INTRODUCTION

Automation in 24kV overhead line network without communication between central control unit and local control units is possible. The functions are based on sequences with very few components. The system can be used in pure radial network and in ring network operated as separate radials. The system will considerably reduce the interruption time for the customers.

WHAT IS CENS

CENS is an arrangement who takes into account all incidents in all grid components > 1kV that result in interruptions of duration > 3 minutes. The incident can be caused by a fault in the network or a planned disconnection. CENS means “Cost of Energy Not Supplied”. CENS is based on estimates of energy not supplied(ENS) and average specific interruption costs(c), c is dependent on the customer type, and is divided between residential/agriculture and industrial/commercial customers. At rates as of 2002, the amount of c is for interruptions caused by fault NOK 4 and NOK 50 per kWh respectively. CENS should reflect the interruption costs, that is to say the end users average costs of interruption from the energy supply.

The system is meant to give the net owner an economic motive to provide an socio-economic optimum supply quality.

NETWORK DISTURBANCES

Table 1 gives an indication of invested value, amount of fault and non-delivered energy in regard to the different network parts.

Table 1 states that the MV distribution network is responsible for about 3/4 of all non-delivered energy despite the number of faults being only about 1/3. This indicates that the duration of faulty situation is much longer in the MV network than in the other network parts. This observation only states the fact that the degree of automation in the MV distribution network is fairly low.

If we look in more detail at the fault statistics for the MV network we will find that there is a clear difference between cable- and overhead line networks.

The cable network shows only 2-3 faults pr 100 km and year, mainly permanent faults.

The overhead line network shows up to 20 faults pr 100 km and year. About 6 of the faults will be cleared off by Fast Automatic Reclosing (FAR), and another 6 faults will be cleared off by Delayed Reclosing (DR). However, there still remain about 8 faults of permanent nature.

<table>
<thead>
<tr>
<th>Network part</th>
<th>Investments</th>
<th>Number of faults</th>
<th>Non-delivered energy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Production</td>
<td>40%</td>
<td>3%</td>
<td>17%</td>
</tr>
<tr>
<td>Transmission</td>
<td>22%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MV Network</td>
<td>20%</td>
<td>32%</td>
<td>76%</td>
</tr>
<tr>
<td>LV Network</td>
<td>18%</td>
<td>65%</td>
<td>7%</td>
</tr>
<tr>
<td>Total</td>
<td>130 billion</td>
<td>31000 faults</td>
<td>55 GWh</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Type of failures</th>
<th>Temporary faults cleared by</th>
<th>Permanent faults</th>
<th>Total number of faults</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>FAR</td>
<td>DR</td>
<td>No</td>
</tr>
<tr>
<td>Short circuit</td>
<td>1.4</td>
<td>7</td>
<td>2.0</td>
</tr>
<tr>
<td>Single-phase earthing</td>
<td>4.2</td>
<td>21</td>
<td>3.0</td>
</tr>
<tr>
<td>Others</td>
<td>0.2</td>
<td>1</td>
<td>0.4</td>
</tr>
<tr>
<td>Total number of faults</td>
<td>5.8</td>
<td>29</td>
<td>5.4</td>
</tr>
</tbody>
</table>
Table 2 gives some average values of disturbances related to a typical overhead line network of about 4000-km. In Table 2 the types of fault are divided into main groups e.g. short circuit faults and single-phase earthing. In addition there will be a smaller group of "Others", consisting of double-phase earthing and conductor breakage. Table 2 also shows that about 70% of single-phase earthing will be cleared by auto reclosing, as well as 50% of the short-circuit faults, and very few of the "Other" faults. This indicates that automation in the MV overhead line network should consist of both FAR and DR. Table 2 shows that about the same amount of faults will be cleared off by DR as by FAR.

**MANUAL OPERATION**

**Operating practice**

The dominating method today for operating the above given network configuration will be a kind of local manual control of the sectionalising switches. During a normal line fault situation the procedure can be as follows:

As the fault occurs the circuit breaker will make a quick reclosing operation. If the fault is still present, the circuit breaker will remain open until the operator is ready to close the circuit breaker after being alarmed automatically.

The operator will, as a first attempt, close the circuit breaker to find if the fault is still present.

After this clarification, the network operating crew will be called to go to each sectionalising switch, and prepare the necessary test operations.

The operating sequence can deviate, but the main purpose is to sectionalise the faulty part of the network as quickly as possible. Then the healthy network parts will immediately be reenergized.

As soon as the faulty part is located and the healthy parts of the network are put into normal service, the operating crew or an additional crew will start locating the fault by foot. When the cause of the fault is discovered, they will start the repairing work.

**Interruption times by manual operation**

The total interruption time can be a sum of the following parts:

- Time to alarm the network operator: 10 min
- Time to reach the remote control centre and to do the first remote operation: 20 min
- Time for the network crew to reach the sectionalising switches: 30 min
- Time to carry out the sectionalising of the fault and obtain normal service in healthy network parts: 30 min

**Total interruption time for the healthy network parts:** 90 min

**Total interruption time for the faulty network part:** 150 min

**Cost example according to CENS**

By using the interruption times above, the compensation rates for CENS and the example of network configuration with faults Fig.1 we can give a cost example according to CENS.

Section S6 in Fig.1 can be energised from another network by operation of only one switch.
**LOCAL AUTOMATIC CONTROL SYSTEM**

**Operating function of the local automatic control system SiMAGIK**

An automatic control system for sectionalising and fault locating in MV voltage overhead line network will increase the operating efficiency, and considerably reduce the interruption times.

A specific control system of this type developed by Siemens, called SiMAGIK, will consist of the following units:

- A common central control unit located in the substation to control the operation of the feeding circuit breaker on each overhead radial line during fault.
- A local control unit at each sectionalising point to control the operation of the corresponding switches.
- Both the central unit and the local control units carry out the operation sequence according to a given programme in each control unit, without the need for any communication between the units.
- A local control unit who takes care of the open loop will be useful if the network can be operated from alternative feeding.

Based on the network configuration and the fault situation given in Figure 1, Figure 2 gives a more detailed explanation of the sectionalising sequence. The fault will, in the first place, trip the circuit breaker, E1, which due to normal relay functions makes a FAR. If the fault is still present, E1 will be tripped for a second time, and from this moment on both the central and local control units start their sectionalising programmes.

From Fig. 2 it will be realised that all the switches L1-L5 open up immediately after the FAR. To test the first part of the network (between E1 and L1/L2), the circuit breaker closes after 20 seconds. The switches L1 and L2 sense the reenergising of the line. Due to the programming of the local control unit, the line switch L1 closes after 40 seconds, and meets the fault. All the line switches are equipped with spring closing devices to be able to meet even short circuit faults.

The central control unit trips the circuit breaker E1 as L1 meets the fault, and E1 remains open until 60 seconds. The local control unit in L1 sensed the voltage only a very short time after its closing. This is the indication that L1 met the fault. The local control unit will command the L1 to open up and remain in the open position.

Now the fault in the network behind L1 is sectionalised. After 60 seconds the central control
unit orders the circuit breaker $E_1$ to close again. At the same time as $E_1$ closes, the line switch $L_2$ becomes a closing command from its local control unit. After 80 seconds the line switch $L_3$ closes according to the local control programme. Both $L_2$ and $L_3$ remain closed as the second fault is outside line switch $L_4$, which closes after 100 seconds. As the line switch $L_4$ close, and meet the fault, the circuit breaker $E_1$ opens up and the same procedure is repeated as for the line switch $L_1$. $L_4$ will open up shortly after the opening of $E_1$, and $L_4$ will be blocked, as $L_1$, in the open position. The circuit breaker $E_1$ closes after 120 seconds, and from that moment on the entire healthy network parts are reenergized, and the faulty parts are sectionalised.

The local automatic control operation finishes the sequence by closing the line switch $L_5$ after 150 seconds. Whether the switches outside the fault should be closed or remain open, is dependant upon the possibility of alternative feeding.

The central control unit will, after the completed sequences, inform the stand-by operator, or a control centre, which of the line switch is next to the fault, and what type of fault caused the relay start.

**Influence of the interruption times**

From the functional description of the local automatic system it can be concluded that the interruption time for the healthy network parts will be considerably reduced, compared to normal local manual operation. The total interruption time for the healthy network parts will be reduced from about 90 minutes, by local hand operation, to about 2 minutes by local automatic control.

The faulty part of the network will also gain by local automatic control. When the failure alarm occurs, more precise information about type and location of the fault is available thus the time for the repairing crew to reach the faulty section can be reduced. The total interruption time for the faulty part of the network will be reduced from about 150 minutes to about 90 minutes.

**Cost example according to CENS**

By using the interruption times above, the compensation rates for CENS and the example of network configuration with faults Fig.1 we can give a cost example according to CENS. Section S6 in Fig.1 can automatically be energised from another network which use the same type of local control system.

<table>
<thead>
<tr>
<th>Section</th>
<th>Load (kW)</th>
<th>$c$ (NOK/kWh)</th>
<th>Outage time (h)</th>
<th>Total cost (NOK)</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>1500</td>
<td>50</td>
<td>0(30s)</td>
<td>0</td>
</tr>
<tr>
<td>S2</td>
<td>250</td>
<td>4</td>
<td>1,5</td>
<td>1 500</td>
</tr>
<tr>
<td>S3</td>
<td>375</td>
<td>4</td>
<td>0(60s)</td>
<td>0</td>
</tr>
<tr>
<td>S4</td>
<td>250</td>
<td>4</td>
<td>0(90s)</td>
<td>0</td>
</tr>
<tr>
<td>S5</td>
<td>250</td>
<td>4</td>
<td>1,5</td>
<td>1 500</td>
</tr>
<tr>
<td>S6</td>
<td>150</td>
<td>4</td>
<td>0(150s)</td>
<td>0</td>
</tr>
</tbody>
</table>

Total costs with SiMAGIK: NOK 3 000

**Experiences with the local automatic control system SiMAGIK**

The local automatic control system, SiMAGIK, has up to now been delivered to more than 50 different utilities in Norway and Sweden. These SiMAGIK systems are reasonably small, consisting of one central control unit and a few local control units each. For the Israel Electric Corporation some larger systems have been delivered, where the central control units controls up to 12 circuit breakers, and up to 80 local control units.

The experiences are mainly up to the expectations. Key factors for proper functions are:

- Correct information about existing relay system.
- A complete functional test after installation.

Customer feedback confirms that the SiMAGIK system works effectively, and reduces the outage time to a minimum for the customers.

**CONCLUSION**

By the use of the local automatic control system SiMAGIK the interruption time during permanent faults in the MV distribution network will be reduced from about 90 minutes by manual operation to less than 3 minutes for the healthy network parts. The automatic sequence based SiMAGIK system is far more effective than a manual operated remote control system (sectionalising time < 3 minutes compared to ~45 minutes). The sequence-based system will also have a lower risk of functional failure than a remote control system depending on the actual communication system.
REFERENCES


Tor Cederkvist, Bjørn I. Oftedal: “Automatiske seksjonering: Kommer KILE i forkjøpet!” Energi & Automatisering, 1999