AUTOMATED CLOSED LOOP UNDERGROUND DISTRIBUTION FOR SUPPLYING SENSITIVE LOADS

Ermínio C.BELVEDERE
AES Eletropaulo – Brazil
erminio.belvedere@aes.com

Antonio P. CUNHA
SINAPSIS Inovação em Energia – Brazil
antonio.cunha@sinapsisenergia.com

Plácido A. BRUNHEROTO
REDENEL - Brazil
pab@solarys.eng.br

Denílson VAROLO
AES Eletropaulo – Brazil
denilson.varolo@aes.com

Bruno L. S. LIMA
SINAPSIS Inovação em Energia – Brazil
bruno.lima@sinapsisenergia.com

João J. S. OLIVEIRA
REDENEL - Brazil
jocal@unysis.com

ABSTRACT

This paper describes the introduction of a new topology for underground distribution in Sao Paulo city based on normally closed primary loop and automated switches.

The work was focused initially on converting an existing primary selective system for supplying customers, which are sensitive even to short interruptions due to load transfer and the return to the normal operating condition.

A case study involving 21 kV circuits from the same substation has been carried out in order to evaluate feasibility, benefits and drawbacks of the new topology.

Protection, automation and monitoring schemes specifically designed for underground applications to take into account faults clearing and loading changes in a closed loop have been also proposed in order to achieve a complete solution.

Due to the benefits of the closed loop this topology emerged as a new standard for underground distribution in AES Eletropaulo concession area.

INTRODUCTION

The underground distribution in Sao Paulo has proceeded by using traditional topologies as distributed secondary network, spot network and primary selective systems.

A hybrid configuration has been introduced a few years ago [1] as an alternative for reducing the capital expenditures associated to the conventional secondary network.

While the hitherto initiatives have been focused on the improvement of the quality of supply due to permanent faults [2], the present work has been driven by avoiding momentary interruptions of sensitive customers.

Presently, many customers with demand in excess of approximately 2.0 MVA are connected through a load transfer scheme, which causes a first interruption, when switching from main feeder to reserve one, and secondly for returning to normal operating condition.

Another motivation is to explore new topologies feasible for underground distribution in new areas which demand better quality of service with limited capital expenditures.

TOPOLOGIES

Although primary closed loop are known, there are different possibilities for their implementation. The chosen topology involves advantages and disadvantages as presented hereafter.

For simplicity the discussion did not involve the connections to the substation transformers. For better reliability each main feeder could be fed by a separate transformer, assuming small angle or voltage differences in order to avoid current circulation within the loop.

Main feeder topologies

Single primary loop

In a single loop configuration (figure 1) all customers are connected in series by automated switches with circuit breakers. As a consequence, loading and voltage may be unevenly distributed along the circuit.

From the reliability point of view the disconnection of one customer – due to internal fault or for maintenance purposes – results in one feeding path for the other ones.

The advantage of this topology is that the feeders can follow different routes, avoiding simultaneous failures by digging.

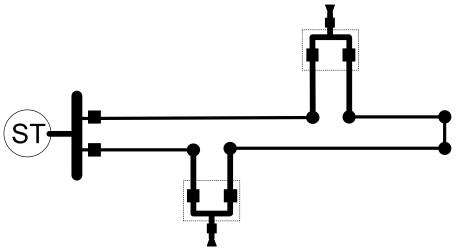

Figure 1 – Single loop main feeder representation.

Parallel primary loops

Such arrangement, showed in the figure 2, requires the main feeders sharing the same route, as usual for primary selective systems. Taking the probability of digs into account this may be a disadvantage.

On the other hand a particular customer can be switched off while keeping the feeding for the others in loop configuration.

Another advantage with respect to a single loop is the better load distribution, with improved voltage profile, losses and cable sizing.

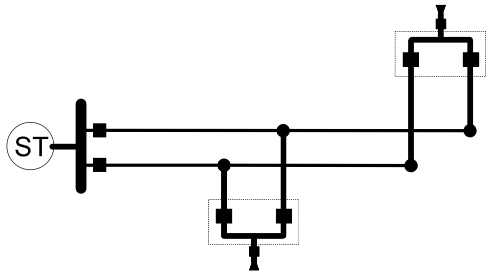

Figure 2 – Topology with parallel primary loops.

Topologies of the laterals

Normally open loop

Open loops can be added downstream the automated switches for connecting transformer in vaults, which usually supply smaller customers.

This topology aims to obtain savings in the cost of the switches because lateral open loop uses simpler equipment. Another benefit is to avoid effects in the main primary loop due to faults in such customers.

Figure 3 shows a sketch of this alternative for the particular case of main parallel loops, but the application of the concept to a single loop is completely similar.

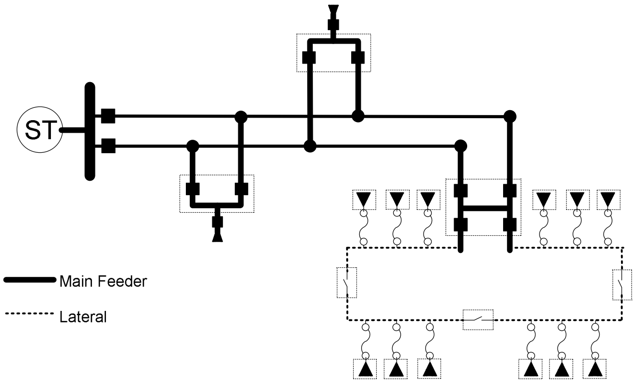

Figure 3 – Supplying of smaller loads with a lateral open loop through a four-way switch.

Radial

Another simpler alternative is just supplying the transformers within vaults in radial configuration. In such case a failure in the lateral will disconnect all customers downstream the automated switch.

PROTECTION AND AUTOMATION

Protection

Since the primary loop provides two paths for a fault, the complete isolation of the failed section requires the opening of more than one protective device.

The usual protection scheme for a closed loop is done with directional current relays.

Figure 4 presents an example of fault in a parallel loop system isolated by switching off four breakers.

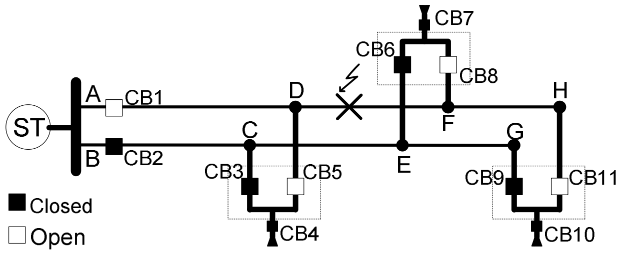

Figure 4 – Example of clearing a fault in section DF.

In table 1 it´s shown the same combination of switching off holds for faults in other sections of the same primary feeder, while for the other one the solution is dual.

Table 1 – Status of the circuit breakers for faults in indicated sections (O open, C closed).

Sections	Circuit Breaker							
	CB1	CB2	CB3	CB4	CB5	CB6	CB7	CB8
AD, DF, FH	O	C	C	O	C	O	C	O
BC, CE, EG	C	O	O	C	O	C	O	C

Therefore, the protection can also be carried out by coordinating the actuation of groups of automated switches either locally or centrally.

Although a central control requires communication among switches, it was preferred considering the relatively small area of the network and other automation benefits.

The local logic of opening may be used as a backup by taking advantage of voltage sensors on both sides of automated switches.

Automation

The automation in the present project deals with functions for loading control, fault location and management of the transformer vaults.

Loading control

This function uses the current sensors data from the switches combined with cable temperature measurements in order to control normal or contingency loading.

Fault location

The situation described in figure 4 – with the opening of four breakers - does not help the identification of the faulty section. Thus, a fault location algorithm is needed to complement the protection. The measurements of current and voltage from the sensors of the switches combined with previously performed calculations are used for this purpose.

Management of the vaults

The management of the transformer vaults involves safety and security issues, which in turn can contribute for operation efficiency. In order to accomplish this objective alarm intrusion, water level, and gas presence sensors have been foreseen.

Architecture

The collected data is intended to be processed at Brigadeiro Substation and sent to the Operations Center for decision support in quasi real time (figure 5).

Only the most important information is intended to be displayed on-line by the SCADA. Most alarms are for logging and afterwards evaluation.

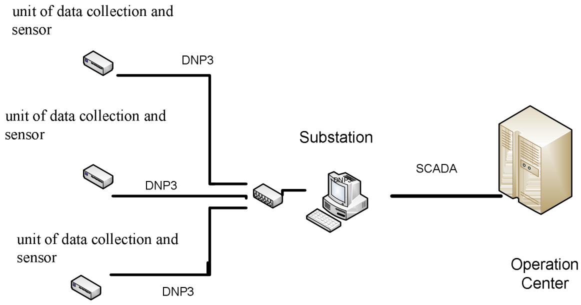

Figure 5 – Automation architecture scheme.

CASE STUDY

Selection of the network

After careful consideration among several possible networks, two 21 kV primary selective circuits from Brigadeiro Substation have chosen for retrofitting due to the sensitivity to short interruptions of their customers. The supply of a new load, 3.5 MVA, and the need to convert overhead circuits to underground in the same area (figure 6) have contributed to the decision also.

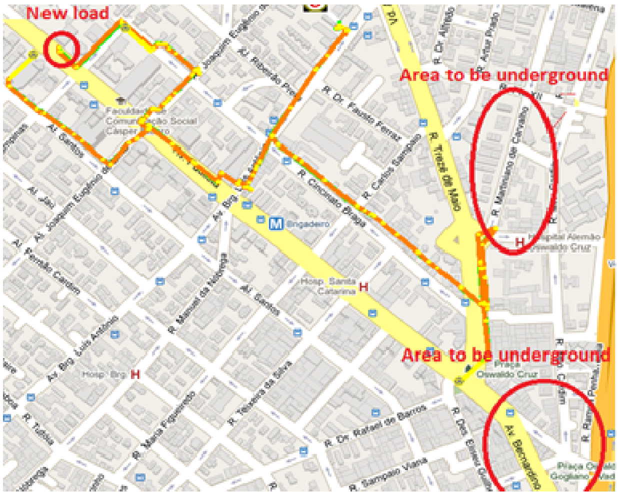

Figure 6 – Area of the project.

Proposed design and simulations

Taking into account the original circuit is a primary selective, the topology with parallel loops was a natural proposal.

The conceptual design has been made after field visits to select proper places for connecting new loads or installing the switches.

Measurements of the existing loads have been taken and the forecasted growth limited the demand of transformer in vaults to 75 % of their nominal power.

The simulations of power flow, short-circuits and reliability indices have been made using a software package previously developed (sinap t&d [3]).

In order to evaluate impacts and benefits some comparisons with the previous primary selective connection is presented.

Loading and losses

Figure 7 shows a schematic representation of the closed loop, including the new concentrated load as well as the vaults of the street whose network is to be undergrounded.

Standardized AES Eletropaulo cable sizes have been adopted: 240 mm^2 for main primary feeder and 70 mm^2 for lateral downstream switches (both are copper conductor, EPR-insulated, 15/25 kV).

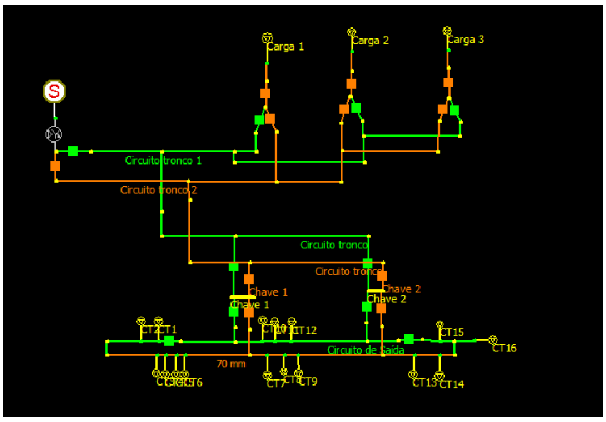

Figure 7 – Closed loop schematic representation.

In such configuration the loading of both feeders resulted well balanced as can be seen in figure 8 and table 2.

Note that primary selective cables are 300 mm^2 PILC-insulated 20/35 kV with slightly different current ratings.

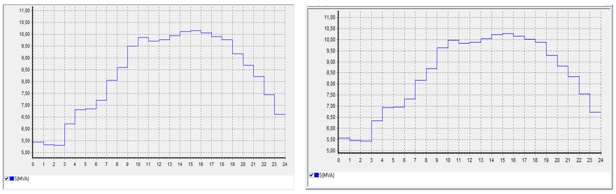

Figure 8 – Loading of feeders 1 (left) and 2 in a closed loop configuration.

Table 2 – Normal condition loading.

Circuit	Primary selective		Closed loop	
	Peak (A)	Rated (%)	Peak (A)	Rated (%)
1	60.6	30.6	279.8	62.2
2	360.0	80.7	282.6	63.0

In spite of the increment of total supplied loads, the benefit of the normally closed loop can be evaluated by the results shown in table 3.

Table 3 – Comparison of annual losses.

Circuit	Primary selective		Closed loop	
	Energy (kWh)	Index (%)	Energy (kWh)	Index (%)
1	3212	0,68	8976	1,56
2	8346	2,09	8446	1,59

The load in a contingency condition in one feeder of the closed loop is presented in table 4. Considering the thermal transient of this kind of installation and the 130 °C limit of the EPR-insulated cables the allowable period of contingency exceeds the necessary for maintenances or repairs.

Table 4 – Load during contingency of one feeder.

Circuit	Peak load (A)
1	561.7
2	562.1

Voltage profile

Due to the characteristics of the circuits, with low impedance e length less than 2 km, voltage profile is essentially the same after retrofitting to a closed loop.

Short-circuit

Table 5 shows a comparison of three phase short circuit levels at different points of the circuit.

As expected the closed loop configuration tends to increase short circuit levels. Taking into account 12.5 kA rating of the switches such values poses no harm.

Table 5 – Short circuit currents (kA)

Point	Primary selective	Closed loop
Load 1	9.452	10.557
Load 2	9,355	10.345
Load 3	-	10.112
Transf. vault 1	-	9.802
Transf. vault 6	-	9.614

Continuity indices

This simulation is done a priori, by assigning expected failures rates by each equipment or km of cable and their respective times to repair. The real network configuration, loads and number of customers supplied are taken into account in a modified minimum cut-set algorithm for predicting indices as average interruption duration (SAIDI) and average interruption frequency (SAIFI) or non distributed energy (ENS). Tables 6 and 7 show conservative values obtained using 0.03 failures/km/year failure rates and 12 h mean repair time. Although the initial motivation for the introduction of a closed loop topology had been the momentary faults, the whole reliability is improved.

Table 6 – Simulated a priori SAIDI indices (h/year).

Load	Primary selective	Closed loop
Load 1	2.078	0.367
Load 2	2.127	0.367

Table 7 – Simulated a priori SAIFI indexes (1/year).

Load	Primary selective	Closed loop
Load 1	0.884	0.300
Load 2	0.874	0.300

ECONOMICS

In addition to the elimination of blinks due to load transfer and subsequent return, the retrofit of the existing primary selective topology by a normally closed loop reduces the losses and energy non distributed.

Such benefits in the present application are expected to be significant based on kind of the customers supplied and simulated savings. Furthermore, there are limited civil works to be done what contributes for the economical feasibility of the project.

Notwithstanding, the comparison with current underground standardization should be performed in real conditions, the primary closed loop, as proposed in this work, has potential advantages of reducing secondary cable length and eliminating protector networks, while keeping a similar first-contingency reliability.

FUTURE EXTENSION

As a subject for future extension of the present work is the implementation of primary closed loop involving different substations.

CONCLUSIONS

A design of a topology with primary feeders and laterals, respectively, in closed and open loop configurations have been proposed for a real application in AES Eletropaulo.

The results of the simulations have confirmed the feasibility and technical improvements.

The retrofit activities on two circuits are currently in course for implementing the designed solution.

REFERENCES

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[3] Gemignani M. M. F. et al., 2009, "Optimization of the Underground Grid Network System in Sao Paulo", *CIRED.*