Highly Dependable Ethernet Architectures in Intelligent Power and Motor Control Centres (iPMCC)

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Make the most of your energy

Revision 1

Summary

Forward

Companies in the infrastructure & industrial sectors operate in a highly competitive economic environment. Whether in Oil & Gas, Petrochemicals, Mining, Minerals, Metals, Water and Waste Water Treatment, Food & Beverage, Pharmaceuticals, Micro-electronics, or Airports, boosting productivity has become more and more necessary.

Reducing power cuts and downtimes for repairs and failures, as well as better asset and energy management are key challenges to increase productivity.

Electric motors account for up to 70% of energy consumption within these sectors. Most of them are part of mission-critical systems that demand for constant process availability. Therefore, since continuity of service is a major stake for competitiveness more and more customers are asking for a certain level of redundancy.

"Redundancy" has become a popular portmanteau word where each one puts whatever content he wants. The word redundancy is used to mean completely different things: the duplication of a component in a system, the possibility to execute the same task by two different methods, the tolerance to a first fault, etc.

The choice among the different types of redundancy can have a great impact on the costs of a system while not delivering a significantly different level of dependability.

It is therefore, essential to clearly define the optimum type of redundancy that delivers the right level of dependability that will suit our real need.

In this paper we shall use the word "redundancy" as variant of "the possibility to execute the same task by two different methods", i.e. the possibility to address a sub-system of motor starters or a specific motor starter via two different paths without manual intervention.

Innovative validated architectures for Optimum dependability

Introduction

Solutions are valuable as far as they address a real need at the right costs.

Traditional fieldbuses, by their nature, allow only the most costly type of redundancy which consists in duplicating the components of the system.

Solutions based on Ethernet present several outstanding advantages:

- Flexible and scalability.
- Openness to the enterprise infrastructure.
- Possibility to offer embedded web services.
- High speed communications.

We are interested in one advantage in particular: the fact that unlike traditional fieldbuses, Ethernet allows a great deal of different network topologies, thus allowing different types of redundancy.

The operation of withdrawable motor starters in highly dependable LV switchboards constitutes a major constraint to be taken care of while defining the right topology.

In the next pages we present two levels of redundancy:

1. The general architecture of the system (the "network") for addressing sub-systems of motor starters ("sub-networks" or "subnets") via two different paths.

2. The architecture of the subsystems (the "sub-networks" or "subnets") for addressing each motor starter via two different paths.

We will also introduce an innovative solution of self-healing network especially adapted to satisfy the constraints of withdrawability.

The backbone

A fast recovery ring network

The backbone

Fast recovery ring network

Many large industrial sites have installed a fault-tolerant Ethernet ring infrastructure on the factory floor.

The main reason to do that is that a ring topology can deliver an extremely fast failover time as well as unlimited connectivity.

Why industrial sites prefer a ring topology to a tree one? In a tree topology two or more cables run between the same points, i.e. wiring is at least doubled.

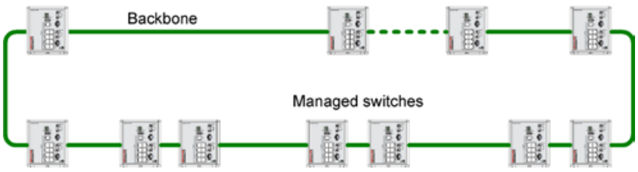
The two main disadvantages of tree topology are:

1. Wires and wiring costs.
2. The number of devices that you can connect to the network is limited by the small number of switches a tree can support. It is generally considered that exceeding seven switches the amount of calculation required and test packets to be sent out become huge.

These two disadvantages disappear with ring topology while still delivering a redundant path that can be used if the active one fails.

Unlike tree topology, in a ring topology there is no practical limit (in a plant context) to the number of devices that can be connected.

Since ring topology is very simple, calculation is much simpler resulting in much shorter failover times.



The only disadvantage of ring topology is the absence of an international standard. This results in different implementations of ring recovery depending on the switches manufacturer. Therefore, all the switches in the ring must come from the same manufacturer.

The choice of a major switches range like Connexium, guarantees the homogeneity and the continuity of supply in the long run.

A first level of redundancy can be achieved by designing a fault tolerant ring running through the whole LV switchboard.

This ring will constitute a backbone composed of managed switches that all sub-systems will connect to.

These sub-systems can be any functional unit (hereafter "FU") or clusters of functional units, e.g. power distribution, motor starters, measuring devices, or any other type of functional unit with communications capabilities.

The FU's can be connected to the backbone using native Ethernet when available, or via a proxy.

In the case of a proxy, the proxy will act as an Ethernet interface between the Modbus/RTU (RS-485) device(s) and the Ethernet Modbus/TCP backbone. It may sometimes fulfil a data concentration task as well.

The ring will be tolerant to any first fault, since it can reconfigure automatically in order to address any device or cluster of devices via a second path. This failover is fast, automatic and transparent.

Typical recovery time is maximum 500 ms.

Example of an LV switchboard.
The backbone is shown by the red ellipse.

The sub-systems
Addressing the motor starters

The sub-systems

The star topology

Once the ring backbone in place, we can attach to it any number of Ethernet devices (or nodes) in direct connexion to the switches.

This is the classic star topology.

This topology guarantees extremely fast communications independently of the number of nodes.

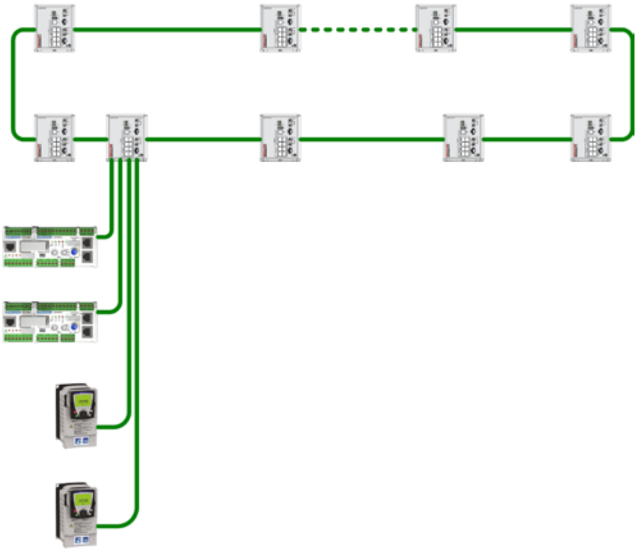
Moreover, in the context of an LV switchboard the star topology guarantees normal operation for any type of mounting system, whether fixed, disconnectable or withdrawable ones.

Removal of any number of nodes does not affect other nodes.

The main drawback of this topology is the fact that the switch constitutes what in dependability studies is called a "common mode". i.e. the health of each sub-system depends on the health of the switch used to connect it to the backbone. A switch failure will provoke a break of communications with all the nodes connected to it.

However, the risk is not very high since the switches are not active elements. The way to reduce the risk is the use of small switches (e.g. switches with 8 ports instead of 24 ports).

Another drawback of this topology is wiring costs: the multiple long runs of cables (aka home runs), and the fact that the number of cables in the cable tray will be equal to the number of FU's in the column of the LV switchboard. If there are many FU's, there will be many cables.



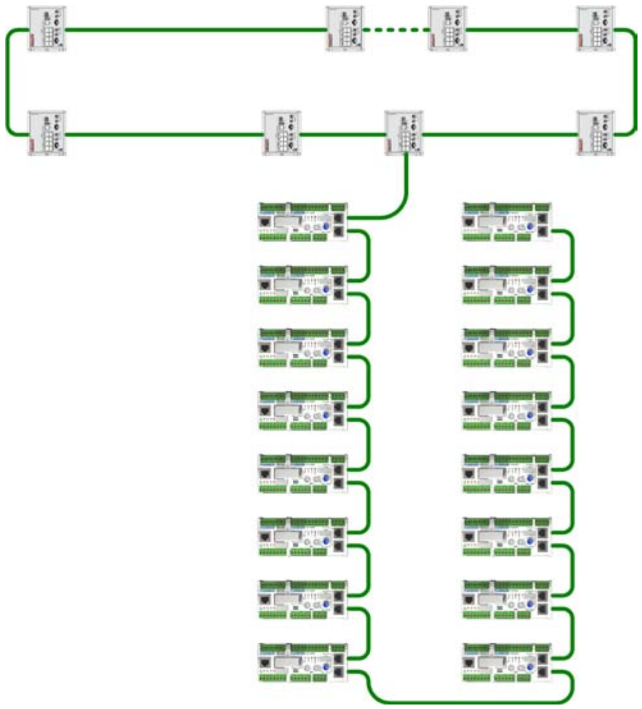
However, due to its simplicity and its outstanding performance, star is an excellent choice for most applications, even the most critical ones.

The daisy chain (DC) and the daisy chain loop (DCL) topologies

An alternative to the star topology could be the daisy chain.

Daisy chain's main value over star is the reduction of wiring costs: if we limit the daisy chain to one column, then we will have only one cable in the cable tray.

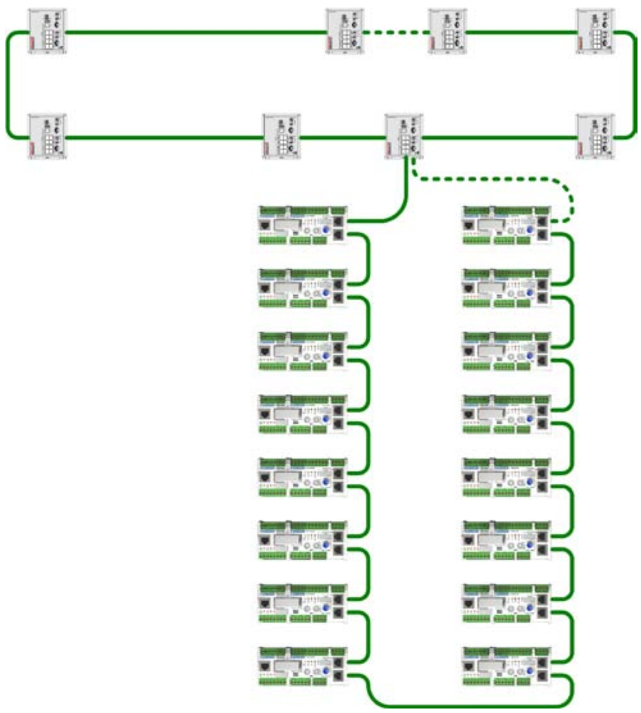
It reminds the topology of a typical bus. However, it is suited for applications using only fixed FU's because the removal of any FU will provoke a break of communications with all the nodes connected "after" the removed FU.

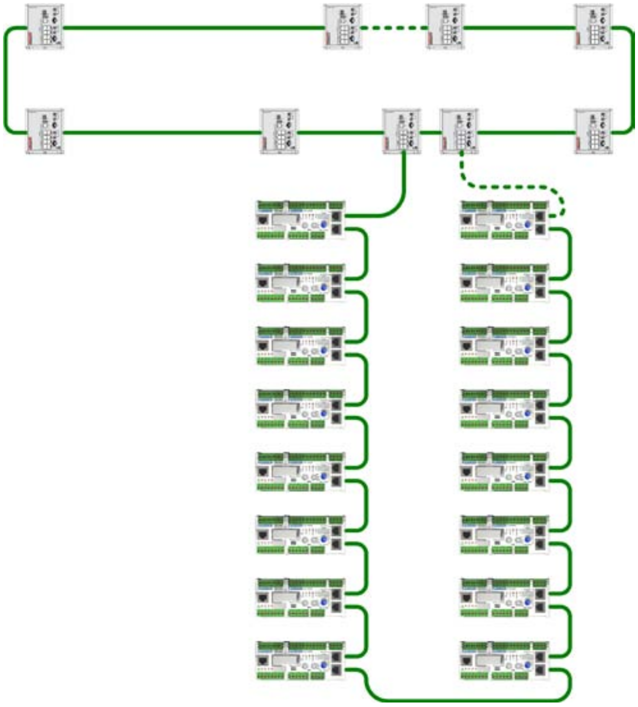


Therefore, a daisy chain must always be looped. The loop creates a *de facto* ring with the same failover characteristics as the backbone ring. This is called a daisy chain loop (hereafter "DCL").

There are two ways to implement a DCL. The first one consists in looping the daisy chain to the same switch where it started. We call this topology a "Daisy Chain Loop with 1 ring switch".

This topology has the inconvenience of delivering almost no additional value to the star one (the dependency on the health of the switch remains), while complicating the wiring.





We can solve this problem by looping the daisy chain to a different switch. We call this topology a "Daisy Chain Loop with 2 ring switches".

In this way we do not have any common mode, and thus we are no longer dependable on the health of one switch. In the improbable case of a switch failure communications with the different nodes will follow the alternative path through the second switch.

Tests show a typical recovery time of 500 ms. When carrying out a great number of tests, the worst case observed is 2 s.

A typical DCL will consist of 8 to 32 nodes.

This topology looks great: we can address any node via two different paths, supporting a first fault at any level of the sub-system.

However, like all DC topologies, it is suited for applications using only fixed FU's.

In fact, it is a little better than the simple DC because the removal of only one FU will provoke a break of communications with all the nodes connected "after" the removed FU but the communications will be re-established after typically 500 ms.

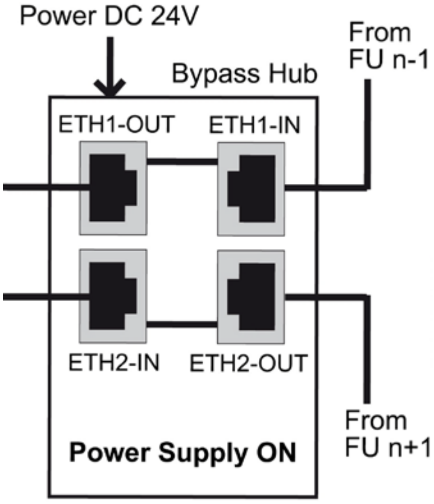
The problem is that in applications using LV switchboards with withdrawable FU's there is always a certain number of FU's which are normally withdrawn. In all DCL topologies, the removal of two non-contiguous FU's provokes the loss of communications with all the nodes in-between.

The self-healing daisy chain loop

In order to get all the benefits of the DCL with 2 ring switches while eliminating its drawbacks the sub-system must be able to "self-heal" after removal of any FU.

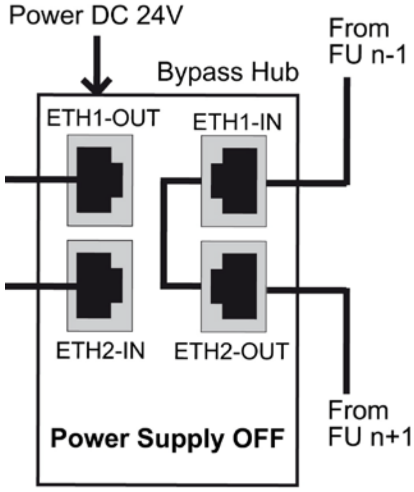
This can be achieved by installing, outside the drawer, a device that will close the loop shortly after removal of a drawer. We call this device a "By-pass switch".

When the drawer is in its place and connected the by-pass switch should be "open", letting communications unchanged.



By-pass switch OPEN (when the FU is connected).

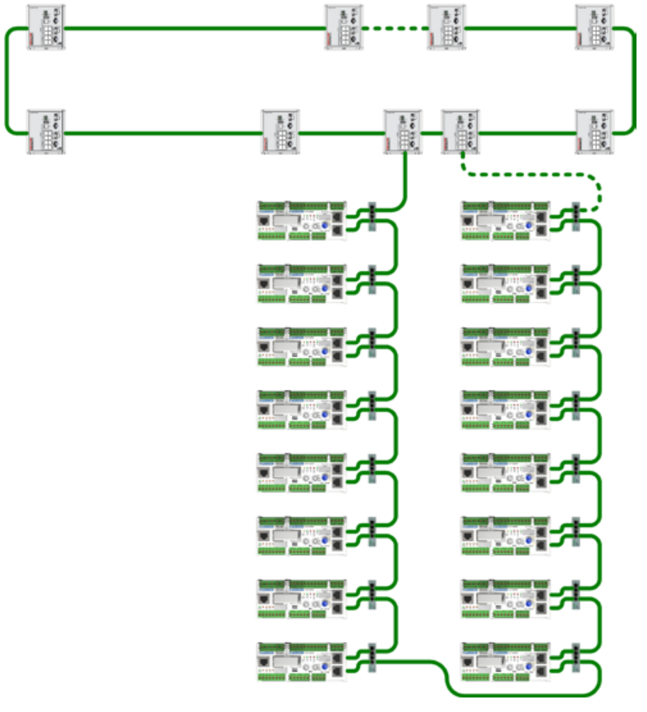
When the drawer is withdrawn the by-pass switch should be "closed", allowing communications to by-pass the removed FU.



By-pass switch CLOSED (when the FU is withdrawn).

The opening and the closing of the by-pass switch should be automatically executed when the position of the FU changes.

The topology obtained will be the following:



In this way, we obtain a self-healing DCL. Self-healing is done automatically and in complete transparency for the operator.

This solution integrates the benefits of DCL without any of its drawbacks.

There is no longer any common mode and the integrity of the DCL is guaranteed for any number of FU's withdrawn.

Conclusion

Optimised level of redundancy

The choice of the right communications architecture is crucial since it has a major impact on the dependability of the system.

But the choice among the different types of redundancy can also have a great impact on the costs of a system while not delivering a significantly different level of dependability.

It is therefore, essential to clarify the level of redundancy that delivers the right level of dependability at the right costs, and that will suit our real need.

We chose two levels of redundancy. The first one is for the general architecture of the system. Based on a fault tolerant ring is ensures a good level of redundancy at the switchboard level.

It can be combined with sub-systems in star topology which greatest advantage is simplicity and reduced costs. This level of redundancy should be suitable for most critical applications.

It can also be combined to a second level of redundancy with sub-systems in "daisy chain loop with 2 switches" topology.

This topology delivers even higher dependability since it removes any common mode and offers communications to each motor starter via two different paths.

In order to allow full operability of withdrawable functional units it requires the integration of self-healing capabilities.

A by-pass switch installed outside each withdrawable functional unit offers this capability.

Pre-tested, pre-validated architectures