WIRELESS CONNECTION IN DISTRIBUTION SUBSTATION

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ABSTRACT

Historicaly, automation investments in MV distribution network were focussed mainly on energy availability.
Since a decade, the emergence of new applications such as distributed generation for instance, induces new challenges regarding voltage plan control, including in the LV network, leading to an increasing need for LV monitoring and control.
As a consequence, sensors have to be installed into the LV pillar of an MV/LV substation, and mainly as retrofitting of existing substations. Wireless sensors have to be considered as the only possibility in most of the cases.
This paper describes the multiple advantages of wireless sensors for LV monitoring in an MV/LV substation. In a first part, wiring and upgrading simplification are analysed.
In a second part some possible architecture are proposed, showing the easiness of installation and the openness of the solutions. Different standards of wireless protocols and systems are compared.
A last part demonstrates the feasibility with an example of architecture based on Zigbee standard communication systems. It will show that a standard created for the residential market could be used in an industrial harsh environment.

INTRODUCTION

Smart grids suppose a great number of new challenges for Electricity Distribution Companies, in a near future. The increasing presence of Distributed Resources, Electrical Vehicles and Energy Efficiency applications will demand from the Utilities the remote management and monitoring of a major part of its Secondary Substations. It's mandatory for them to find a cheap and effective solution for the monitoring of MV and LV infrastructure.
The distribution automation systems are until now mainly based on wire connections. Wiring is expensive to install and in most of the retrofit cases impossible to do. As a result, DSOs limit the sensor amount only for economical reason, which restricts the interest of an automated distribution grid..

The use of wireless sensor technologies for monitoring and control of a distribution network has many benefits against wired connection. After a brief summary of the communication in a distribution substation, in a first approach, this paper will enhance the main advantages such as cost reduction and easiness of substation upgrade. Then some drawbacks of the technology will be analysed with the way to avoid their consequences. An example of deployment of a solution based on Zigbee is presented and analysed.

COMMUNICATIONS IN A DISTRIBUTION SUBSTATION

Even if we can consider that a MV/LV distribution substation is a simple element in complete distribution substation automation, it encounters a variety of communication needs, as summarized below:

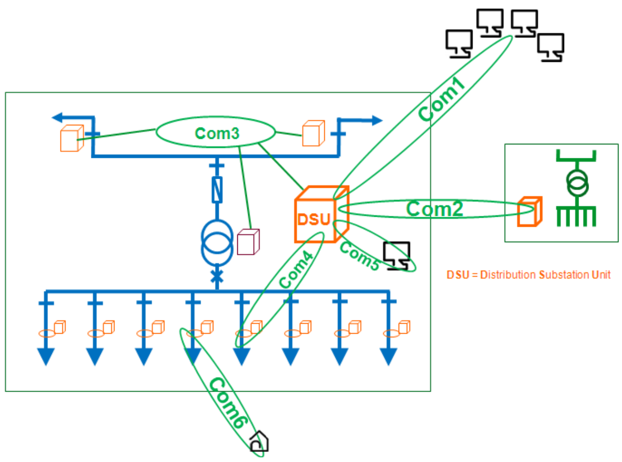


Figure 1

COM1 : Long distance communication with SCADA.
COM2 : Medium distance communication with other substations.
COM3 : Intra substation communication with devices.
COM4 : Intra substation communication with LV feeders devices.
COM5 : Intra substation communication with configuration and maintenance tool.
COM6 : communication with Smart Meter

The Distribution Substation Unit (DSU) is a complex gateway, which gathers data from different environments.

Each of these communication system are supporting various levels of data quantity, distance, transmission speed, security,…An example of positioning is given in figure 2

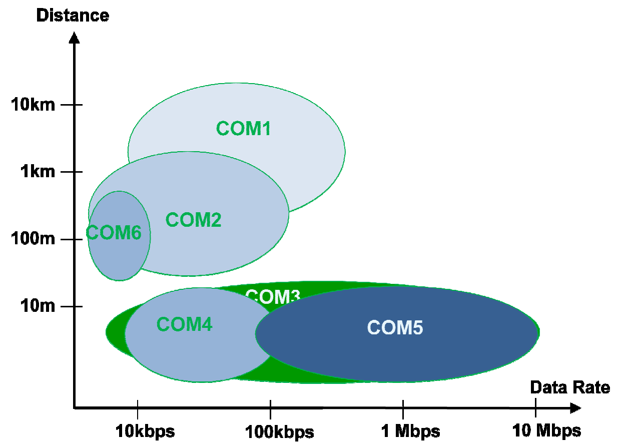


Figure 2

The table below gives a brief summary of the main points of each of these communication levels in the substations.

COM1	In most of the cases the communication with the SCADA is already through wireless systems such as Radio or GPRS.
COM2	Communication between substations, used for self healing application for instance, is not common. It concerns a few data, but high speed is required. Typically, a wired connection is used, but specific radio transmission is also possible.
COM3	This communication level is especially developed in modern DSU system based on decentralised devices localised inside the switchgears. It concerns the local bus for devices on transformers and MV part of the substation. Depending on the size of the substation and on the protocol used, RS485 or Ethernet are commonly used at this level.
COM4	There, is a typical new communication level in a substation directly linked with new monitoring points on the distribution network. Use the wireless communication here allows keeping a small (compact) DSU with an unlimited monitoring sensors connection. This communication could be used for substation status (doors, temperature fire...) or metering sensors.
COM5	The configuration and maintenance tools based generally on PC used principally wire connection. The wireless communication allows using new tools like Smartphone or digital tablet connected in Bluetooth or Wi-Fi.
COM6	When connected to the concentrator installed into the distribution substation the Smart meters communicate through Power Line Carrier.

Table 1

Among all these communication networks, it is obvious that the most valuable network to be moved from wired technology to wireless technology is the communication with the LV feeder power monitoring sensors. The paper is focussed on this level of communication inside the distribution substation.

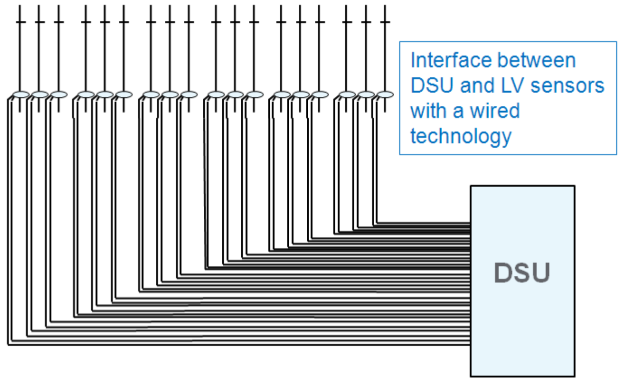


Figure 3

Benefits and drawbacks of a wireless technology are analysed on the specific application of the LV monitoring of an MV/LV substation

BENEFITS OF A WIRELESS SENSORS NETWORK (WSN) FOR LV MONITORING

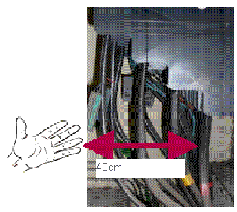
The benefits of a WSN for LV monitoring in a MV/LV substation are mainly linked with the difficulty to wire connections with all the LV feeders in an existing substation.

Installation: cost effective, fast, safe,

The most difficult operation for monitoring an MV/LV substation is the connection of all LV feeders. Typically a MV/LV substation may have from 5 to 20 LV feeders of 3 phases each. This represent from 15 to 60 sensors to be connected to the DSU (Distribution Substation Unit).

Installation cost optimisation

Generally it is evaluated that the sensors themselves represent only 1/3 to ½ of the total cost of installation. Beyond the fact that the number of sensors is important, the LV pillar in a MV/LV substation has a very harsh accessibility.



Thus, clearly the first benefit of a wireless solution concern the man hour of the wiring.

The Total Cost of Ownership of a WSN solution is cheaper than a wired solution.
If we take the example of a Substation with 6 LV feeders, the installation man hours may be decrease from 5h to 1h

Mastering installation time
But beyond the benefits in term of installation time, it brings also a warranty to mastering more accurately the average time to wire a complete substation.

Safety of people
In most of the case, the installation of sensors on the LV part is done with live working procedure. As wireless sensors are supposed to be isolated of all voltage contact they can be installed in safe condition.

Quality of installation
The risk of connections error is avoided with a WSN technology. It is now possible to accept that the sensors may be mounted in both direction, and whatever is the phase. In these advanced solutions the smart sensor concentrator is able to detect and automatically reconfigure the mapping.

Flexibility
In relation with the easiness of installation, the flexibility of such a technology is also a major facility to improve the installation.
New feeders may be equipped with sensors with no limit. With a wired connection, the expansion of a system is limited by the number of terminal blocks in the DSU.

With a wireless system it becomes very easy to install temporarily a monitoring of some feeders.

Easy maintenance
Generally in an installation process there is no warranty that all connections on the terminal blocks are correct on the long term.

The risk of bad wiring by the people in charge of the installation is totally avoided with WSN. And beyond this advantage, the wireless systems communication is self monitored and each failure in the radio communication is send to the control centre and may be fixed immediately.

Harsh condition installation
In an MV/LV substation a particular attention has to be paid to insulation between electronic devices connected to the LV and to the MV part.
Obviously, a WSN brings a perfect solution to this constraint.

SOME DRAWBACKS OF A WSN

Power supply
The sensors with wireless communication have to be supplied. And in order to keep the main advantage of such a technology, a self powered sensor should be considered as a major requirement. If the sensors need a wired power supply, it maintains a number of wires and it decrease drastically the economical interest of the solution

In order to avoid the use of battery which has to be changed periodically, a power harvesting technology should be preferred.
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Cyber security.
The communication should be accessible around the substation, and could be seen as a weakness.
The LV part is monitored and not controlled, so the risk is limited to either access to the data of the substation or disturb the data (failure of the communication or hacking and modification of the data)

All these risks may be avoided by use of special algorithm and through the choice of the pertinent wireless standard.

The first level of security, which could be considered as sufficient in such applications, is at least to use the device identification in the DSU.

Interferences
Interferences have to be managed when using wireless system in a bandwidth already used in the neighborhood. It should be the case for instance if the WSN is IEEE 802.15.4 or IEEE 802.15.1 and if a WiFi network IEEE 802.11.x is operating around in the 2.4GHz band.

In fact, the some of the channels in these bandwidths have no overlap between these 3 wireless network standards.

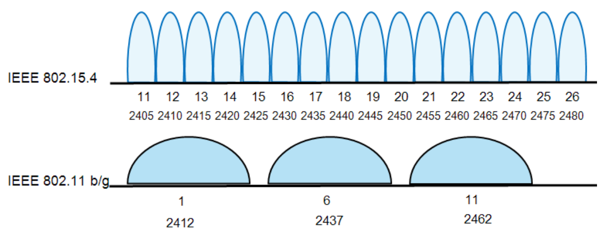

Figure 4

COMPARISON OF SOME WIRELESS COMMUNICATION STANDARDS

In order to simplify the analysis, in this paper only the following wireless networks standards are compared:

- WiFi (IEEE 802.11.x)
- Bluetooth (IEEE 802.15.1)
- Zigbee pro (IEEE 802.15.4)
- Bluetooth Low Energy (BLE) (IEEE 802.15.1)
- Zigbee Green Power (ZGP) (IEEE 802.15.4)
- EnOcean (IEC 14543-3-10)

The respective positioning of these standard is shown in figure 5

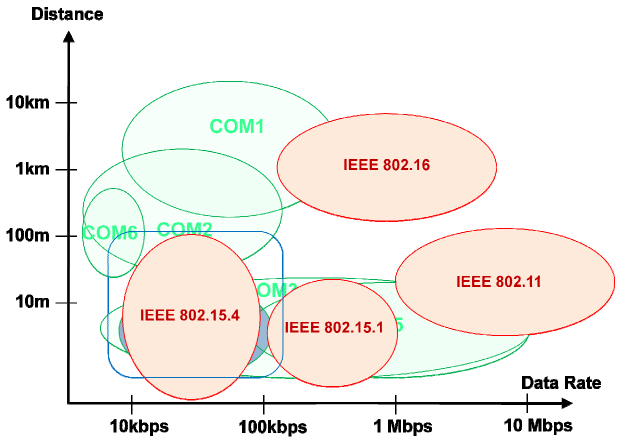

Figure 5

Non eligible standards

As per the main constraints described in the first parts of this paper, some of the wireless standard does not have the minimum requirement which is:

- A low consumption that enables harvesting principle to make the system self powered without battery.
- Bandwidth in the ISM range
- Very short message for low consumption but also for robustness against disturbance
- Encryption facility

For some of these above reasons, but mainly from the consumption criteria, the following wireless standards have been tagged as non-eligible for the application:

- WiFi
- Bluetooth
- Zigbee

Eligible standards

The following standards are compliant with the above list of criteria.

- Bluetooth Low Energy
- Zigbee GreenPower
- EnOcean

Between those standards other criteria based on specific needs will be applied such as:

- Openess to a catalog of devices available for the MV/LV substation application (load current, temperature, water level, digital contact, …)
- Facility to synchronize the message
- Very low consumption

The eligible standards are all with a very low consumption. The figure 6 illustrates the range of consumption of the above standards..

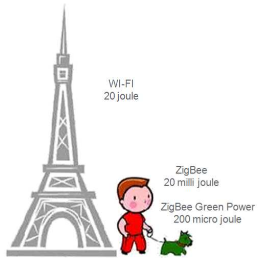

Figure 6

EXAMPLE OF A REALISATION BASED ON ZIGBEE PRO GREEN POWER STANDARD

In this part, we have a description of a possible architecture based on ZigBee PRO Green Power for LV feeders power quality monitoring.

Schneider Electric is about to launch a sensor package based on ZigBee PRO Green Power, in compliance with the criteria described above.

Components

The overall architecture is based on a ZigBee transceiver function located into the DSU and for each feeder a set of 3 sensors with a ZigBee transceiver.

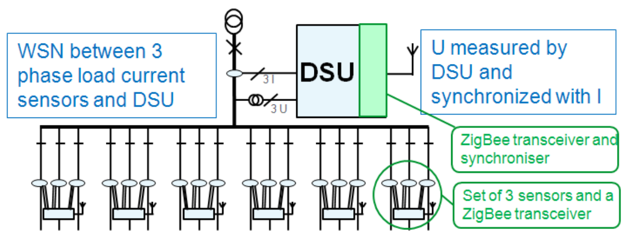

Figure 7

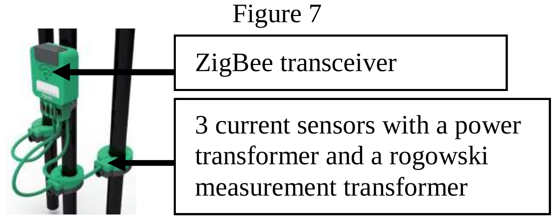

Figure 8

The DSU integrates a dedicated module which concentrates the data from all the sensors.

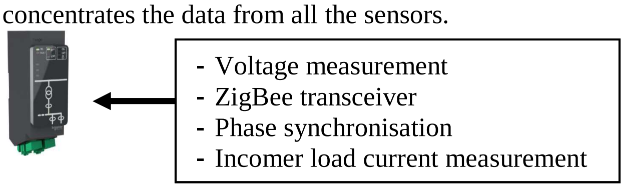

Figure 9

In this case the tricky/unsafe task is voltage measurement downstream the feeder protection.
The Zigbee PRO Green Power enables accurate time synchronization between the different sensors. Therefore a single voltage measurement, in a safe area

of the substation is sufficient to calculate the active and reactive power associated to one given current measurement.

Performance and characteristics

Despite the low consumption of the sensors, the reached performances in term of monitoring are in line with industrial standard IEC 61557-12.

Consumption	Minimum load current = 2A
Accuracy	Current : 1% Power : 2%
Sampling	36 samples / period
Harmonics	H1 to H15
Basic current	Ib = 400A
Max load	Imax = 1200A
Operating temperature	-40°C to +70°C

Table 2

Compliance with standards

The solution is compliant with IEC 61557-12.

Due to edge effect, the compliance is not fully reached at low energy level. The figure 10 shows that from 2A to 20A not all the specifications of IEC 61557-12 are fulfilled. The difference concerns the Harmonics for power which are not yet fully reached after H5.

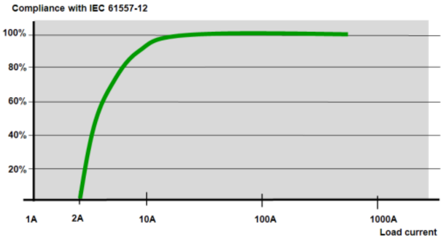

Figure 10

Monitored data

- 3 phases load current for each feeder with direction
- 3 phases load current for incomer
- 3 phase voltage for the busbar
- Power and energy
- H1 to H15 for RMS current
- H1 to H5 for power

Additional function

The easiness of the installation being a major target for this kind of solution, an algorithm has been introduced into the DSU interface in order to accept that the sensor can be mounted on whatever are the phase and whatever the upper face is. It automatically compensates the mounting error.

Additional sensors

Once a Zigbee sensors network is installed for LV feeders monitoring, the utilities may take advantage to install several sensors for these other applications (As examples and non exhaustive):

- Intrusion monitoring
- Water level in gutters
- Temperature for transformer, substation
- Humidity rate

Installation

A dedicated tool is used to mount the sensor on the feeder phase cables. This tool allows easy access to all the phases, even the phase located in the rear part of the pillar.

The sensors and the transceiver could be installed in substation part where water flood could occur. An IP67 level has been applied.

The experimentations have given an average of less than one hour to install a LV monitoring for 6 feeders. This allows equipping up to 4 substations per day per installation team.

Experimentation conclusion

The test done on this solution have given an evidence that a WSN concept is fully compliant with the main requirements:

- Low consumption,
- Performance compliant with measurement standard,
- No interference with other wireless systems in the neighbourhood,
- Time to install a monitoring of the LV,
- Robustness to installation error,
- Synchronisation performance between load current (measured at the current sensor level) and busbar voltage (measured at the DSU level).

ZigBee PRO Green Power is probably not the only possible solution, but this experimentation, shows clearly that it perfectly suits with expectation for a monitoring of LV feeder in a distribution substation.

CONCLUSION

Wireless is the only solution enabling to make possible the monitoring of LV feeder. Within all wireless technologies, the example shown in this paper, based on ZigBee PRO Green Power, demonstrates that solutions are now available, with expected level of performance, and the easiness of installation.