STRATEGIES FOR THE RENOVATION OF PROTECTION AND CONTROL SYSTEMS IN ELECTRICAL SUBSTATIONS

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1. SUMMARY

Improvement of electricity distribution management is stimulated by energy market deregulation and dictates investment choices for power stations, distribution lines, remote control centres and electrical substations. The aim of this paper is to look at various strategies followed by utilities for the choice and installation of protection and control systems in electrical substations. It focuses on substation refurbishment corresponding to the most common situation found in industrialised countries. The first part of the paper briefly introduces the main reasons for modernising the substation level. It then looks at the various industrial policies that may be adopted depending of the utility objectives.

2. REASONS FOR MODERNISING THE SUBSTATION

Cost reduction is the driving factor for modernising an electrical substation in order to improve its efficiency. This is achieved through a better network operation and/or substation maintenance.

The figure 1 below represents the typical devices found in the substation and will be used in this presentation to illustrate the changes:

- RTU: Remote Terminal Unit. This computer is used for remote control of the substation and local automation. This equipment is currently present in about 40% of the distribution substations and 80% of the transmission substations.
- SOE: Sequence Of Events. This computer is used to store and print the history of the events.
- Mimic: Wall mimic used for local supervision and control.
- Marshalling cubicles are used to connect the devices together, de-couple the I/O and perform simple logic.
- P is a protection device, for example an overcurrent protection.
- A is automatic device, for example a voltage regulator.

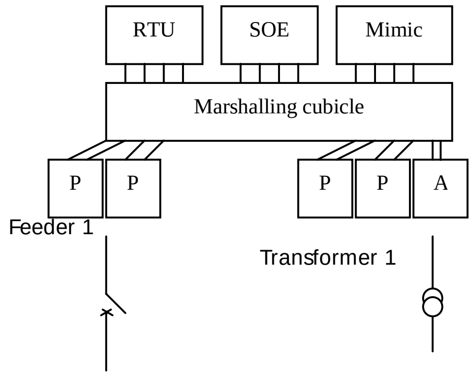

Figure 1: Devices of an electrical substation

2.1 Network operation

2.1.1 Changing conditions

Network operation may be affected by changing conditions in the substation's environment. Deregulated electricity market is one of them and has consequences on:

- The protection scheme, in order to cope with the arrival of independent power producers. The protection devices may be changed or at least complemented to cope with a meshed network (instead of a pure hierarchical one).
- The quality of electricity. It shall be improved as any industrial product and monitored. New HV apparatus may be needed, like additional transformer for back-up, capacitor bank for harmonic filtering or even lines. New LV devices shall also be introduced, like power quality monitors (Q in the figure 2) or fast recloser.

Changes in the network topology, for example increased proportion of underground lines due to ecological reasons, will introduce more reactive currents and may also lead to a revision of the protection needs.

These changes are reflected in figure 2.

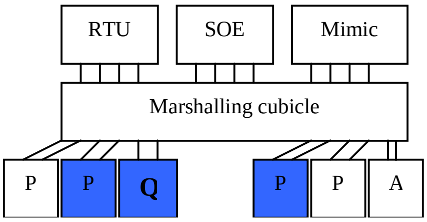

Figure 2: Changing protection and control devices

2.1.2 Better control

Network operation may be improved through a better control. This will result in:

- Installing a (new) dispatching centre in order to co-ordinate the different substations. Impact in the substation will be to add a RTU or change the RTU protocol. This will also reduce the need for an operator in the substation and benefit to the cost reduction.
- Adding some automation (A), for example load shedding, transformer change-over, inter-tripping, … This again will reduce the expertise requested for the operator, therefore decreasing the training costs.

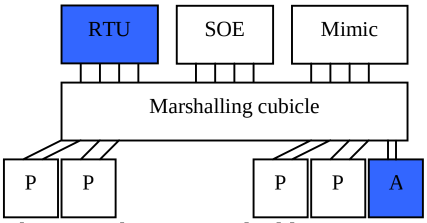

Figure 3: Changing the RTU and adding automation devices

2.2 Substation maintenance

2.2.1 Keeping or replacing

As a general comment, keeping or replacing existing equipment shall be decided when examining the maintenance costs. Common rules are that:

- The primary equipment life expectancy is 30 to 40 years, while protection and control devices one is about 15 to 20 years. An average of two generations of protection and control devices shall therefore be used with the same apparatus. This has a consequence on the interface of the new generation of protection (see next section).
- The cost of spare parts maintenance generally increases with time for a given technology. The reason is that new technologies progressively replace the old ones with better cost/functionality ratio. Manufacturing of devices with old technology is therefore limited to spare parts: the amount of production decreases and the relative cost of each piece increases. This may shorten the life of electronic devices especially to 10 years (cf. the PC world).

2.2.2 New technologies for protection and control devices

Looking at the new technology available for modern protection and control devices may influence the decision to switch faster than expected to new scheme for minimising the maintenance costs:

- Self-checking capabilities are significantly reducing the need for periodic maintenance, if such information can be retrieved remotely.
- Functional integration capabilities allows to group all the feeder functions into one device thus replacing a collection of elementary elements (like overcurrent protection, transducers, disturbance recorders, …). This reduces the cost of the spare parts and copes with the new functional needs identified in the previous sections.

2.2.3 Primary equipment condition monitoring

Apparatus condition monitoring is another new technology emerging in order to improve the preventive maintenance of the transformers and circuits breakers:

- Very simple monitoring, like the sum of the squared currents cut by the circuit breaker. This is achieved with the digital protections.
- Deeper analysis through the use of specific sensors like mechanical position monitoring. Additional equipment are needed (CM in the figure 4).

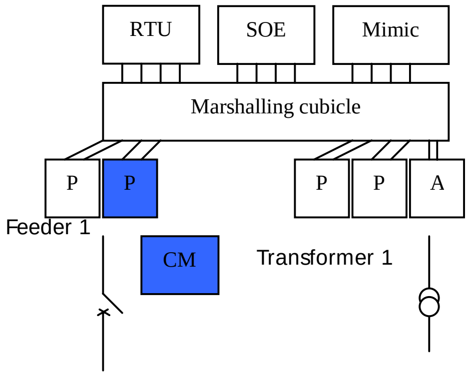

Figure 4: Condition monitoring devices

3. POLICIES FOR SUBSTATION REFURBISHMENT

3.1 Basic strategies

There are two basic strategies when refurbishing the substation:

- Big bang, i.e. remove and rebuilt everything. This will happen when the apparatus is removed or when the complete set of protection and control devices is removed.
- Progressive changes, subdivided into two complementary directions:
    - Functions: protection or control or remote control may be changed separately.
    - Bays: one bay or a set of bays may be renewed keeping the other ones untouched.

Big-bang approach provides an homogeneous solution, less expensive than the progressive change since there are no specific cohabitation interface to be developed (see next section) and a single configuration and test.

The advantages of the smooth changes include:
- Adaptation to yearly budgets.
- Continuous improvement reflecting both the changing user needs and technology changes.
- Rapid installation on each bay.

Progressive changes situation is the most common one and requests to set up a migration strategy, defining the different steps to be followed to match the operational objectives: which functions first, which bays ?

3.2 Constraints

Main constraints when refurbishing a substation are:
- Minimisation of the down time, i.e. when the line or the transformer is no more energised or not protected. This applies to a single bay (feeder, transformer, etc.) and of course to multiple bays: refurbishment of one bay may have an influence on the other bays (for example: breaker failure protection) but shall not force those bays to be stopped.
- Cohabitation between various generations of devices, since investments have usually been progressive and shall be optimised. For example a new transformer with its new protection and control devices has been added some years after the first one has been installed.
- Compatibility of operation with the previous generation in order to be easily used by the operators. For example, the old mimic may have to be emulated, using the same security rules.

3.3 Competence management

Conventional systems usually split protection devices from control ones, with different specialists for each domain making the choice of the devices, their installation and configuration (protection, control, telecommunication, marshalling cubicle, …).

Modern trends radically change this approach for cost reduction (less specialists) but also because the use of digital control systems modifies the requested competence:
- The same device performs both protection and control functions.
- Serial links allows to carry more information than parallel wiring but request more complex configuration during its commissioning.
- Configuration tools perform data consistency between protection, local control and remote control functions.

System knowledge becomes mandatory, and an open question (concerning the competence management) is to decide whether to keep or not specialists for the configuration and the installation of the system whithin the utility. This is dependant on the number of substations of the customer:
- When few substations are concerned it is usually better to externalise the service.
- When substations are refurbished regularly, i.e.more than 5 per year, it may be interesting to train some specialists.

3.4 Single or multiple suppliers

3.4.1 General

Choosing whether a system shall be composed of devices form a single or from multiple suppliers is another classical decision to be made.
- Main advantages of a turnkey system from a single manufacturer include a reduction of the customer expertise costs and an optimised integration between the different devices.
- Advantages of multiple suppliers are the better cost/functions ratio at the device level (due to the competition) and better technical knowledge by the customer.

3.4.2 Serial communications

Use of serial communication between devices make the problem more complex, since interoperability between devices is a must. There is currently a single international standard for communication in the substation, the IEC 60870-5-103, restricted to the supervision of protection relays. The standard is limited to the monitoring of information acquired or calculated by the protections, the change of setting groups and retrieval of disturbance records. It may not be sufficient for the user needs, for example is the settings have to be changed individually, or if the performances are not enough to cope with automation needs. A new IEC standard is in preparation (IEC 61850), but is still at the stage of committee draft (CD) and unlikely to be implemented within 2-3 years by the manufacturers.

3.4.3 Alternative

A compromise between the turnkey approach and the individual device purchasing can be done, see [1]:
- The substation is divided into "lots" corresponding to homogeneous electrotechnical entities, like busbar or transformer.
- The busbar lot contains for instance the protection and control devices of all the feeders and capacitors connected to the busbar (typically 10 feeders).
- Each lot works autonomously, solving internally the needs for performances for example, and cohabiting with the rest of the conventional substation.
- Each lot can be supplied by different manufacturers
- The need is then only to interconnect the lots between them, which is far easier than to connect protections from various manufacturers.

3.5 Solving constraints

3.5.1 Minimisation of down time solutions

Digital control system allows a better minimisation of the down time during refurbishment than with conventional systems through various principles:

- Serial link is replacing (most of) the parallel wiring between the bays and the substation computer (the substation computer is used for local control and connection with the remote control centre). The time for installation and tests is greatly reduced. Note that conventional wiring may however be kept to match cohabitation constraints (see below).
- Database management. The databases corresponding to different configurations of the substation during progressive change are prepared in advance and downloaded from a central location. Changes are easy since the databases are purely software made, no more maps defining the physical connections between devices.
- Bay mode management. The alarms resulting from a bay being commissioned are automatically suppressed: this is avoiding to stress the remote control centre.
- Factory tests can simulate the complete protection and control system to have a detection of potential problems prior to commissioning.

3.5.2 Cohabitation solutions

Cohabitation between different generations of devices has to address the following needs:

- Reuse of the existing wiring, between the "old" devices that remain and the new ones. The new devices may have to provide extra parallel (conventional) inputs/outputs that would not be needed when using the serial link in a complete digital solution. The existing physical connectors and voltage polarities must be kept.
- Emulate the behaviour of the previous equipment as seen from the other. A classical example is the "select before operate" sequence traditionally used in previous RTU from the remote control centre. More complex examples include the cohabitation between automation like dealing with an existing central synchro-coupler with distributed synchro-checks. It is mandatory for the digital system to be flexible enough to cope with this need.
- Connection of serial protocols to IEDs. The serial protocols have generally been introduced to take advantage of new numerical devices, for example remote setting from a PC. The IEDs and corresponding PC programs are generally issued form different manufacturers and shall be integrated into the same PC.

3.6 Example of migration strategies

3.6.1 IEDs first

All or part of the protection, monitoring or automation devices are first renewed in this strategy. The rest of the substation is still conventional. The communication between the new protections and the RTU and SOE is done through parallel wiring. They are also connected by a serial link to a PC for setting changes, disturbance records retrieval, software or database downloading, etc…

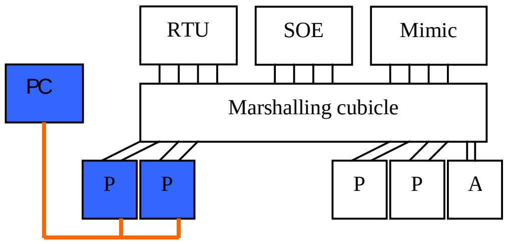

Figure 5: Integrating IEDs

If there are protections from different manufacturers then a serial link per type of protocol may be needed.

When migrating to the full digital substation, most of the parallel wiring will be suppressed: functions requesting fast communication between devices, like logical selectivity between incoming and outgoing feeders will probably remain hard-wired since the serial link installed at first will be unable to fulfil the constraint.

3.6.2 Control first

In case of a new remote control centre protocol, or if there was no remote control before, or if the RTU becomes obsolete, the following scheme applies for all bays:

- A new RTU is introduced, and may cohabit for a while with the previous one. Both RTUs can work in parallel for a smooth change.
- The wall mimic is replaced by a PC and becomes the Human Machine Interface able to visualise new types of data like alarm list, self-check status, sequence of events, … The cohabitation between the old mimic and the HMI has to be avoided to minimise the risks of inconsistency.
- Optionally bay computers are connected locally to the conventional protections, in order to reduce the wiring, allow local automation (like new recloser scheme) and prepare the full digitalisation.
- Existing protections with parallel wiring are kept.
- All the digital devices are connected on a central communication network.

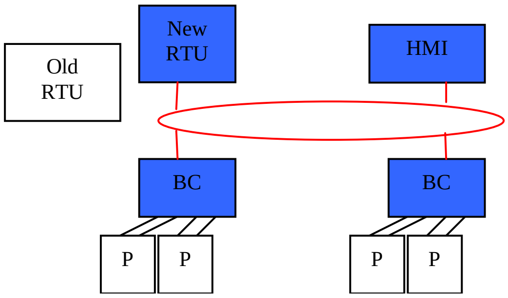

Figure 6: Changing the control first

Full digitalisation will then simply change the protection and connect them to the bay module or directly on the communication network.

3.6.3 Mix or complete refurbishment

When mixing the previous scheme or for complete refurbishment, the architecture is described below.

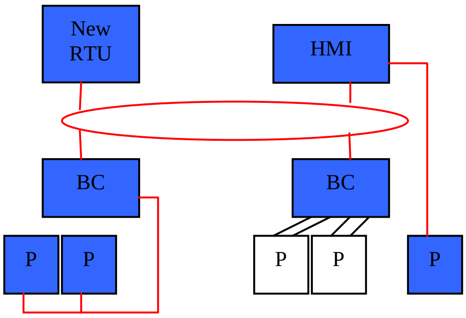

Figure 7: Complete refurbishment

4. CONCLUSION

Substation refurbishment may follow different paths from conventional protection and control devices to fully digital ones. There are field proven proven principles used to minimise the down time and allow the cohabitation between different generations and origins of equipment. Decision must be made by the user for engineering, multiple suppliers selection and migration strategy. This shall be done during the cost evaluation study on a case by case basis.

REFERENCES

[1] J.F. Brisset and al. "PCCN: Protection and Control of EDF Distribution Substation", CIRED 99.