The use of Sectionalising Circuit Breakers in Urban MV Distribution Networks

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Introduction

The UK electricity regulatory body (OFFER) has been monitoring the quality of supply delivered by the Regional Electricity Companies (RECs) since privatisation in 1990. The main parameters used by OFFER to measure the performance of the RECs are:

- Security (supply interruptions per 100 customers)
- Availability (minutes lost per connected customer)

The figures submitted by the RECs are published by OFFER in a yearly report. This information is useful in identifying trends as well as allowing comparison between the performance of the different networks. The RECs have agreed targets with OFFER for security and availability improvements, to be achieved by the year 2000 (see OFFER Report (1)).

Figure 1 - 1996/97 Security and Availability Statistics

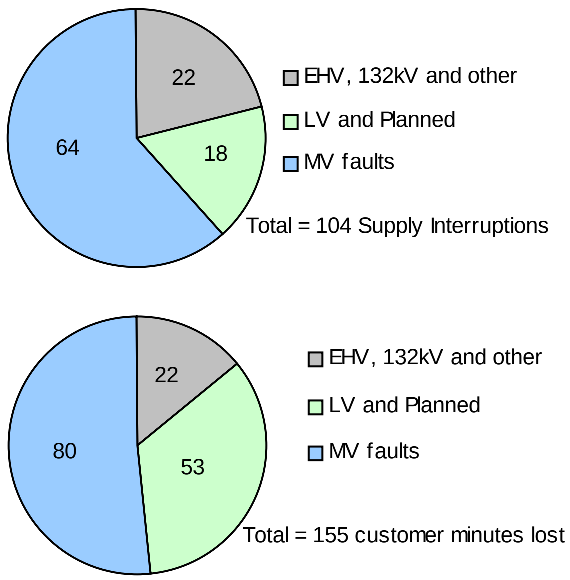


Figure 1 illustrates the crucial role of the MV secondary distribution network in the quality of supply experienced by customers. Over 60% of the interruptions are caused by MV faults.

The 1996/97 OFFER report shows that most RECs have achieved a significant reduction in customer minutes lost. This is mainly due to improvements in the control and operation of MV networks, through improved working practices for planned outages (e.g. use of mobile generators) and investment in telecontrol systems for the distribution network, Hammond, M.. et al (2).

It is worth noting that none of the RECs has shown a significant reduction in the number of interruptions per 100 customers since 1990.

One possible interpretation of this statistic could be that most MV networks are run as open rings. They have a single source of supply and any MV fault causes tripping of the primary feeder breaker, resulting in disconnection of a large number of customers. Some RECs are tackling the problem in the MV overhead line network by installing remotely controlled pole mounted autoreclosers. However, faults on the urban network have the largest impact on security.

This paper analyses the influence of the MV network topology on the quality of supply and proposes possible solutions to improve the current performance of open ring networks. The following points are covered :

- the effectiveness of strategically positioned, remotely controlled sectionalising circuit breakers in improving security and availability in MV open ring networks;
- a possible migration path to MV closed ring networks with unit protection;
- the switchgear, protection and control building blocks required to implement these network schemes.

Closed ring MV distribution network

In closed ring networks more than one HV/MV source is permanently connected to each MV/LV substation using a three circuit breaker arrangement (two cable feeder breakers with unit protection and a transformer feeder breaker with overcurrent and earth fault). In the case of an MV cable fault, only the two breakers at each end of the faulty cable trip and no customers are disconnected. Closed ring networks inherently deliver a very high quality of supply, however, the high cost of switchgear and protection has limited their application.

RMU with directional earth fault indication suitable for closed ring applications

Pilot wire differential unit protection scheme

Pilot wire differential unit protection schemes have traditionally been used in MV closed ring applications. They provide fast (<150 ms) fault clearance times by tripping both breakers at the end of each zone.

The differential principle is based on the comparison of the current magnitudes at each end of the zone. As the relays are a distance apart, metallic pilot wires provide the necessary communication link between them. These have to be laid at the same time as the MV cable.

Directional comparison schemes

The principle of operation is based on the “comparison” of the fault current direction at each end of the protected feeder to establish if the fault is outside or inside the zone, Tobias J. et al, 1997 (4). The ring feeder circuit breakers are equipped with directional overcurrent and earth fault relays capable of giving independent “start” and time delayed outputs for both “forward” and “reverse” directions. In the case of a cable fault all affected directional overcurrent “start” elements pick up and generate a blocking signal, which is sent to the relay upstream of the fault. All relays receive a blocking signal except the two relays at either end of the faulty section, which trip and isolate the fault.

Directional blocking schemes are used extensively in EHV transmission networks. Up until now, the application to MV distribution systems has been limited due to the high cost and space required for conventional electromechanical relays. Modern multifunction numerical relays can achieve all the required functionality in a single device and provide a cost effective solution.

Differential vs directional blocking unit protection

The directional blocking scheme has three inherent advantages compared with differential protection :

- if one of the ring breakers fails to trip the zone extends "outwards" to the next breaker. This avoids tripping the primary feeder and the loss of all the load, as would occur in a differential scheme;
- several RMUs can be included within the protected zone provided that discrimination can be achieved with the tee-off transformer protection;.
- protection signalling is of the "on-off" type so it can be transmitted by means other than pilot wires.

One disadvantage of the directional scheme is the need for a voltage reference. However, the advent of low cost voltage dividers has removed this limitation.

Open ring MV distribution networks

The open ring configuration is the most commonly used topology for MV distribution networks. Open rings are simple to operate and can be implemented using low cost MV switchgear. The ring provides at least two alternative paths to each secondary MV/LV substation fed from it, the maximum number of substations connected to a single ring being typically 20. The MV/LV substations are connected to the ring by load break switches, all of which are closed except one, which is referred to as the Normal Open Point (NOP). Each section of the ring can then be treated as a simple radial feeder, with the only protection being time graded IDMT overcurrent protection at the primary substation. An MV cable fault causes the feeder breaker to trip, disconnecting all MV/LV substations fed from it. Supply can be restored to the healthy part of the system by opening switches at each end of the faulted cable to isolate the fault, closing the primary feeder breaker and the NOP. Traditionally restoration has been achieved manually, a process that takes several hours.

Telecontrol systems enable the restoration of supplies to a large number of customers within minutes by monitoring and controlling a few strategically positioned MV switches, Tobias, J. and Hull, D. (3). This improves availability by reducing the time taken to identify and isolate the faulty network section. However, telecontrol systems do not improve security because the primary feeder breaker trip still takes place.

Improving open ring security

In the past electricity companies have tried to improve the inherent low security of open rings by introducing one or more sectionalising circuit breakers, with time graded overcurrent and earth fault protection, between the primary feeder and the NOP. These schemes did not prove popular due to the following limitations:

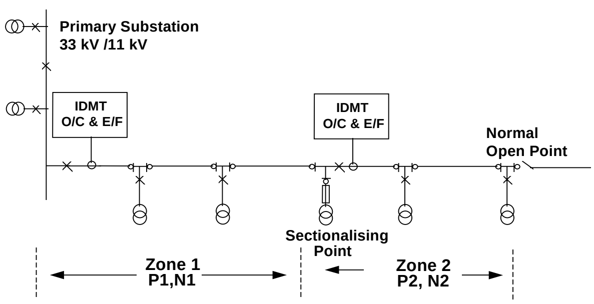
- lack of remote indication of the sectionalising breaker status meant that in case of fault operation customers could be off supply for a long time if nobody alerted the electricity company.
- long fault clearance times at the primary feeder breaker (> 1 sec) stressed the MV cable sheaths and extended the duration of the voltage dip.

Remotely controlled sectionalising circuit breakers with time graded IDMT protection

One of the limitations mentioned above can be overcome by introducing motorised sectionalising circuit breakers equipped with RTUs and telecommunication equipment. This allows the breaker to be remotely monitored and controlled via the SCADA system. Supply restoration can take place within minutes, gaining a significant improvement in security and availability. The telecontrol system can also be used in conjunction with modern numerical relays to alter the IDMT protection settings remotely when the MV network configuration changes.

Figure 2 shows an open ring with a single IDMT time graded sectionalising point, which effectively creates two zones. It does not seem practical to install more than one time graded sectionalising circuit breaker, as it would result in unacceptably long tripping times. The expected improvement in security by implementing this solution is 25 % (see Appendix A).

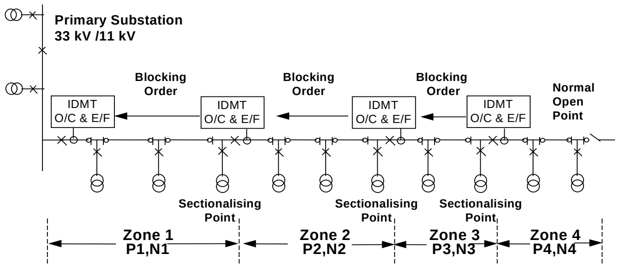
Figure 2
Open ring with single sectionalising point (2 zones) wit
IDMT overcurrent and earth fault protection



IDMT protection with logic selectivity

If further improvement on the open ring performance is required more than two zones are needed. To avoid the penalty of long tripping times overcurrent protection with logic selectivity could be used. In this scheme the IDMT relays at the primary feeder and at the sectionalising breakers need to have a “start” output contact and a “block” input signal. IDMT relays in the sectionalising points have the same setting as the primary feeder, to allow the clearance of any MV/LV transformer fault.

Figure 3
Open ring with 3 sectionalising points (4 zones) with
IDMT protection and logic selectivity



Upon detection of a fault all relays will instantaneously operate their “start” contact to send a signal to the relay up stream to prevent it from tripping. The relay nearest to the fault does not receive a blocking signal and therefore trips. The blocking signal is automatically removed 200 ms after a trip has been issued to provide back up in case the downstream breaker fails to clear the fault. As the relays are a distance apart, a communication channel is required to send the blocking signal.

Figure 3 shows an open ring with three sectionalising circuit breakers with IDMT protection and logic discrimination, effectively creating four zones. This gives probably the highest cost/benefit ratio, with an expected 37% improvement in security (Appendix A).

Migration from open to closed rings

Calculations show that the maximum improvement in security that can be achieved in an open ring with sectionalising is 50%. To improve this further it is necessary to consider closed ring networks. However, any utility wishing to convert an MV open ring system to closed ring with unit protection faces several constraints:

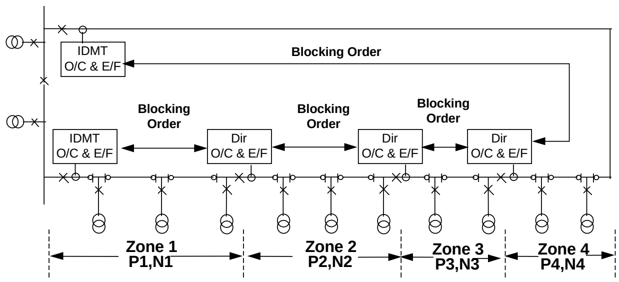
- lack of dedicated pilots for protection signalling.
- possible increase of fault level if primary substations have to run in parallel
- MV cable sections too small to carry the load current

Provided that the "system" constraints can be overcome, it would be possible to migrate from open ring to closed ring using a network model based on unit protected zones that include the existing RMUs. The proposed closed ring network model uses strategically positioned remotely controlled sectionalising circuit breakers with directional blocking unit

Protection. The directional elements have IDMT characteristics to allow co-ordination with the MV/LV transformer protection. The RMUs in the protected zone would require directional fault passage indicators to facilitate the identification of the faulty section. Directional relays may need to be retrofitted to the primary feeders.

In networks where it is not possible to parallel two primary substations, closed rings could be achieved by connecting two feeders from the same primary substation and installing three sectionalising circuit breakers, effectively creating four unit protected zones (see Figure 4). The expected improvement in security by using this arrangement is 75 % (see Appendix A).

Figure 4
Closed ring with 3 sectionalising points (4 zones) with directional logic sensitivity



The system building blocks

Recent advances in technology have changed the possibilities that are available to electricity companies to improve the performance of their MV distribution networks. The main developments are :

- outdoor SF6 fixed circuit breakers available as single units or as part of an RMU;
- microprocessor based protection relays;
- micro RTUs and dedicated control cabinets for the remote control of secondary MV switchgear;
- reliable radio and distribution power line carrier (DPLC) telecommunication systems.

Some examples of new generation equipment that could be used to implement the proposed network models are described below.

Switchgear

Figure 5 illustrates a 630A outdoor SF6 circuit breaker rated 13.8 KV and 1 KA. This unit can be used as a sectionalising circuit breaker as part of an extensible switchboard or as a stand alone unit (i.e. cable in and out).

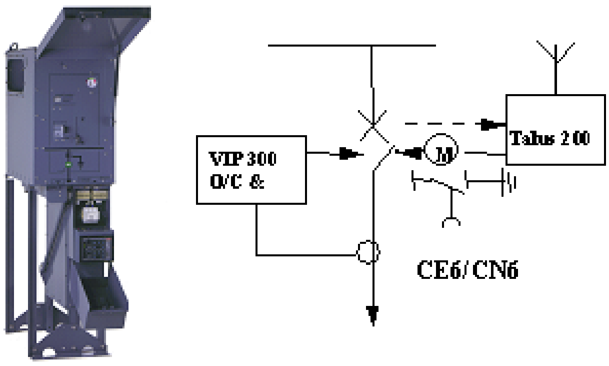
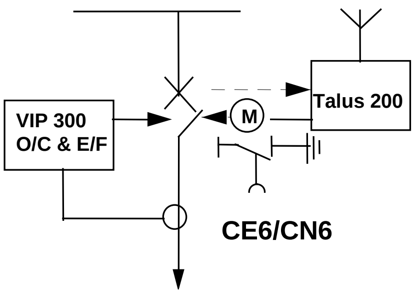


Figure 5
Ringmaster CE6 (extensible) 630A outdoor SF6 remotely controlled sectionalising circuit breaker with integral VIP300 IDMT overcurrent and earth fault relay

Figure 6 illustrates a 13.8KV, 21 KA SF6 RMU with a remotely controlled 630A sectionalising circuit breaker and two load break switches. This can be a cost effective arrangement for an MV/LV substation, using one of the switches to control the transformer.

Both units use SF6 rotating arc technology to provide a three position (On/Off/Earth) switching device in a fixed pattern arrangement. This design provides a "circuit breaker disconnecter" function in the open position and a fault making earth switch in the earth position.

Figure 6 – Ringmaster RN6 Ring Main Unit with 630A motorised sectionalising circuit breaker and integral VIP300 IDMT overcurrent and earth fault relay and Talus 200 remote control cabinet



All switches and sectionalising circuit breakers have fully interlocked cable testing facilities and can be motorised for remote control applications.

The main protection is a self powered IDMT overcurrent and earth fault relay, which is fully integral to the switchgear. The relay derives its power supply from the CTs, that charge an electrolytic capacitor used to release a permanent magnet trip coil. The protection system has an IP rating and operating temperature range suitable for use in outdoor applications.

Alternatively these circuit breakers can be equipped with a dual set CTs suitable to implement pilot wire differential protection schemes. It is also possible to fit VTs to obtain the necessary signals for a directional blocking scheme. In this case the protection relays are indoor rated and they have to be housed in a separate wall mounted relay panel.

Telecontrol cabinets

Figure 7 shows a control cabinet that provides all the functionality required to remotely monitor and control up to four MV switches or circuit breakers. The design uses a modular approach, with a plug -in card arrangement, which minimises the internal wiring. The power supply card incorporates a microprocessor controlled temperature compensated battery charger that provides 12 VDC for the telecommunication equipment and 24 VDC for switchgear operation. It has integral battery testing facility that checks daily the battery's ability to supply a load.

Figure 7
Talus 200 outdoor remote control cabinet for Ringmaster range of secondary switchgear

The plant interface card provides the digital inputs and outputs necessary to control the switchgear. It also incorporates an AC analogue module that provides load current measurement and phase and earth fault passage indication. The control panel module indicates the status of the switchgear and fault passage indicator, allows selection of the operating mode and local operation of the switchgear. The communication card connects the unit to the control centre via the telecommunication equipment. Three protocols are available as standard including IEC 870-5-101. The unit is housed in an outdoor cabinet of compact dimensions and is supplied already connected to the switchgear.

Numerical protection relays

The advent of low cost numerical IDMT overcurrent and earth fault relays with "start" output contacts and "block" input signals has opened up the possibility to use logic selectivity schemes based on blocking for open ring applications. An example of such device is shown in Figure 8.

Figure 8
Sepam 1000 numerical IDMT O/C and E/F relay with logic selectivity (back) and Sepam 2000 multifunction numerical relay suitable for directional blocking (front)

Directional blocking schemes can be implemented using programmable numerical relays which provide all the functionality required in a single hardware box. (see Figure 8). The digital inputs are used to monitor switchgear status and receive the blocking and intertrip signals. The relay outputs are used to trip and close the circuit breakers and to send the blocking signals. The directional blocking logic is programmed using ladder language. This facility is essential to implement the complex logic conditions for tripping and blocking as well as to provide switchgear monitoring functions such as trip circuit supervision, VT supervision, SF6 gas low, etc. Facilities to carry out remote testing of the blocking scheme can also be incorporated

Protection signalling

The implementation of the blocking schemes for open and closed ring operation needs “on-off” type signals to be conveyed between the relays at each end of the protected zone. The blocking signals transmission equipment requires :

- Fast operation to reduce fault clearance time
- High dependability (absence of blocking signal would cause erroneous tripping).

If a dedicated VF channel is available at every sectionalising point one of the solutions is to use frequency shift key (FSK) modem. In this technique the transmitter sends a continuous “guard” frequency which holds the receiver in the non operated state and, at the same time, it provides the basis for the continuous monitoring of the VF communication channel. The blocking signal generated by the protection relay causes the transmitter frequency to shift to the “block” tone. A high speed frequency discriminator in the receiver at the remote end responds to the “block” tone, causing the output contact to operate.

Most RECs do not have dedicated pilots between MV/LV substation. Preliminary studies indicate that it is feasible to achieve the required performance using licensed radio channels or distribution power line carrier. This would open the possibility to “retrofit” unit protection to open ring networks.

Conclusion

Further improvements in network security could be achieved by the use of remotely controlled sectionalising circuit breakers operating in open or closed rings.

Distribution companies that are planning a switchgear asset replacement program could have an opportunity to enhance the inherent quality of supply of their MV urban networks with minimal additional investment.

References

1) OFFER, “Report on Distribution and Transmission System Performance” 1996/97
2) Hammond, M et al., 1997 “Implementation of automatic post fault reconfiguration in a MV distribution system”, DA/DSM Europe
3) Tobias, J. et al., 1994, “The building blocks of a distribution telecontrol system”, IEE Conf Pub No 400,
4) Tobias, J. et al., 1997“ Improved quality of supply in MV distribution networks using directional blocking scheme” CIRED 97 Paper 4.29, IEE Pub No 438

Appendix A. Security Improvement Using Sectionalising Circuit Breakers

Assuming that the number of customers (Nx) and the probability of fault (Px) is the same in each zone, it is possible to calculate the average number of customers disconnected for a fault anywhere in the network. This can be used to give the expected improvement in security compared with the conventional open ring. The results are summarised in table 1:

Table 1.

Open Ring With Sectionalising			Closed Ring With Sectionalising		
No. of zones	Average number of customers disconnected	Security Improvement	No. of zones	Average number of customers disconnected	Security Improvement
2	P1* (N1+N2)+P2*N2	25%	2	P1*N1+P2*N2	50%
3	P1*(N1+N2+N3)+ P2*(N1+N2)+P3*N3	33%	3	P1*N1+P2*N2+P3*N3	66%
4	P1*(N1+N2+N3+N4)+ P2*(N1+N2+N3)+ P3*(N1+N2)+P4*(N4)	37%	4	P1*N1+P2*N2+P3*N3+ P4*(N4)	75%

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