substation equipment. This approach could be improved when used as inter-substation synchronization system, for this, the nodes of the communication network are required to be Boundary Clock capable or at least transparent clock as depicted on figure 8.

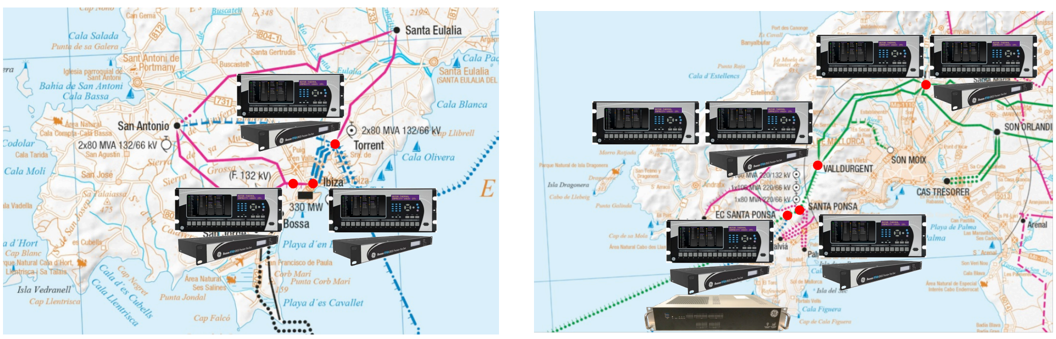

Figure 7. PTP system distribution.

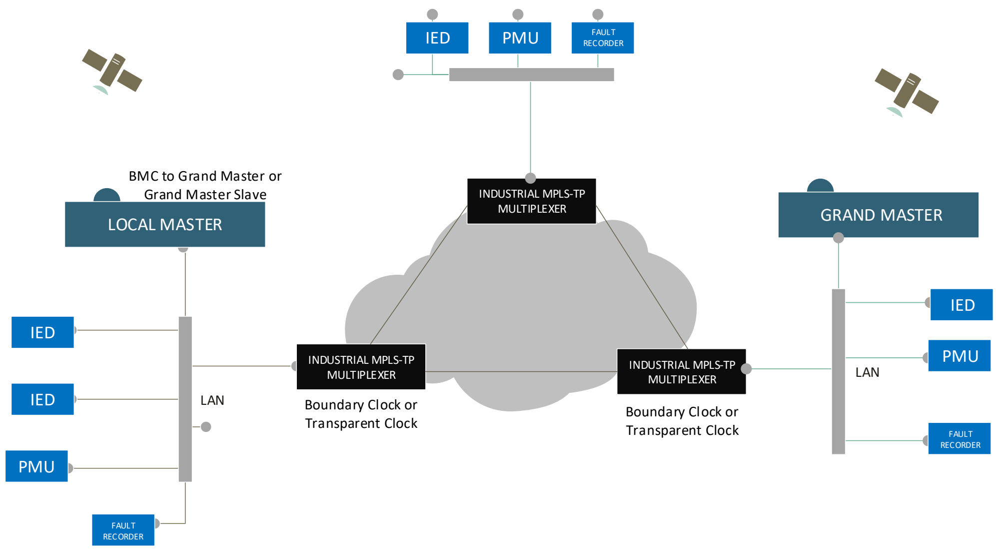

Figure 8. MPLS-TP as PTP distribution platform

In the following paragraph the description of and scenario of MPLS-TP as communication platform to implement ***Selective Backup Protection for AC HV and EHV Transmission Lines*** [2]

Here it is a new vision of backup protection, focused on the application on transmission lines (it can be applied also in other areas extending the criteria). One of the major today problems in HV Transmission Systems is remote backup correct operation. The normal practice is the Zone 3 use, but this philosophy presents limitations that have caused several blackouts, due non desired operation caused mainly by line overloads. It can define in the grid super nodes with the corresponding overlaps, extending the coverage that normally exists for bus protection in nodes.

As a *super node* is perfectly balanced during normal operation, differential criteria can be used to detect any internal fault in a similar way as it is with a Node but in this case, using Phasor Measuring Units (PMUs) as sensors. The main difference is in the operation time that in case of Super node will be time delayed. Doing this, a new protection philosophy based on “three defense lines” can be applied:

- Primary protection (as usual, distance, line differential) as the first defense line.
- First Backup selective protection: Differential (Active Power) time delayed with PMU (200 to 300 ms could be enough). Other criteria as current differential or directional also could be used. Active Power is preferred because it is inherent non-affected by line charging, Inrush current from transformers. Differential criteria works well with none, or reduced infeed during faults as in case with non-renewable (wind and solar) energy sources. This is the second defense line.
- Second Backup Protection: As usual, BF, Zone 3, overcurrent, etc. (disabled while First Backup is active and automatic enabled if First Backup is non-active or failed). Alternative second defense line (no deterministic).
- System Integrity Protection: SIPS or equivalent to maintain the stability of the network as a third defense line. Alternatively, other methods as planned islanding and emergent frequency and voltage control to prevent expansion of an event into a large area power blackout.

The above scenario brings a new proposal, bringing the user the advantages of using PMUs for protection, to solve problems unsolved until now. Figure 9 depicts the solution proposed:

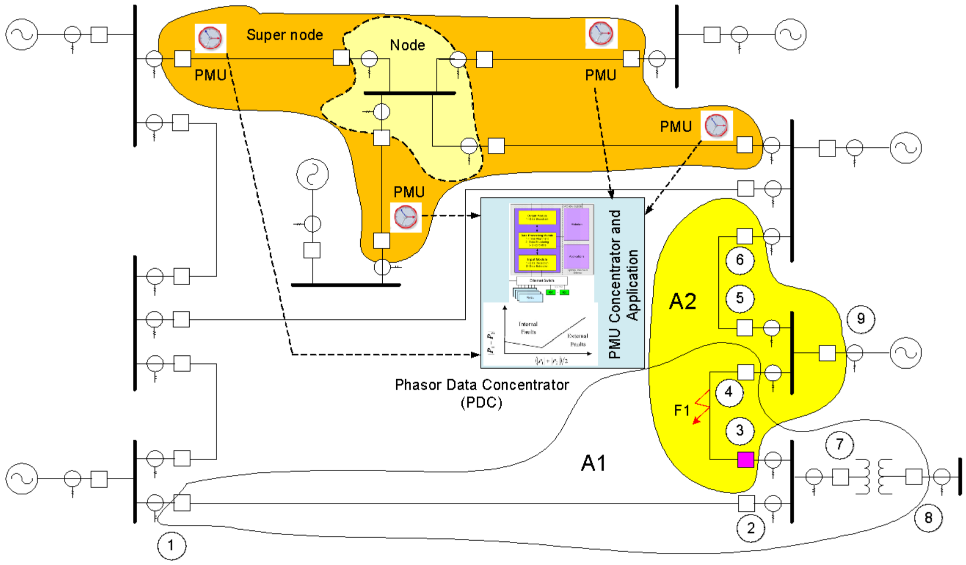

Figure 9. Supernodes.

For example, in case of fault in F1 and breaker 3 fail to open, Area A1 will trip time delayed (breakers 1, 7, 8 and eventually 2). If breaker 4 is open correctly by primary protection, a signal to remove in the PDC the PMU signals from breaker 3 in A2 is given preventing this area to trip. This is a similar technique used in trip for breaker coupler in bus protection (double bus arrangements). In this case, combined with remote breaker open criteria used in line pilot schemes.

In this protection scheme, communication MLPS-TP based technology is critical to provide an adequate bandwidth to transmit PMU data to remote locations (several kilometers) and receive signals to trip the circuit breakers

On a practical case, system depicted on figure 9 implemented as backup protection might expect acting times between 200-400 ms. RTDS simulation for 50 phasors/s gives 90 ms (see figure 10, most faults are resistive per nature and those fault impedances are above 1 Ohm in most cases), this includes processing time on IEDs and telecom infrastructure.

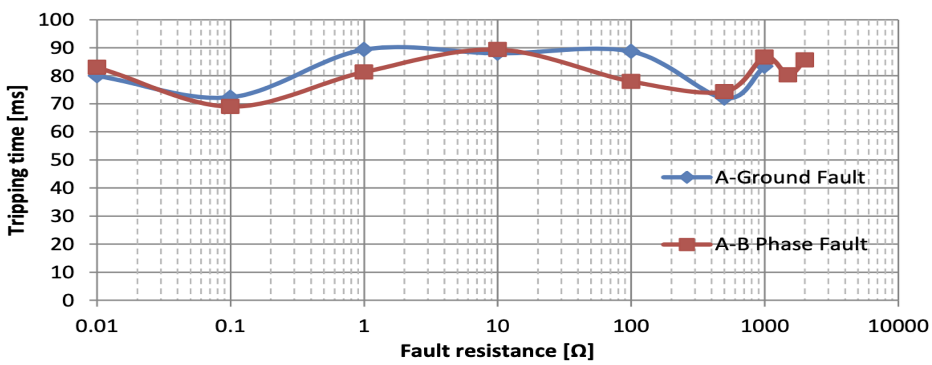

Figure 10. Tripping time of "Backup Protection" contains operating time of RTDS simulator with amplifiers and GOOSE massage sending time between PLC Logic and PMU relay. [2]

CONCLUSIONS

Packet Switched Networks (PSN) are challenged from PACS systems in the same way as with TDM networks. PACS systems communications evolved to packet maintaining the same requirements they had in TDM. Being said that, PSN requires special features to support power system applications, these characteristics aren't available on all commercial technologies. In that sense, MPLS-TP derived from MPLS appears favorable performance for such critical applications.

Distance protection schemes requires low latency on PSN in order to support the stability times of power systems. Typically, <10 ms for direct protection ethernet to ethernet including the required time or path switching within the network.

Differential protection still working over C37.94 when implemented over PSN. MPLS-TP platforms on the market are providing latency of <2.5 ms in accordance with IEC TR 61850-90-12:2015 (Latency class TT6 <3 ms)

Symmetry becomes a key feature on PSN, some test has been performed over MPLS-IP platforms leading to similar characteristics as for MPLS-TP, drawback is the complexity and higher cost due the required traffic engineering [4].

Reliability on power system information exchange is associated to redundancy on communication systems. Such redundancy is associated with at least one alternative path of communication that must switch in a short period of time <10 ms to meet the protection scheme operate on each country regulator defined Stability Time. In average, for 220KV 100 ms is the stability time to clear a fault including end to end relays operation and communication. Field measurements of path switching of current available MPLS-TP platforms fulfill such requirement.

Time-stamp for PSN requires PTP as timing source, then is desired each PSN's node to have the functionality of at least transparent clock in order to simplify the BMC implementation for reliable timing source on the network.

PMU based protection scheme can take advantage of the MPLS-TP features in order to warrant a fast and reliable Selective Backup Protection for AC HV and EHV Transmission lines that overcome limitations of the actual backup protection system in transmission. This new solution fits better with the actual and future network with high penetration of Renewable Generation.

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