Study Committee D2

Information Systems and Telecommunication

Paper 10938_2022

EXPERIMENTAL EVALUATION OF TELEPROTECTION SERVICES OVER PACKET-BASED NETWORKS

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Motivation

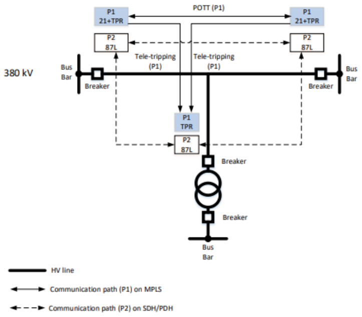
A large part of the TSOs still use a TDM network (Time Division Multiplexing) of type SDH/PDH to transport the data of the secondary systems equipments (to protect/control/measure the electrical network). SDH/PDH technology is becoming obsolete and new developments are mainly focused on packet networks. To tackle this problem, a “smooth” migration strategy must be developed. Different approaches are possible (depending on the TSO situation) such as adding interface-protocol converters, emulation on packet network, progressive replacement of secondary systems equipments by native packet equipments, ... This migration from a TDM network to a packet network is very challenging for real time systems that are critical to the operation of the electrical network, i.e., the protection relays.

The purpose of this study is to verify the performance and determinism of native packet teleprotection (TPR) over MPLS-IP network. The messages between TPRs are standard GOOSE IEC61850 messages.

Method/Approach

The study is based on the most critical high voltage topology of the Elia (TSO Belgium) electrical network: 380 kV line with a transformer protected by 2 independent protection relays (see figure).

The first protection system (P1), subject of this paper, is composed of 2 distance relays (21) and TPR at the ends of the line (site A and site B) with a Permissive Overreaching Transfer Trip (POTT) scheme that accelerates the tripping of breakers at both ends. The breaker of the tap transformer (site C) is tele-tripped from both ends (site A and site B) of the interconnection line. The second protection system (P2), not covered in the paper, is composed of line differential protection relay (87L) connected in a ring to each other



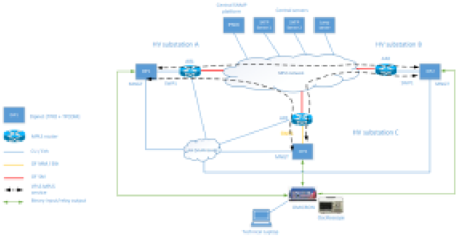
Objects of investigation

The objective is to qualify the Dip.net TPR device on packet network (MPLS-IP) in line with Elia’s requirements.

The MPLS-IP network is a deployed and operating network (400 sites) based on router NOKIA 7705-SAR. The transport of GOOSE messages is established through more than 40 nodes.

Experimental setup

Two scenarios are tested: the first scenario with MPLS e-pipe services (point to point) and the second scenario (see figure) with MPLS VPLS services (multi-point).



hand on the TPR (increase in the number of BI/BO injected) and on the other hand on the MPLS network (see table).

Test	MPLS network	Bandwidth allocated for TPR	Non-competing traffic	Concurrent traffic	Network failure
A	No	100 Mbps	N/A	N/A	No
B	Yes	100 Mbps	No*	No	No
C	Yes	2 Mbps	No*	No	No
D	Yes	2 Mbps	Yes	No	No
E	Yes	2 Mbps	No*	Yes	No
F	Yes	2 Mbps	No*	No	Yes

Tests results/Discussion

Injection	1BI/1BO			4BI/4BO			8BI/8BO		
$T_{TPR} + T_{Datacom}$ (ms)	Average	Min	Max	Average	Min	Max	Average	Min	Max
TEST A	3,8	3,6	4,2	4,2	3,8	5,3	6,1	4,5	8,3
TEST B	9,5	8,6	10,1	10,2	9,9	10,8	10,8	8,9	12,4
TEST C	9,5	8,7	10,0	10,3	9,6	12,2	10,9	9,0	12,7
TEST D	9,8	9,0	10,5	10,6	10,0	12,6	11,3	9,2	13,1
TEST E	/	/	/	/	/	/	11,2	9,4	12,8
TEST F	transmission on new path < 50 ms								

Number of simultaneous BI/BO injections : additional latency ≈ 4 ms (TEST A 1BI/BO vs 8BI/8BO).

MPLS network latency : ≈ 5 ms for 40 routers (TEST B vs TEST A).

MPLS network constraints : additional latency ≈ 0.7 ms (TEST C to E vs. TEST B). Traffic engineering is applied.

Conclusion

The results are deterministic, repeatable and in line with the expected requirements (see next poster).

$T_{TPR} + T_{Datacom} < 20$ ms. The solution is applied in the Elia’s electrical network.

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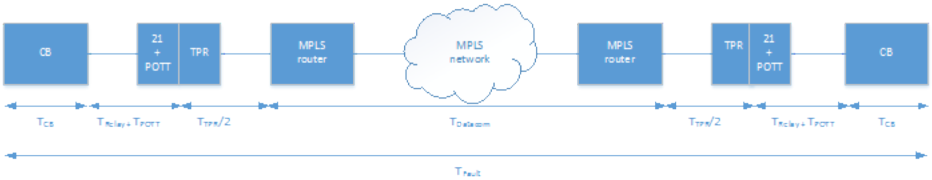


Latency

The time of elimination of the defect on the high voltage line (T_{fault}) is defined by the technical regulation, in **Belgium** **100 ms at 380 kV and 120 ms at <380 kV**

This time is calculated by the following formula (see figure):

$T_{fault} = T_{prot} + T_{Datacom} + T_{CB}$ (1)

- Tprot = time needed for the pair of protection relays to detect the fault (Trelay) + the time needed to transmit/receive the data between the teleprotection without the telecommunication network from binary input to relay output (TTPR) + the time taken by the POTT logic.

$T_{prot} = T_{relay} + T_{POTT} + T_{TPR}$ (2)

- $T_{Datacom}$ = time taken by the Datacom network (MPLS) to transport the relay/teleprotection data from one site to another
- T_{CB} = time to open the circuit breaker (CB), including the time needed to turn off the arc

The values of T_{CB}, T_{relay} and T_{POTT} is based on real current values.

A requirement of a **Latency T_{TPR} + $T_{Datacom}$ ≤ 20 ms is needed at 380 kV (See Table below)**

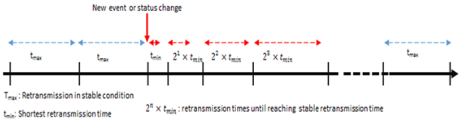
Dependability and Security

The metrics and testing conditions are not yet defined for packed based networks in IEC60834-1 (See proposed modeling next poster).

Asymmetry

TPRs transmit protection orders asynchronously between sites. Round trip latencies do not have to be equal or symmetrical. Not applicable for TPR.

Bandwidth



Heartbeat repetition at a fixed frequency of Tmax in stable condition and burst repetition at an exponential frequency of Ts = 2n x Tmin in case of new event until reaching Tmax.

The maximum bandwidth needed by TPR is theoretically calculated hereunder based on following parameters: GOOSE size (260 bytes) + Ethernet header (20 bytes) + MPLS header (4 bytes) = 284 bytes. 4 GOOSE messages (maximum) are transmitted together (following our tests configuration). T min = 5 ms and T max = 10000 ms.

Signal	n	Ts (ms)	Absolute time (ms)	Bandwidth (bps)
1	Event		0	857
2	0	5	5	1.715.200
3	1	10	15	857.600
4	2	20	35	428.800
5	3	40	75	214.400
6	4	80	155	107.200
7	5	160	315	53.600
8	6	320	635	26.800
9	7	640	1275	13.400
10	8	1280	2555	6.700
11	9	2560	5115	3.350
12	10	5120	10235	1.675
13	11	10000	20235	857

Determinism

The results must be deterministic (repeatable) and no loss of orders (pulses) during testing are allowed.

Relay	U	T_{Fault}	T_{CB}	T_{relay}	T_{POTT}	T_{TPR} + $T_{Datacom}$
Z+TPR	380 kV	100 ms	40 ms	30 ms	10 ms	20 ms
Z+TPR	< 380 kV	120 ms	50 ms	30 ms	10 ms	30 ms

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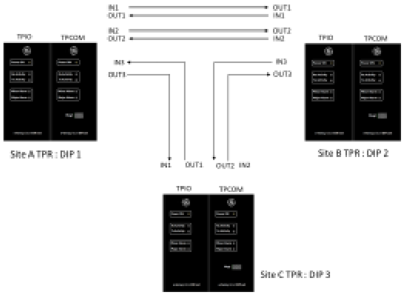
Commands Injection Sequence



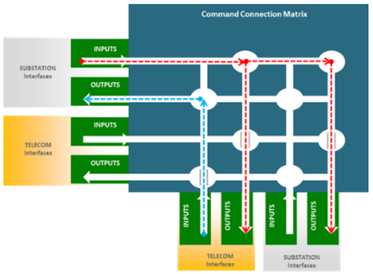
Single commands (1BI/1BO): sequence 1 to 8 from a given site to the other,

Two simultaneous bidirectional commands (2BI/2BO): sequence 10, for Site A to C and Site C to Site A. and Sequence 11 for Site B to C and Site C to B.

Four simultaneous bidirectional commands (4BI/4BO): sequence 9, for Site A to B and Site B to Site A,

Four simultaneous bidirectional commands (4BI/4BO): sequence 12, for Site A to B, Site B to Site A, Site A to Site C and Site B to Site C

Eight simultaneous bidirectional commands (8BI/8BO): sequence 13 from all sites to each other.



IEC 60834-1 Considerations

Nominal transmission time **(T0):** transmission time under noise-free conditions, for digital communications is set to 10 ms, by the standard.

Actual transmission time **(TaC):** maximum transmission time measured under noisy conditions for a defined dependability and signal-to-noise ratio or bit-error rate.

T0 and TaC of less than 4 milliseconds, with zero pulse (command) loss and thus largely less the defined maximum by the IEC60834-1 standard. (Sequence 1 to 8 for the back-to-back of the TPR).

Dependability and Security

For the digital TDM based networks, transmission as "failed" only if more than one message in 1000 is delayed more than 10 ms.

Protection Scheme	Security Puc	Dependability Pmc
Blocking	$< 10^{-4}$	$< 10^{-3}$
PUTT	$< 10^{-7}$	$< 10^{-2}$
POTT	$< 10^{-7}$	$< 10^{-3}$
Intertripping	$< 10^{-8}$	$< 10^{-4}$

A typical GOOSE repetition rate of once per second, when ignoring burst mode, requires the exchange of 86,400 messages a day. Aggressive burst mode will improve application performance but is momentary, occurs only during a detected event, and contributes less than ten messages to the total. Thus, the **following values could be assumed as corresponding values PuC and PmC for the case packet-based networks and GOOSE protocols**. This type of test can be performed for different PER, non-concurrent traffic, etc.

Protection scheme via 1-second GOOSE repetition	Security Puc	Dependability Pmc
Blocking	< 9	< 86
PUTT	< 1	< 864
POTT	< 1	< 86
Intertripping	< 1	< 9

Surveillance of Communication Link

Loss of incoming signal and Alarm in the case GOOSE message is not received after a time = 1,5 x Tmax, where Tmax was set to 10 seconds.

Command Injection sequences between the 3 Sites A, B and C

Sequence		DIP1 Site A						DIP2 Site B						DIP3 Site C			
		IN1	IN2	IN3	OUT1	OUT2	OUT3	IN1	IN2	IN3	OUT1	OUT2	OUT3	IN1	IN2	OUT1	OUT2
1BI/1BO	1	X									X						
	2		X									X					
	3			X												X	
	4				X			X									
	5					X			X								
	6									X							X
	7						X							X			
	8												X		X		
4BI/4BO	9	X	X		X	X		X	X		X	X					
2BI/2BO	10			X			X							X		X	
2BI/2BO	11									X			X		X		X
4BI/4BO	12	X		X	X			X		X	X					X	X
8BI/8BO	13	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X