REDUCE THE NUMBER OF OUTAGE BY INTRODUCING CIRCUIT BREAKER IN THE DISTRIBUTION NETWORK, DREAM OR REALITY?

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ABSTRACT

The use of CBs in the loop allows to decrease SAIDI and SAIFI
The use of CBs in the loop, yesterday economically not possible can be now considered because:
- current available offers are more adapted to the strict requirements of secondary distribution needs
- modern protection relays allow now an adaptation of the existing protection scheme by adding selectivity levels between HV/MV substation and MV/LV substations.

INTRODUCTION

The distribution network is generally operated in open loop allowing a backup solution in case of fault. It is historically equipped with manual switches, with only one protection device per feeder, located in the HV/MV substation. The increasing demand for quality of supply leaded to the deployment of remote controlled substation bringing lower shortage duration. Nevertheless, in case of fault, all the customers supplied by the faulty feeder are disconnected. But in fact the customers upstream the fault could have been unaffected.
The use of circuit breaker instead of switches in the loop allows disconnecting only the customers connected to the faulty part, a significant benefit regarding the number of affected customers compared to the traditional solutions.

WHY ARE CIRCUIT-BREAKERS IN THE NETWORK NOT WIDELY USED?

There are two types of brakes to implement CBs in the network:
- MV CBs and their associated equipment were expensive and more adapted to HV/MV substations than to MV/LV substations,
- usual time discrimination protection system lead to a limitation of the number of discrimination levels.

Brakes coming from CBs and sensors

MV/LV substations do not need all functionalities that are required in HV/MV substations and cannot support their corresponding cost. For instance, withdrawability of CBs was justified by maintenance reasons [1]. MV circuit-breakers made in the 1950's or 1960's were using air or oil for breaking medium. Often, only a few short-circuit clearances were possible on a circuit-breaker before maintenance. Interchangeability of a circuit-breaker during maintenance operations was an important facility.

Figure1 – Example of 1970's withdrawable bulk oil.

From these years, MV circuit-breakers have been improved a lot together with the evolution of the standards requiring a higher electrical endurance. Mainly in HV/MV substations, circuit-breakers are still withdrawable type, even if the need for maintenance is much lower today.
The disadvantage of using this approach was an increase in the front to back dimensions of the switchgear to allow for the horizontal movement of the circuit-breaker. So, primary switchgear were designed for an environment where space is not an issue. As a contrary, compactness is strongly required in MV/LV substations.

Figure2 – Example of MV/LV compact substation.

Beside the CBs in primary substations, old generations of big sized sensors with heavy burden are still used. For example 5A – 10 to 15VA current transformers or 30 to 50VA voltage transformers were justified in conjunction with old electromechanical relays but are no longer necessary with modern digital relays. The real need of consumption of digital relays is in the range of 1VA. Then, big sized coupling transformers are necessary to cope with 5A or 1A inputs.

Brakes coming from time discrimination protection systems

With a distribution network operated in open loop, the protection system is generally based on overcurrent relays with time discrimination to ensure the coordination. According to the neutral earthing system, directional earth fault protection can also be used in the primary substation. If a large generator is connected into the MV network, directional phase overcurrent protection can be necessary in the primary substation for the concerned outgoing feeder. But, for all these cases, the coordination is always based on time discrimination. Of course, in particular cases, other protection systems can be used (differential line protection, distance protection …), but today these systems are not well adapted to the MV power systems requirements.

With a protection system based on time discrimination, the time interval between the protection stages is generally 300ms. This value has fixed a limitation in the number of protection stages, to avoid too long clearing time at the upper level. The figure 3 gives an example with a simplified single line diagram. The timer settings are defined with independent time (DT curves) to simplify the example, but the same approach could be done with dependant time curve (IDMT curves).

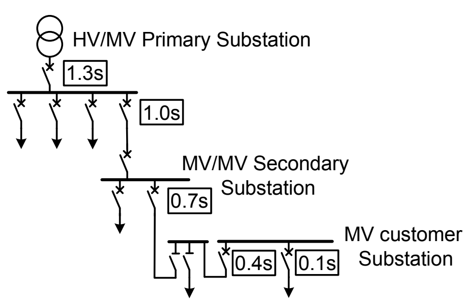

Figure3 – Example of DT timer settings with time discrimination

In this example, the timers at the upper levels are more than 1s. These settings are often not acceptable because the voltage sags are too long in case phase faults on the MV outgoing feeders, and the clearing time is too long in case of busbar short-circuits in the primary switchboard. Generally, protection relays are only used in primary substations and customer substations. The secondary substations are based on switch-disconnectors without protection relays. Only MV/LV transformer feeders are equipped with protection relays

FEED BACK ON SOME EXPERIMENTATIONS AND STUDIES

Despite these breaks, several experimentations have been done, aiming to add circuit breakers in the loop.
In general, major criterions were:

A simple and economic upgrade,
No or low impact on operation modes

a. Dong Energy - Copenhagen:

The solution consists of adding one or two circuit-breakers in a radial feeder. Practically, one switch of the RMU is replaced by a circuit breaker, driven by a local automatism: if the voltage is off, and no fault has been locally seen, then the incoming switch is open and a second switch is closed on a back-up line. If the voltage is off and a fault current has been seen, then the circuit breaker trips, isolating the downstream section.

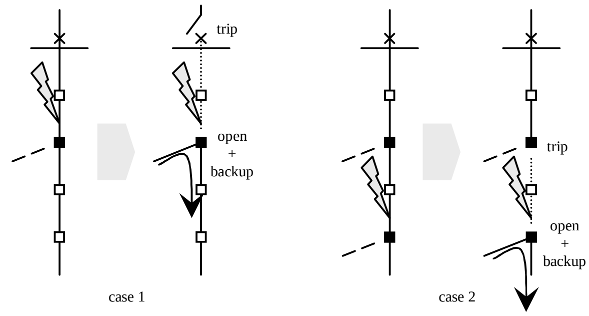

Figure4 – Illustration of Dong's concept

In case of fault, the faulty section is automatically isolated while the healthy sections are still alive thanks to a backup [2], [3]. Based on local decentralised automatism located in the MV/LV substations, the system does not require any communication infrastructure. On the other hand, circuit-breakers require a higher electrical endurance. They have to withstand 40 to 50 breakings at the full fault current, assuming that we do not know the real amplitude of broken current at each fault.
Therefore, a new feature exists now in modern protection relays, allowing knowing the prompting level of the breakers.
In addition, Dong's system requires particular network architecture with an available back-up ingoing in each upgraded MV/LV substation.

b. ENEL

ENEL has deeply investigated the topic [4], [5] and finally achieved the specification of a new switchgear. Three key characteristics were clearly identified to achieve an innovative solution:
- the switching time
- the making and breaking capacity
- the electrical and mechanical endurance

These key point being addressed, a particular care was taken to have a compatibility with installed base in order to facilitate the implementation. This point is quite easy in

Italy since most of substations are equipped with air insulated switchgear, usually bigger and more accessible than gas insulated switchgear, and then more convenient to upgrade. But ENEL has planned to expand this specification to a future SF6 insulated RMU.

c. New Berlin [6]

In this case, the network is operated in closed loop with several breakers in the circuit. A peer to peer communication links each breaker to its neighbour and the protections are directional type. Protections are set to open the breaker if its neighbour has seen the fault in an opposite way (directional logic locking, commonly used in industry). This solution requires a specific communication system, which is an important drawback.
The operation in closed loop is not applicable in most of feeders where each end is supplied by a different primary substation, but it can be operated also in open loop.

As a conclusion, the implementation of circuit breakers along the feeder, while bringing interesting benefits in terms of quality of supply, generates some technical and/or economical constraints which are not always acceptable.

MODERN SOLUTIONS

On an ideal point of view, solutions including low cost CBs, low cost sensors, no communication, without specific network architecture and easy possible upgrade would allow to reduce the outage at a cost effective level.
Today, adequate and economically viable answers to the needs of MV/LV substations do exist, in both following areas:
- optimized integrated CB for network applications, including LPCTs,
- adaptation of existing protection systems by the reduction of time discrimination interval or the use of logic discrimination in substations between incoming and outgoing feeders.

Optimized integrated CB for network applications

For compactness and for the best integration, fixed technology is used as it is now proven that fixed CBs are of very high reliability and maintenance free [1]. Modern fixed designs offer reliable service provided the switching devices meet the service application during their whole life and the manufacturer has considered the important operational requirements which are:
- safe working procedures for cable jointing,
- cable fault location and testing procedures,
- system phasing out procedures,
- protection testing procedures,
- working procedures for switchboard extension.

These CBs are integrated in a switchgear module that is insensitive to harsh environments. These modules include optimized sensors that are able to operate with self powered relays.

On another hand, digital relays can now easily accept voltage signals from Low Power Current Transformers (LPCT). Figure 5 shows there is a huge difference in size between two types of CTs at equivalent characteristics.

Figure5 –24kV CTs comparison, LPCT on left side, traditional CT on right side.

Adaptation of existing protection system

With digital relays and modern CBs, several improvements of the existing protection system allow insertion of one or two protection stages without too long clearing time.

- **The time discrimination interval can be reduced to 200ms.** The following chapter explains how this reduction is possible.
- **The logic discrimination can be used in substations between incoming and outgoing feeders**. This principle allows same timer settings for both stages. If physical wires are necessary, connections are delimited to the same switchboard. If digital links are used with the GOOSE service of the IEC61850 communication, the logic discrimination is easily implemented.
- **The setting groups can be used for an adaptative protection system.**

With these two improvements, the example of the figure 3 leads to the following timer settings (figure 6)

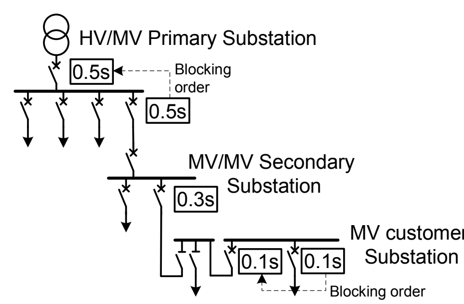

Figure 6 – timer settings after improvement

Reduction of time discrimination interval

In the figure 7, the upstream relay A is set with a timer T_A and the downstream relay B is set with a timer T_B.

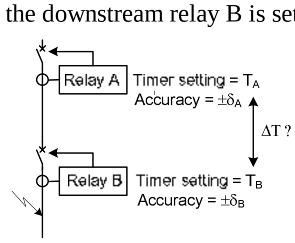

Figure 7 – time discrimination between two relays

To ensure a proper discrimination between A and B relays, the time interval ΔT must be above or equal to the sum of the following items:

- The maximum negative error (δ_{A-}) of the timer T_A (without the B relay, the A relay would trip with the timer T_A-δ_{A-}).
- The maximum positive error (δ_{B+}) of the timer T_B (the B relay could trip with the timer T_B+δ_{B+}).
- The maximum clearing time of the B circuit breaker
- The overshoot time of the relay B
- A security margin.

For DT curves of modern relays, the timer accuracy is generally around ±2% or ±20ms. The maximum error between the timers of A and B relays would be less than 40ms.

For IDMT curves, the timer accuracy also depends on the current measurement accuracy. This timer accuracy is generally around ±5%, mutiplied by a factor according to the current magnitude (as described in the IEC 60255-151 standard). Due to IDMT curve principle, the time interval between the A and B curves must be met for the maximum short circuit current. So, for typical settings, the maximum error for the timers of A and B relays is less than 50ms.

The maximum clearing time of circuit breakers depends on the technology.

- With a shunt trip coil system, the clearing time depends on the auxiliary voltage level. With the rated voltage level, the clearing time is generally less than 80/90ms, but with a reduced level of 0.7 times the rated auxiliary voltage, 50ms must be added.
- With modern CBs associated with self-powered relays, the trip command is based on low power tripping coil without any auxiliary power supply. As the result, the clearing time is more repetitive, and for modern circuit-breaker, the maximum clearing time is generally less than 60 to 80ms.

The overshoot time for modern digital relays (as defined in the IEC 60255-151 standard) is generally less than 40ms. This time is only due to the depth of Fourier filters (1 cycle), which are commonly used in the overcurrent protection algorithm, and the execution cycle duration to compute protection functions.

In conclusion, without safety margin, the time interval ΔT must be above 170ms (50ms + 80ms + 40ms). To ensure proper discrimination, a safety margin is needed, and a time interval of 200ms is recommended.

<u>Used of setting groups for adaptative settings</u>

With this reduction of the time interval, one or two protection stages could be introduced between the primary substation and the customer substations. With two stages, according to the operating modes of the MV feeders (the position of the opening point of the MV loop), the timer settings of the secondary substation protection relays could be different. This “active” setting modification can be done with a low speed communication channel which activates the right setting group of the protection relays. Each secondary substation relays could be set with two setting groups, with two different timers, and the choice of the active setting group will be defined by the distribution management system according to the operating mode.

CONCLUSION

Today, with modern circuit breakers for secondary substations and digital protection relays, adaptation of existing protection systems allows to introduce one or two protection stages in the distribution networks.

The insertion of CBs in the feeder allows to reduce dramatically the number of affected customer in case of fault. Another benefit is the reduction of SAIDI index by reducing the time of reconfiguration. Consequently long duration outages become short duration outages.

In the future, new protection systems, possibly based on latest developments in communication technologies, will be designed to better fit the MV grid evolutions (distributed generation, closed loop operation,…) .

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