NEW GENERATION OF SMART LV SWITCHGEAR AND CONTROLGEAR ASSEMBLY

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ABSTRACT

In the framework of Smart Grids development, MV switchgear with advanced functionalities such as automation, remote management and monitoring and new distribution transformers with low-voltage regulation and losses reduction have been defined. Now is the time of the evolution of low-voltage distribution switchgear and controlgear assembly, moreover with the necessity of Distributed Energy Resources (DER) and Electric Vehicle (EV) charging integration. These assemblies will have an increasingly important role in energy metering with smart low-voltage meters, integrating low-voltage energy monitoring with communications, as well as protection functions, and even evolving increase the operability, with main objectives of improving efficiency and low-voltage network management.

INTRODUCTION

Once Smart Grid have been developed on the MV side of a transformer substation with automation, remote metering, fault detection and advanced meter infrastructure, even in distribution transformer with development of low-voltage regulation, it is necessary to deploy these concepts also on the low-voltage side to help to energy balance, energy metering, greater safety and efficiency improvement to convert the classical low-voltage distribution switchgear with persons and assets protection as main function into a smart low-voltage switchgear and controlgear assembly (hereinafter referred to as "smart LV switchgear") with advanced functionalities ready for future network challenges, such as DER integration, EV charging, storage, etc.
This paper summarizes the main requirements of this smart LV switchgear equipment from four points of view: safety, asset management, low-voltage protection and monitoring with communication and operability.

SAFETY REQUIREMENTS

According to different databases, the number of arc fault accidents on LV are higher compared to MV side with a relation of approximately 3:1. Most accidents occur during maintenance work on site rather than in normal service or during operation. As LV equipment is accessed more often and live-working is a normal practice, the accidents numbers in LV are higher compared to MV/HV[1],[2].
In terms of safety, the main requirements demanded from low-voltage switchgear and controlgear assemblies are related to: arc faults due to internal faults, accidental contact with hazardous live parts, and fire hazard as well as reaction to fire (low emission of smoke and toxic and corrosive gases).
So, new smart LV switchgear should follow IEC 61439 to achieve safe operation under normal operating conditions as well as under abnormal operation conditions. In addition to being arc fault tested according to IEC/TR 61641[5], the design should reduce the possibility of internal arc. This is possible, for example, with a non-flammable solid polymer insulation material for all conductors (arcing Class I) providing the following advantages:

- Protection against electric shock in normal operating condition, at least IP2X.
- Segregated busbars phases to prevent accidental contacts.
- Over-voltage resistance improvement in order to prevent insulation failures.
- Short-circuit resistance improvement.
- Fire resistance and reaction to fire improvement.
- Over-heating avoided due to bolts loosening.

Figure 1. Internal arc test in smart LV switchgear

In case the smart LV switchgear design has the possibility of interchangeability of a functional unit produced by different manufacturers, it is recommended to perform the arc fault test and short-circuit test on all possible arrangements, in order to validate the results of all situations IEC/TR 61641[5].

Moreover, in order to prevent fire hazard according to IEC TR 63054[7], the smart LV switchgear plastic materials must have good reaction to fire tests, in terms of flammability, smoke density and gas toxicity. As such, it should be properly tested according IEC/EN 60695-11-10[8], trying to obtain maximum flammability category V0 and F0 classification for fire behaviour (smoke density and gas toxicity, index IF≤5) according to NF F 16-101:1988[9].

Another important point is the safe operation that should be assured in other situations such as when a generator is connected (increasingly demanded by customers), to improve the quality of services, and extension with other smart LV switchgear. For this, the smart LV switchgear should be ready to relief connection point to a generator, preventing access to live parts during the busbar connection. It should be ready for distribution busbar extension with a coupling system design, that permits to do this operation safe, fast and even with live voltage, keeping protection degree IP2X, reducing exposure to electrical hazards during busbar extension and with reduced space, in order to minimize the service interruption time.

Finally, it is necessary to implement in the incoming of main busbars of smart LV switchgear a load-break switch- disconnector or a disconnector suitable for isolation perfectly interlocked with the MV side and with voltage presence indication. This concept will be explained in detail in the operability section.

ASSET MANAGEMENT

The process of exploitation and maintenance are improving drastically due to the increase of asset information. The digitalization of installations is necessary to maximize the energy distribution, to minimize the lack of supply and to extend the end of life of assets. As MV equipment has begun this transformation, it is necessary to deploy similar features to smart LV switchgear, in order to have a complete asset management.

The information available can be divided in two groups:

- Information for operation.
- Information for maintenance.

The information for operation is focused on knowing if the installation is correct for its purpose. This information could be available remotely for commissioning, programmed maintenance tasks, etc and may include:

- Voltage presence.
- Interlocking activation status.
- Alarms status.
- Fuses and protection status, if they have operated.
- Health of disconnector or switch-disconnector and status.

With this information, the safety of operators is increased because it is possible check safe conditions before going inside the transformer substation using a digital device (i.e. smartphone).

The information for maintenance is focused on having enough indicators to know the equipment health for:

- Planning predictive maintenance actions.
- End of life extension.
- Replacement planning.
- Comparison these parameters with parameters checked during routine tests in factory.

The information needed to obtain these benefits could be:

- Thermal model with temperature sensors to know critical hot points and connections status related to ambient temperature and load of smart LV switchgear.
- Status of disconnector, switch-disconnector or circuit breakers disconnectors, in terms of mechanical and electrical endurance spent, number of operations or operation times and speed.

LOW VOLTAGE MONITORING & COMMUNICATIONS

As mentioned in the previous points, to face the new challenges of electrical distribution, it is essential to acquire measurements in smart LV switchgear. For this purpose, electronic equipment and sensors have been designed to be integrated in smart LV switchgear avoiding the necessity to install, in the MV transformer substation, a new control box for this functionality, saving costs and space. These integrated sensors should fulfil next requirements:

- Current sensors for general diconnector and LV output lines integrated in the smart LV switchgear.
- Independent of the rated power of the transformer. The smart LV switchgear should be unique for rated power distribution transformer from 160kVA to 1000kVA.
- Protected busbar voltage sensors connections in order to protect the electronic acquisition equipment failure.
- Voltage measurement sensors integrated in the LV output lines.
- Voltage detection sensors integrated in the incoming connection of the distribution

transformer.
- Phase busbar temperature sensors.

These sensors can communicate magnitudes of V, I, P, Q, E +, E-, Q1, Q2, Q3, and Q4, T^a^ measurement, per phase and three phase per LV output line, within the necessary accuracy to perform energy balances. Additional functionality is to provide information on the status of the fuses, LV output line protection devices, and of the smart LV switchgear.
Additionally, devices have been designed to read and communicate the data received from the smart LV switchgear measurements sensors. These devices measure V, I, P and Q, working as a real time quality network analyzer. It can also record, E+,E-,Q1,Q2,Q3, y Q4 from the LV side of the step-down power transformer. All measurements can be read as single or three phase.
This device also provides real time remote terminal unit (RTU) fully compatible with utility system requirements (IP protocol) in real time.
As a result, in just one device, it is now possible to centralize measurements from LV output lines, temperature, and oil pressure and oil level of the distribution transformer.
All this data will be available in the managing system of the utility, serving multiple purposes:

- Analysis:
    - Dynamic customer-phase and feeder association. Feeder mapping.
    - Optimal state of LV network.
    - Energy balance (technical and non-technical losses).
    - Health of fuses.
    - Health of protections.
    - Health of smart LV switchgear.
    - Losses in the distribution transformer.
    - Health of distribution transformer.
    - Imbalances (See Figure 2).
    - Load profiles.
    - Reactive control.

- Safety (alarms) in real time
    - Overload.
    - Over-temperature in smart LV switchgear.
    - Fire risk.
    - Problems with temperature, pressure and oil level in the distribution transformer.
    - Fuse or protection malfunction.
    - Voltage near or out of range.
    - Energy flow inversion in the distribution transformer.
    - Zero-sequence in wire breakage.

OPERABILITY

In recent years the automation of the MV network has been deployed and this attribute will be extended to the LV network. On the other hand, utilities are launching projects to monitor the LV network at the low-voltage switchgear assembly output lines. So with more information of LV network, it will be possible to operate and act on the LV network. This will be necessary to have visibility on what happens in the LV network and to control new generation elements (PV installations, for example) and consumption, such as EV charging.
This operability could be deployed from two points of view. The first one would be to have control of the LV outgoing lines from the smart LV switchgear being able to disconnect and connect them locally or remotely according to safety procedures.
The second point is the necessity to operate the incoming of the smart LV switchgear to open the connection from LV side of transformer, to isolate it if for example a generator must be connected or maintenance work must be done. This operation must be safe, opening and closing operation must be independent of operator speed and skill, and with visible or clear and reliable indication of contacts position. This device must assure:
- Short-time withstand current capabilities.
- Safe isolation according to local legislation[10] and standards, such as 10kV power-frequency-withstand voltage and 20 kV 1,2/50 µs impulse withstand voltage.
- As a disconnector is the most efficient solution it should have proper interlocks to avoid wrong operation, because the breaking duty could be combined with MV switchgear.

In the case that a circuit-breaker is chosen to operate the incoming of the smart LV switchgear, it should have full breaking capacity, such single phase current as three phases current, because as the transformer is very close, both short-circuit currents have the same magnitude due to low-zero sequence source impedance, reduced connection resistance and low impedance cabling between source and devices.

With these two kinds of operation, it would be possible to disconnect the complete smart LV switchgear or one or more outgoings to have control of the distribution network,
- To control the network quality in terms of harmonics, over or under-voltage in case of some LV producer exceeding the standard limits.
- To balance the load and generation to not invert the distribution transformer energy flow, that could generate a lack of protection in some situations.
- To detect and rapidly clear LV single-phase faults.
- To have possibility of re-connection once it is reliably known that it is possible to reconnect.

Finally, there are many utility projects to install electronics in the low-voltage switchgear assembly in order to manage and measure network electric parameters and communicate with the control centre. This information can be used for the low-voltage supervision and for remote protection relays installed in the outgoings with the possibility of remote operation. In this way, the deployment for metering data-meter concentrators AMI equipped with communications permits use of these media to control the low-voltage grid maintaining standardization, protocol, databases, etc that utilities already have with medium-voltage remote control.

FIELD EXPERIENCE

Some examples of this new generation of smart LV switchgear with advanced feeder supervision have been installed at Enel Smart City Network in Malaga, Spain. The smart LV switchgear incorporates several concepts described in the paper and is equipped with a LV Remote Terminal Unit for on-line monitoring, measuring and processing the information from the feeders, figures 2, 3 and 4.

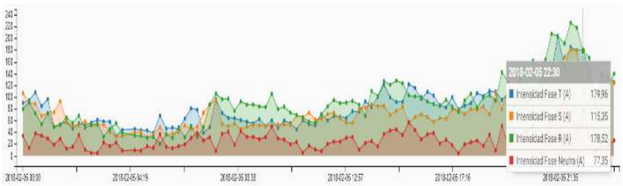

Figure 2. Example of imbalance in Transformer Substation number 395 on 05/02/2018 in feeder 4. Smart City Network in Malaga

Classical low-voltage distribution switchgears were replaced by complete brand new smart LV switchgears, equipped with advanced feeder monitoring devices. They were manufactured, mounted and tested as a whole unit in the manufacturer facility. This permitted replacement according to security procedures, without the necessity of skilled workers availability, within minimum interruption time and extending the LV switchgear life cycle.

Moreover, this replacement provides to LV switchgears, functions such as internal arc resistance, IP2X, fire resistance features, generator connection function and short-time withstand current capability.

In addition, feeder supervision, measuring and communications are factory tested, and all LV switchgear general dimensions, footprint, height of incoming cables and LV output cables are the same of the retrofitted units. So a Plug&Play solution was achieved in order to minimize the interruption time.

Figure 3. Eight feeders smart LV switchgear

This makes possible to use the existing cable connections with the power transformer and the existing cable outgoings without changing the lay-out of the existing cables (no need of cutting, new cable terminations or bending). Sometimes is not possible to modify cables, because they are filled with concrete and/or it is not possible to modify them.

Finally, it is desirable to have modular extensible LV switchgears in order to make easier the retrofit of LV equipment in old transformer substations, where accessibility sometimes is not good.

Figure 4. Four feeders Smart LV switchgear

CONCLUSIONS

The Smart Grid deployment, integration of DER and new challenges such as EV charging, are facing the necessity to digitalize secondary substations. Smart LV switchgear is a key element to achieve this in order to improve efficiency and network management. New and smart LV switchgear is necessary to fulfil all safety requirements in terms of asset and person protection, equipped with sensors that permit remote supervision of equipment status in order to verify the safe conditions of secondary substations and to predict maintenance actions. This smart LV switchgear must have advanced monitoring integrated to know and communicate energy metering and balance in order to help network management. LV switchgear monitoring, together with MV monitoring and LV smart meters, may help to improve energy efficiency, reducing losses being a very important point for DSO. Finally, a desirable feature of this new and smart LV switchgear is to have similar operability as MV equipment, with the possibility to connect and disconnect remotely and safety one or more feeders, or even the complete smart LV switchgear, in order to have reliable protection of the network and to control the supply quality.

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