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EFECTS OF THE NETWORK TOPOLOGY IN THE RECOVERY TIME

A PRACTICAL CASE STUDY

by

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SUMMARY

IEC 61850 standard defines a new architecture for the Substation Automation System. Among many other new concepts, the use of IEDs to implement protection and control is a new concept that introduces a number of communication challenges that may impact on the reliability of the whole system.

Since communication between IEDs becomes a critical service, the availability of this service as to be considered. Consequently, LAN design should include fault tolerance concepts in its architecture. The criticality of the substation will determine the degree of tolerance to outages in the communication system. Outage recovery time is the most important factor as defines how long a critical function would be out of service. This may range from a single failure tolerance to fully redundant being the cost of the system one of the limiting factors.

The paper will focus on the factors that determine the service recovery time in the presence of outages. Recovery time is strongly affected by the topology and the service recovery algorithm running in the network.

The paper describes some popular topologies analysing their performance and its service recovery time considering how service recovery algorithms interact with the topology and the equipment configuration.

KEYWORDS

Layer two Ethernet switching, Ring Topology, RSTP, MRP, Proprietary protocols

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1. INTRODUCTION

In the IEC 61850 environment, communication between IEDs becomes a critical issue in the reliability of the Control and Protection operation.

Usually inside a substation, the IEDs, from a communication point of view, are organized in different hierarchical levels: Process level, Bay level and Station level.

In the physical plane, the IEDs from the same level are connected to concentrators, Ethernet L2 Switches, and also the concentrators are interconnected in between in order to build a redundant network. The access to the upper level is provided by one or two of those concentrators. Upper level may group some networks from the lower level.

In the logical plane the IEDs of the same level interchanges information at least with one or two IEDs, which acts as level controllers and processes the incoming information. Communication between same level IEDs are not common exception to the level controllers.

This behaviour means that the data flows from the low level IEDs, Process bus, towards the top of the pyramid and backwards with virtually any communication between equals and this information have its relevancy during the network design phase.

Early in the IEC61850 implementations the data flows are not numerous and any switch with default configuration was enough to cope with this amount or traffic. With the time, the number of IEDs and, of course, the number of switches involved at each level process is continuously increasing complicating the data flow management.

2. NETWORK TOPOLOGY

During the design phase of a substation's bay, its normal considers a certain number of IEDs distributed in levels. Also we can consider a certain number of Ethernet L2 switches which take care of the communications between IEDs and between levels and as a normal procedure, the IEDs are provided with redundant communications ports. How to connect it in efficient way?

Many solutions can be implemented with several degrees of redundancy and cost / effectiveness balance.

The first point to be considered is the physical way in which the devices are connected: We have two choices copper cables or fiber optics. In terms of cost, copper is lower than fiber but fiber has superior performance in terms of induced noise. Decision primarily depends of the available interfaces in the IEDs and, in equal condition; the best trade-of is accomplished using copper inside the cabinet and fiber between cabinets.

The second point concerns about the topology or how to interconnect the devices in between.

Several topologies are proposed in the Industry with diverse level of reliability and cost effectiveness.

The classical approach to the network structures divides them in 7 groups as indicated in the next figure. Practical structures are a combination of these fundamental shapes.

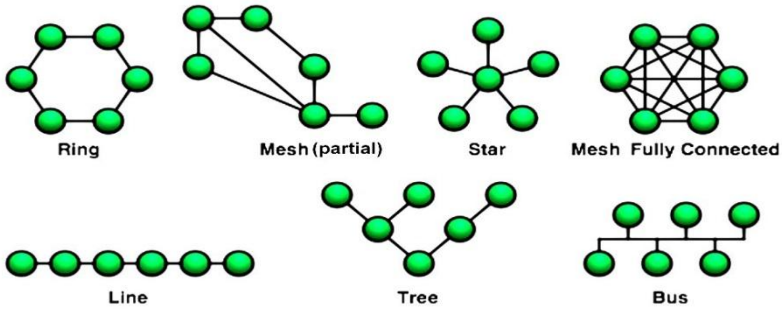


Figure 1

In Ethernet wired links, the Bus structure cannot be implemented because the Ethernet ports cannot be tied in parallel.

The most usual topologies are:

- Star. Was the first idea to connect IEDs. Configuration without redundancy
- Double Star. Same as a Star but with redundancy
- Ring. The most common, simple and path redundant.
- Line. This is the topology in which falls a ring in case of single failure.
- Mesh. A priori the redundancy champion; but too much complex and expensive

For a network and considering all the paths with the same probability, the route availability is function of the number of alternative possibilities

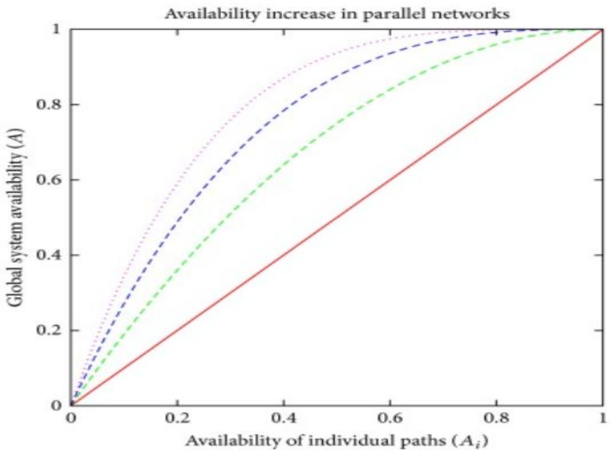


Figure 2. Global availability for 1 to 4 alternative paths

There are several approaches to provide high availability architecture but in the last years ring technology emerges as a simplest and pervasive topology which is fully adopted around the world.

One time defined the network topology some of its properties becomes fixed because are inherent to the topology. Other performance parameters more dependent of the hardware and software performance could be evaluated and will make a difference between vendors.

3. POWER SYSTEM REQUIREMENTS

Once a Power System is in operation, it is designed to support instabilities due to electrical faults in any part of the System. In order to reduce system's components damage or recover the power interchange between sources and loads, the time of these faults should be reduced. Zero recovery time is not possible to achieve, because protection relays, switchgears and other network elements, requires some time to react. As fast the involved elements react more security margin is obtained. This time, could be up to 50 ms, without produce power outage, as shown in Figure 2.

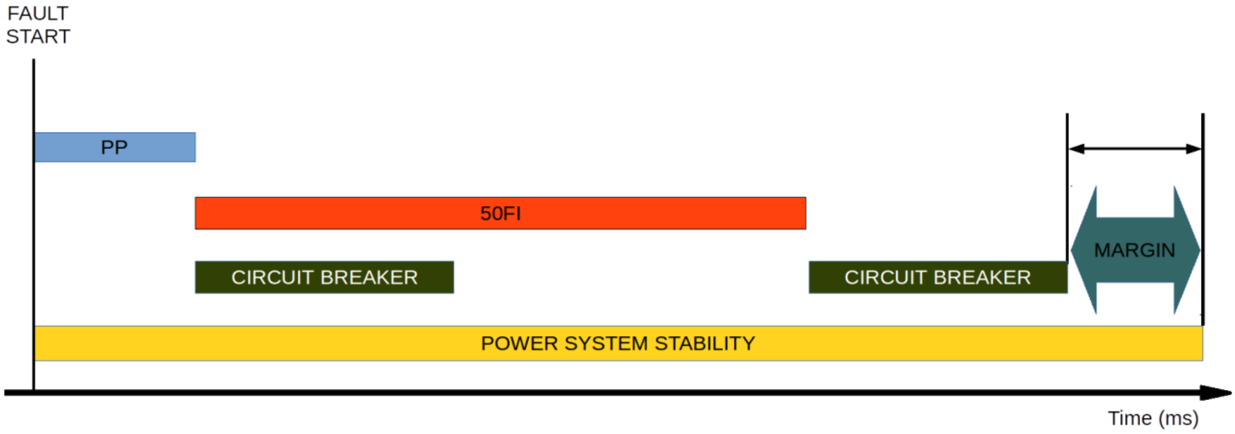


Figure 1: Power System outage margin estimation.

4. RING TOPOLOGY CHARACTERISTICS

Actually and if we focus on industrial range, first class Layer 2 Ethernet switches, more or less all vendors provide devices with similar hardware characteristics and the differences must be found in the firmware inside the device.

In normal working conditions also there is a big similarity in performance and the main differences can be found on its behaviour during fault conditions.

In order to compare those performances lets to define some terms:

- Availability is the fraction of time a system is in the “up” state (capable of operation) It is expressed in % (“duty cycle”)
- Outage time refers to the time that Ethernet frames couldn’t be transported by the LAN and its components. Also the delay time in which a GOOSE message is transported from one device publishing it to others ones in the LAN due to the network impairments

Also the IEC 61850-5 classifies the recovery time demands as the following

Communicating partners	**Service**	**Application recovery tolerated delay**	**Required Communication Recovery Time**
SCADA to DAN, client-server	IEC 61850-8-1	800 ms	400 ms
DAN to DAN interlocking	IEC 61850-8-1	12 ms (with Tmin set to 4 ms)	4 ms
DAN to DAN, reverse blocking	IEC 61850-8-1	12 ms (with Tmin set to 4 ms)	4 ms
Protection trip excluding Bus Bar protection	IEC 61850-8-1	8 ms	4 ms
Bus Bar protection	IEC 61850-9-2 on station bus	< 1 ms	Bumpless
Sampled Values	IEC 61850-9-2 on process bus	Less than two consecutive samples	Bumpless

There are numerous proprietary ring-based protocols available today from several vendors; these protocols do not interoperate with each other and in case of a non vendor uniform ring the system backs to the performance of the IEEE 802.1D-2004 standard that runs in the baseline.

Also IEC 62439 adds more noise to this panorama defining at least 6 protocols:

IEC 62439-2 **MRP** (Media Redundancy Protocol).
IEC 62439-3 Two seamless protocols (**no recovery time**)
PRP (Parallel Redundancy Protocol)
HSR (High-availability, Seamless Redundancy)
IEC 62439-4 **CRP** (coupled redundancy protocol)
IEC 62439-5 **BRP**, similar to CRP
IEC 62439-6 **DRP** (Distributed Redundancy Protocol), similar to MRP and including the clock synchronization.
IEC 62439-7 **RRP** (Ring-based Redundancy Protocol, another ring redundancy protocol which is executed in the end nodes instead of the switches

And others are coming.

In the major part of the proprietary protocols and, also, the defined in the IEC 62439, the recovery time have a dependence more or less strong of the number of elements inside the ring and this is because the protocol defines one of the elements as a Master and, at first time, a short period is necessary to propagate the failure condition to the Master and when it takes a decision also more time in necessary to propagate the reaction.

Our approach is on a proprietary solution which is independent of the number of IEDs of the ring. In fact we use the same BPDU messages of the IEEE 802.1D (2004) in addition of other improvements. In order to evaluate the performance of this approach we do two different tests. The first one using a Network Test Set and manually cutting the link between switches and in second time using an OMICRON relay Test Set. The obtained results are explained in the next chapters.

5. A PRACTICAL CASE STUDY USING NETWORK TEST SET

In order to verify the behaviour of the protocol we do some recovery tests using a ring of 9 switches and a Network Test Set SPT-9000.

For the those cases, all the switches have a defined routing cost and at the power-up RSTP protocol elects SW1 as a Root and logically opens the ring between SW5 and SW6.

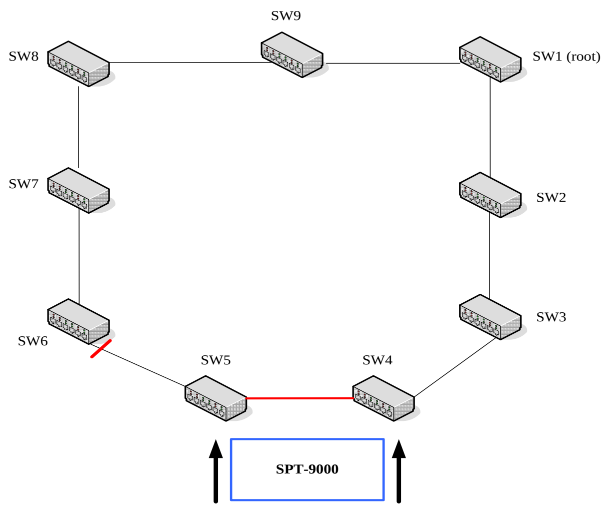


Figure 3. Test set for the case 1

In that condition we inject traffic between SW4 and SW5 and that traffic flows following the red segment between SW4 and SW5.

When the system is stabilized we cut the red link and measure the recovery time. We repeat the test 20 times and the averaged recovery time was 6.12 ms.

For the case 2 we move the test set, SPT-9000, to connect SW5 and SW6 that is in between the switches which have the logical link open.

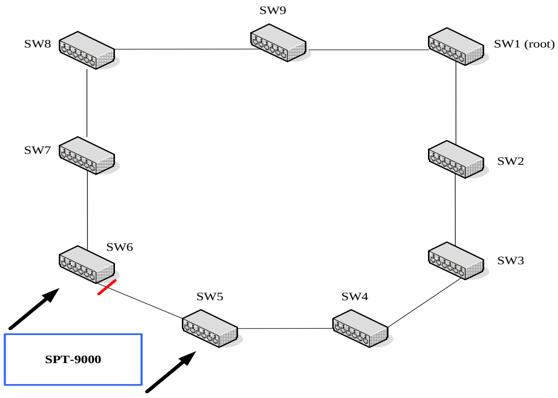


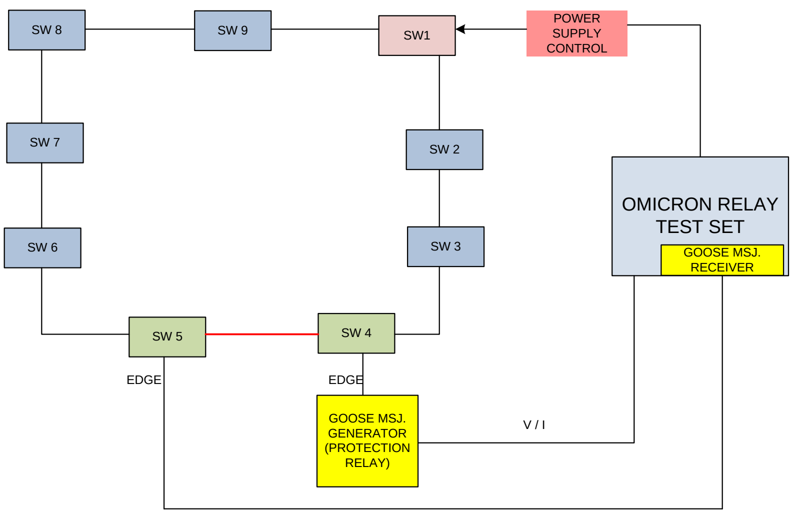
Figure 4. Test set for the case 2

When the system stabilizes we cut one by one the links between switches and the averaged recovery time was 9.37 ms. In this case the time is slightly higher because the affected switches informs the failure to the Root and it sends to the SW6 the order to activate the link port

In order to show the independence of the recovery time and the number of switches which conforms the ring, we do, Case 3, another test involving 134 switches in a same ring and repeat the Case 1 test. The averaged recovery time was 12.03 ms.

6. A PRACTICAL CASE STUDY USING OMICRON's PROTECTION RELAY TEST SET

By using the facilities provided by the instrument, is it possible to test the ring response when the Root switch fails. This is accomplished cutting the power supply of the Root switch and computing the time spent into elect a new Root and establishes the GOOSE messages traffic. The paper of the Reference [1] discuss the test procedure and the nature of this test include some conditions difficult to neutralize in order to consider only the recovery time of the switches in the ring, but produce a condition that simulates the failure of a network node while GOOSE messages are traversing all switches. The Root node failure provokes the interruption of the multicast traffic during the new root election and new tree determination because it may interfere whit the BPDU messages.



Results are depicted in next table.

	Measured Value (ms)	**Total Recovery Time (ms)**
Average	60.68	38.27
Maximum	64.20	41.79
Minimum	51.70	29.29
Deviation	4.00	4.00

While recovery time is near to the limit of 50 ms established early, and is expected to be increased when network grows with more switches, the tested devices shows a relatively constant recovery time of 38.27 ms ±4 ms, not matter the number of devices. This was confirmed by changing the number of switches in the ring and no change in recovery time was observed.

7. TEST CONCLUSIONS

As a results of the test carried out following points can be concluded:

- Is it possible to maintain the RSTP protocol (IEEE 802.1D) appended with extra conditions and a specifically designed topology.
- The obtained results for a short ring are according the requirements
- For a very large ring the results are clearly better than others.
- Test based on Test Set for Protection Relay, involves many processes which contributes to increase the dispersion of the results. Probably an accurate configuration of the devices and a calibration of the loose times will show similar results. In any case the measured recovery time is under the acceptable window.
- As a result of the routing algorithm improvements, the recovery time considering the GOOSE messages (Multicast packets) is kept in a short interval of time with independence of the ring position of the IEDs. Further tests are required, with more switches on the ring and complete the results of constant recovery time.
- The improvements on RSTP, the performance, back compatible with most existing systems and IEDs, including its specialization on rings, produces good results and are suitable for this application.

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