AUTOMATION IN CABLE DISTRIBUTION NETWORK (10 KV)

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ABSTRACT

The increased focus on quality of supply and replacement of overhead lines with underground cables has stimulated the introduction of remote short circuit indicators and remote control switchgears for 10 kV cable networks in Denmark.

Danish Energy Association has investigated whether it is possible to use automation in selected 10 kV secondary substations. The automation is divided into several levels:

- *Basic Level:*
  - *Localization and isolation of faults.*
- *Higher levels :*
  - *When supply is maintained automatically for most of the non-faulty secondary substations (use of circuit breakers)*
  - *When the primary station is automatically reconnected after the faulty feeder has been isolated*
  - *When one or more secondary substations with backup are connected automatically after the faulty feeder has been isolated*

INTRODUCTION

Underground cables have replaced most of the 10 kV overhead lines in Denmark. Some Distribution Network Operators have established remote short circuits indicators and remote controlled switchgear in the secondary substations. Danish Energy Association has studied the feasibility to establish automation in secondary substations. The automation shall locate and isolate short circuit faults when the primary station has disconnected the faulty feeder or before the primary station disconnects the faulty feeder by means of circuit breakers.

In principle, the automation shall make the same connections as the control centre does in short circuit fault situations - just faster:

- Short circuit indicators detect the short circuit.
- The primary station disconnects the faulty feeder when a short circuit occurs, unless the automated secondary substation has circuit breakers.
- Voltage indicators indicate whether the primary station has disconnected the feeder and whether there is voltage at the secondary backup substation.

Automated secondary substations disconnect only if there is no voltage at the feeder (unless circuit breakers are used) and the automation connects to backup only if there is voltage to the secondary backup substation.
It should always be possible to disable the automation system from both the control centre and the secondary substations.

LOCAL OR CENTRAL AUTOMATION

Automation can be established with local or central automation.

Local automation

Automation is isolated to selected secondary substations at the feeder level. When a fault occurs, the primary station disconnects the faulty feeder (unless the automated secondary substations have circuit breakers installed). The only communication between the control centre and the automated secondary substations is:

- Feedback from short circuits indicators
- Indication of the switchgear position (open/closed)
- Remote control of the switchgear
- Remote control of automation (the control centre can always disable the automation system in the secondary substation)

There is no communication between the automated secondary substations. The automated secondary substations carry out switching sequences as autonomous units. When the automatic switching has taken place, the control centre will be notified.

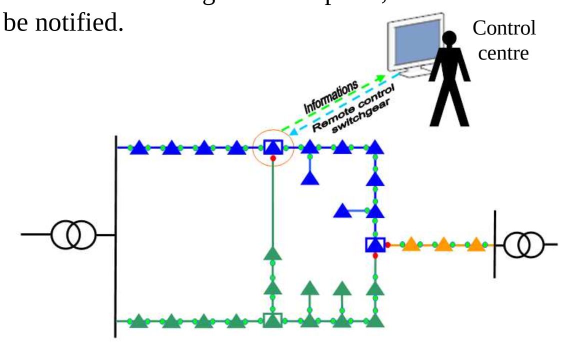

Figure 1: Local automation.

Central automation

In central automation, the automation has overview of all the secondary substations with communication. Secondary substations with communication report all their observations (short circuits, earth faults, measurements, etc.) to a control unit in the control centre.

The control unit decides how the operational situation has to be handled based on reports from automated secondary substations. Therefore, central automation is far more advanced than local automation. Problems with reclosure, faults on higher networks and double faults, etc. are resolved easier with central automation than with local automation. On the other hand, the communication and control units are far more comprehensive with central automation.

Decentralized automation

Another method could be decentralized automation, i.e. a mixture between local and central automation. For example, it would be useful if an automated secondary substation communicate with a secondary substation backup, provided the switchgear is located at the secondary substation backup. However, the physical distance between the communication units (two secondary substations or the primary station and a secondary substation) has no influence on the speed of the communication. There is therefore no advantage in establishing decentralized communication rather than central automation.

METHODS OF AUTOMATION

The automation can be divided into several levels:

- Basic level:
  - Localization and isolation of faults.
- Higher levels :
  - Supply is maintained automatically for most of the non-faulty secondary substations (use of circuit breakers)
  - Supply from the primary station is automatically restored after the faulty feeder has been isolated
  - One or more secondary substations with backup are connected automatically after the faulty feeder has been isolated

Localization and isolation of faults

When faults arise, the primary station disconnects the feeder. The automated secondary substation isolates the faulty part of the feeder. The control centre reconnects the primary station if possible. This is shown in Figure 2.

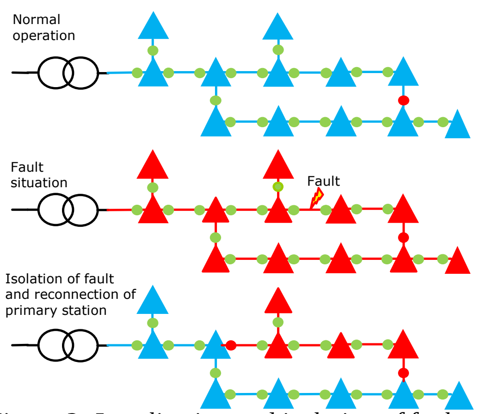

Figure 2: Localization and isolation of faults.

Isolation of faults with circuit breakers

In some fault situations, the use of circuit breakers in automation may obviate that the primary station disconnects a whole feeder. With use of time selectivity in the primary station protection, circuit breakers in the automated secondary substations can disconnect the faulty part of the feeder before the primary station responds to the fault and disconnects the whole feeder. This means that some substations will maintain supply. See Figure 3.

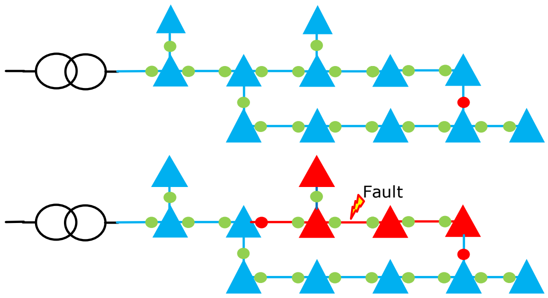

Figure 3: Isolation of faults with circuit breakers.

NETWORK OPERATIONS WITH AUTOMATION

This chapter reviews the considerations that are taken into account concerning automation and operation of the network.

Switching and voltage transients

All faults and switching in a network will cause voltage transients. This will occur both with and without automation. Automation for isolation of short circuit faults will not worsen or improve the problems of voltage transients.

The automated secondary substation will only carry out switching in fault situations. The number of switching operations with automation will not differ significantly from what is necessary with local or remote controlled switching.

Faults in HV networks

If the automated secondary substations do not only isolate faults but also connect backup in fault situations, faults in HV networks are a challenge to the automation.

If an automated secondary substation is without voltage and if it has not registered a short circuit, the automation does not know whether the secondary substation is without voltage because the primary station has disconnected the feeder or whether there is a fault in the HV network supplying the primary substation. Time selectivity and voltage indicators at the secondary backup substation can solve these challenges. If the missing voltage is due to a fault in the HV network, this outage is usually very short and a built-in time delay in the automation can ensure that the automated secondary substation does not connect to backup before the voltage is back.

If the fault in the HV is of longer duration, the automated secondary substation will only connect backup if the secondary backup substation is energized. This means that for long-lasting faults in HV network, the automated secondary substations will only connect to backup if the backup is supplied from a HV network, which is not faulty. Voltage indication at secondary backup substations is therefore required.
Establishment of central automation communicating all events in the network solves the problem of dealing with faults in HV networks.

Secondary faults and double faults

When a fault in the network provokes a second fault, this new fault is called a secondary fault. When two separate faults occur on the same feeder simultaneously or within a short time period, they are called double faults.

Double faults

It will be difficult for automation to detect double faults, if not impossible. However, as long as there are 10 seconds or more between faults automation will disconnect the first fault and reset, whereupon the next fault will be treated as any other fault.

Secondary faults

When a fault occurs it happens that another fault occurs shortly after because of the higher voltage, phase failure, etc. The automation does not react when earth faults occur but at short-circuits only. Automation will therefore not prevent that two of the phases of a faulty feeder due to the earth fault will have higher voltage to ground than normal and this may aggravate the weaknesses that the components already could have.
A fault that occurs when the automation already has disconnected a previous fault will be handled as a common fault. When a short-circuit occurs, the fault will be isolated and disconnected. Earth faults will not activate the automation unless the fault develops into a short circuit. Faults have to occur in a very rapid sequence in order to actually be considered as secondary faults and not as a separate fault by the automation. The automation does not worsen or improve the problem with secondary faults.

Communication

Automation requires communication between the automated secondary substation and the control centre. The cost of communication should be as low as possible but at the same time, the requirements to the communication are:

- Speed - The automation must improve the reliability of supply and the communication must be fast.
- Operational stability - communication must be stable
- Safety - No extraneous system penetration. The security system shall be such featured that no person using simple technology will be able to control the automated secondary substations. At the same time, the substation security requirements shall be comparable with the present security requirements - a simple lock on the door in secondary substations.

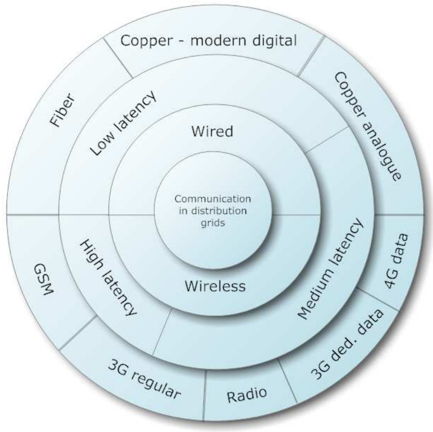

Figure 4: Illustration of communication methods

The running cost of communication will approximately be:

- Wired (optical fibre): 27 EUR per secondary substation per month.
- Wireless (GSM): 20 EUR per secondary substation per month.

The expenses for establishment will depend on the choice of communication.

RECONFIGURATION BASED ON LOAD, GRID LOSSES OR SMART GRID

Electric cars and heat pumps may introduce new challenges to the 10 kV networks in terms of overload. Therefore, it has been investigated whether automatic reconfiguration to avoid overload or reduce grid losses is possible.

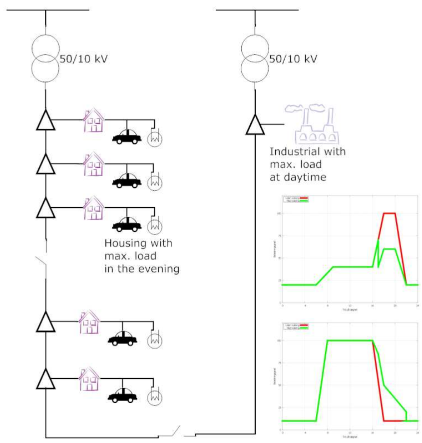

Figure 5: Illustration of switching based on load

Reconfiguration based on load

If two related feeders have maximum load at different hours of the day (e.g. a feeder for industrial customers with maximum load a daytime and a feeder with private households with electric cars, which will be a loaded in the evening and during the night) the load may be shared between the two feeders. The industrial feeder may e.g. supply half of the households at night (when the electric cars recharge), daily switching between the two feeders will therefore occur.

The prerequisites for daily switching are:

- That the switchgear can handle many switching operations both mechanically and electrically and the arc suppression coils automatically adjust themselves after the zero-sequence voltage (e.g. with time delay)
- That the voltages on both sides of the switch are almost equal
- That the protection works in both of the configurations. Normally, disconnection of a number of secondary substations should not affect the protection in any way, but it should be investigated (because the relays in the primary station that protect the feeder when faults occur are usually adjusted according to the cable impedance and the minimum short circuit level at the secondary substation furthest from primary substation).

Switchgear and circuit breakers

Standards for switchgears and circuit breakers do not contain any tests testing for situations of many disconnections. The typical test for switchgears is up to 200 disconnections at their rated breaking current. Manufacturers report that circuit breakers can operate between 1,000 and 30,000 times at nominal load current. However, the number of switching operations is based on the manufacturers own tests; there is no standard test which shows the electrical durability when many switching operations are carried out.

Grid losses

The differences in grid losses between an ideal meshed 10 kV grid and a grid with feeders have been calculated. The calculations show that the losses do not increase significantly by operating the grid in feeders contra meshed. The costs of reconfiguration to minimize grid losses - either by remote or automatically, will be much higher than the benefits. The biggest losses are in the transformers.

Smart Grid

The investigation of automatic switching based on load or grid losses shows that the only control of the load probably will be the control or shifting of the consumers' electricity consumption also known as a part of Smart Grid.
Smart Grid requires that the Distribution Network Operators install measurements in the secondary substations. The report "Smart Grid in Denmark" from 2010 [1] estimates that 25,000 of the existing 68,000 secondary substations in Denmark in 2025 will have measurements of the load. Measurements and communication for Smart Grid can be used in the automation to handle fault situations or, oppositely, the communication to automation can be used to relay measurements to the control centre and for Smart Grid purposes.

CONCLUSION

Automation in secondary substations is suited for feeders with branches, for grids with many consumers and for long feeders which in the case of a fault can be split up, so that half of the feeder can be reconnected quickly or get back-up supply.
According to the manufacturers, components are available for both local and central automation. (Local automation has been established by one of the Danish Distribution Network Operators).
Table 1 shows the additional costs for remote controlled switchgear and local automation per secondary substation. It has not been possible to conduct useful cost-benefit calculations of the costs of automation. The grid structures, strategies for operation and strategies for maintenance and business differ too much between the Distribution Network Operators for a general cost-benefit calculations to be meaningful. The individual Distribution Network Operators would not be able to use the results of such a general cost-benefit evaluation.
Automation is a new technical possibility. Society often embraces technology and expects that businesses and government use the new technologies available. In spite of the fact, that automation in secondary substations may not be economically profitable in relation to quality of supply it might be demanded by society in time. Either that automation is used in many secondary substations to improve an already good quality of supply or at consumers with important functions like hospitals, police stations or consumers with a great number of people gathering like stadiums, shopping centres and similar places or as a service to companies where long-term outages are expensive.

REFERENCES

[1] Energinet.dk and Dansk Energi, 2010, "Bilags rapport Smart Grid i Denmark", Denmark (In Danish).

	Additional price in EUR			
	2 functional units (cables)		3 functional units (cables)	
	Min.	Max.	Min.	Max.
Local automation contra Remote switchgear	900	3.000	900	3,000
New switchgear motor-operated from factory contra Switchgear with retrofit motor	5,400	4,000	6,800	4,800
Circuit breaker contra Switchgear (both motor operated from factory)	2,000		3,100	
New secondary substation contra New switchgear motor operated from factory	23,500	22,800	29,800	29,100

Table 1. Additional min. and max. prices