# UNDERGROUND DISTRIBUTION HYBRID SYSTEM

**M. R. GOUVÊA, R.F. COSTA**
**ENERQ/USP – Brazil**
gouvea@pea.usp.br , rfcosta@pea.usp.br

**A.P. BRUNHEROTO**
**Servel Engenharia – Brazil**
servel@terra.com.br

**E. C. BELVEDERE, J.J. OLIVEIRA, P.E. MASCIGRANDE, C.E.P. MAGALHÃES**
**Aes Eletropaulo – Brazil**
belvedere@AES.com , joao.oliveira@AES.com , mascigrande@aes.com , cassio.magalhaes@AES.comT

## *INTRODUCTION*

*The "network" system in underground distribution applied in several areas of Eletropaulo and is constituted by secondary nets in mesh, supplied by radial feeders and protected by breakers of low voltage(LV), with directional relay, coupled to each transformer, whose basic function is interrupting the feeding of primary net failures for inverse power flow comes from secondary net.*

*Although it offers high reliability degree, configuration net presents a high cost for counting with great reservation transformers capacity and MV/LV net, beyond of protection devices mentioned - "network protector" - whose cost is also very high.*

*Looking for solutions to improve the efficiency and the cost of their installations, Eletropaulo and Enerq/EPUSP developed a study, related in this article, where they are proposed and analyzed configurations alternatives deriving from configuration "network", without of the network protector and can be applied gradually and regarding radially secundary net, conventional protections and use in underground primary switch transfer automatically, the transformer feeding when primary fails.*

*The application of the results obtained is presented in a pilot net located at the old downtown of São Paulo's city.*

*The studies and researches form developed in the extent of the Program of Research and Technological Development of Eletropaulo - Cycle 2001/2002 - entitled "Hybrid development patterns for underground nets".*

## OBJECTIVE

This article intend to present a methodology and the procedures to determine a new configuration of distribution underground system , that it was gradually able to eliminate the use of the network protector, in the present system.

Special attention was dedicated to the hybrid system, where mash radial secondary nets are supplyied by the same primary feeder..

## ELETROPAULO UNDERGROUND DISTRIBUTION NETWORK SYSTEM

The object of this work is the distribution system of Eletropaulo which main characteristics are the following ones:

- Quantity of supplyied consumers: 120 thousand
  transformers MV/LV:
  installed capacity: 1300 MVA
  quantity: 2300 units
  nominal capacity: 500 kVA or 750 kVA
- submergible in vaults with ventilation forced;
- Feeders net
  Quantity of feeder: 60
  Primary voltage: 21 kV
  Length feeder: 2950 km
  Predominant cable:3x1x70 mm2, XLPE, in ducts
- Secondary nets
  Secondary net's length: 4800 km
  Secondary voltage: 208/120 V

## ADOPTED METHODOLOGY

The adopted methodology consists of the following stages:

1rst Stage: Evaluation criteria and proposal of derived topologies of network - Initially, the concepts were established and basic criteria for analysis of merit from different configurations of underground distribution nets like operational aspects, protection, reliability, expansion costs and maintenance, including the replacement of equipments. Alternative net configurations were proposed, that could derive from network system to others, that meet the conditions of supply quality and cost.

2nd Stage: Analysis of the Alternatives – Once the concepts, criteria and patterns were established in previous stage, the behavior of the proposed configurations, in normal condition and contingency, considering switching, protection and of reliability. Simultaneously to performance analysis, switching and protection equipments in the national and foreign market were considered.

3rd Stage: Technical and economical analysis - The economical analysis of the configurations *versus* technical behavior, yield to merit evaluation of each configuration pattern and their components, making possible the selection and definition of the most appropriate pattern. It is important to point out that the possibility of components and equipments nationalization was considered as relevant aspect.

4th Stage: Basic specification of the experimental net, design criteria, analysis of the behavior and guidelines for implementation - Based on the technical and economical analyses of configuration proposed, in this stage an

experimental net was defined and its behavior was analyzed by studies and simulations in several operative conditions. The design criteria and basic specification of the experimental net were established, considering the configuration, electrical system, switching and protection equipments, as well as the implementation guidelines, by means of the elaboration of a "Design and Implementation Handbook".

## CONFIGURANTIONS PROPOSED

The configurations of considered underground nets are:

A) Network - It consists of a system of radial feeders that supplies secondary nets in mesh, through transformers equipped with network protectors that interrupt the circuit when current circulates in inverse direction (feeding by the secondary).

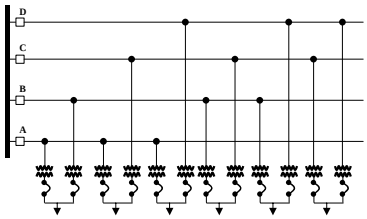

Illustration 1 - Underground Network topology - Network (feeder)

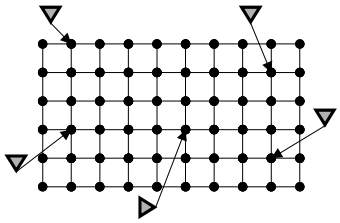

Illustration 2 - Underground Network topology - Network (secondary in mesh).

B) Primary Selective - It is similar to the network as for the function because it supplies blocks of loads. The transfer switch operates automatically or manually when there is a primary failure, changing the feeder. The associated secondary net operates in radial configuration.

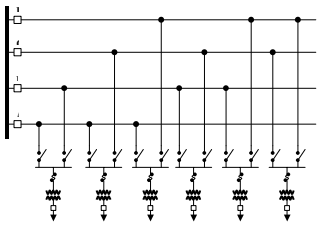

Illustration 3 - Underground Network topology - Primary Selective.

C) Radial with Alternative Source or Open Ring - The feeders operate as radials, with feeding transfer in transformers when there is a failure. The primary net dimensioning should foresee the operation with any part out of service. The secondary net operates in radial configuration.

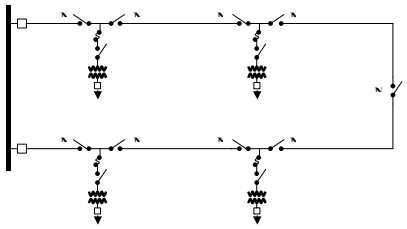

Illustration 4 - Underground Network topology - Open Ring.

d) Hybrid System - It operates simultaneously in network and primary selective.

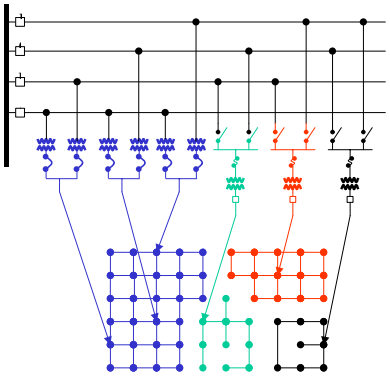

Illustration 5 - Underground Network topology - Hybrid System.

## EVALUATION STANDARD

The evaluation of topologies was accomplished through the economical and technical evaluation of planning, operation/protection and reliability:

### Criteria of Economical Evaluation

The cost of each alternative is calculated being computed the service annual cost, composed by the sum of installation costs, losses, operation and not-supplied energy. The not-supplied energy represents the lost income resulting from interruption and the damages to the community in general.

### Criteria of Technical Behavior Evaluation

It was established the following criteria of technical behavior evaluation:

### Planning criteria

The planning criteria establish the analysis guidelines for behavior evaluation in the net on loading and voltage in cables and transformers, when operating in permanent regime and contingency. Normal condition is understood as the operative situation in which all the components of the net are in conditions to operate. Simple contingency occurs when only one transformer or net part is unable to operate.

Net part is the group of cables belonging to an electric circuit between two transfer equipments capable to isolate the fault without permanent discontinuity in supplying, except to those parts connected to the part out of operation.

A solution for a net configuration supplying a load is considered acceptable if it meets the following planning criteria:

A) Voltage Levels

Based on the regulatory and engineering rules, the following restrictions of voltage are established:
- maximum voltage levels that should be observed in normal condition of operation, for primary and secondary net ;
- maximum and minimum voltage levels that should be observed in conditions of simple contingency in the primary or in the secondary;
- maximum value of voltage fluctuation in permanent regime in the part of normal condition for simple contingency;
- maximum value of voltage unbalance among busses of the primary net should not cross the limit value that makes possible the operation of the network protector, when there is no failure in the primary net.

B) Loading Levels

- Cables - the acceptable maximum currents in cables are established obeying the limits, in function of national and international norms, to the eletrical features used;
- Transformers - The maximum loadind adopted derives from of loading curve, to not allow loss life of the equipment in normal and emergency condition.

Studies should be optimized in wich contingencies that overload transformers are not often.

**Criteria of operation and protection**

The operation criteria and protection adopted foresee a tolerable maximum amount of switch transfers in primary net and in fuses boxes for reconfiguration of secondary net, when a failure provokes the disconection of net parts. The primary switch transfer can be automatic or not.

Primary feeders failures from a proposed configuration is admitted that there is a soon interruption of supplying, to a manual or automatic transfer, setting the system up to operate in condition of first contingency. Also an acceptable maximum period to operate in normal configuration was defined, including the time of teams preparation, location, repair and re-establishment. The parameters involved to define those limits were:
- Displacement medium velocity;
- Transfering medium time of underground primary switch
- Verification medium time of defect indicator
- Testing medium time for failure location
- Repairing medium time of primary cable

Secondary net failures in radial or in mesh, it is permited the temporary interruption of supplying, in parts not affected by the failure, during an established maximum period and should be prepared the teams, failure localization, isolation of the part failed and supplying, operating the link boxes or generators transported by car to the event place. The transformers are included in the secondary nets. Besides the parameters above considered, to the time calculation of primary net supplying, the parameters of secondary net, follow below:
- Open/close medium time of link box
- Repairing medium time of secondary cable

Protection system should present devices that:
- Assure that failures in one of the feeders of primary net not provoke the shut down of other;
- Allow that transformers failures can provoke temporary failure operation of others that supplyind the same secondary net, until to the elimination of transformer in fail and to establish the service again;
- Assure that secondary net failures not provoke the shut down of primary feeder;
- Assure that secondary net failures not provoke the transformer shut down that feeds its;
- Assure that secondary net failures not impede to supply of the others consumers, after the identification and isolation of branch in failure;
- Impede the automatic shut on after a shut down;
- Allow the integrity of all net components, in short circuit or overload cases, except in specific situations where it is foreseen explicitly burns free from part as resource to eliminate the failure.

**Criteria of reliability**

The evaluation, as reliability levels of each solution of proposed configuration, it is accomplished through its behaviour for the service continuity that it offers. Considering the expected failure taxes for each component, the repairing time, continuity indexes that check the merit of each net topology and the consumers affected in each interruption.

The continuity indexes that check the merit of each alternative applied are: DEC and FEC and the service time to supply the affected is an index of merit of configuration in analysis.

The maximum values admitted to the net indicators are based in the values limits for control groups foreseen by ANEEL.

**OBTAINED RESULTS**

The proposed network topologies were applied to a typical pilot area of Eletropaulo and analyzed by established criteria in previous stage, obtained the following results

**By Technical Acting**

A) Criteria of Planning

The studies accomplished about the behavior of proposed configurations, operating in normal and contingency simple condition indicates that voltage levels are appropriate. However, the best choice is network configuration, justified for presenting secondary net in mesh and redundancy of transformers.

It was not observed overloads because the cables of the secondary net and transformers were measured appropriately.

In situations of contingency feeders in hybrid system where there is an unbalance among feeders provoked by the transfer of feeders, in network protectors can operate in a wrong way because the light loadings and traveled by inverse flows.

B) Operation and protection

The proposed configurations were satisfactory as the operation and protection of system primary, preferentially for the system network, since the redundancy of installations and the sophistication of network protectors make possible the automatism in operation and protection.

The other proposed configurations request automatism in transfering switch or demand the human interference in switching feeders, when there is a primary net failure.

The failures occurrence in secondary net there is an advantage to the network system, in supplying service. In that system there is no interruption service, while in the other ones, it is necessary to displacement the teams to identificate of part in failure and repairing actions, with all of consequences of interruption time due to the radial net.

Some protection subjects of nets radial deserve a detailed study, such as: protection coordination in overloads transformers and the system areas vulnerability, faced to high impedance failures. The immediate solutions involve the use of fuses of high cost and current breakers.

C) Reliability

The reliability associated to each one of the configurations is determined by the frequency and duration of interruption of service, due the corretive maintenance to establish of supplying, when there is failure in some net component or for the interruption the outages from necessity preventive maintenance or expansion/refurbishment works.

The service interruptions from preventive maintenances or expansion/refurbishment works it is not necessary to analyse, because it is not usual to interrupt the supplying, and the possibilities of resources, to avoid the interruption. Besides, the similarity of nature and amount of present components in several net configurations proposed and the same expansion possibility also competes for the disregard of that aspect in comparative analysis of reliability offers.

So, remains analyze the effect of corrective maintenance in reliability of each one of configurations that is, components function and redundancies of characteristic resources present. The accomplished analysis was preceded, considering the defects in the primary net, in secondary net and in the transformers. Also some were mentioned considerations about failures in transfer equipments.

Considering an area to be assisted, alternatively for each one of net configurations proposed, it is possible to affirm that primary net failures of each one configurations provoke similar interruption levels, one time that:
- Failure tax in cables of average tension is very low;
- Primary length net of analyzed configurations is similar and failures impact is practically the same, because in all of the cases there will be automatic transfer of the load for a healthy feeder, when there is failure in preferential feeder.

Obviously, the configuration in network presents advantage of automatic transfer load, and in the others is manual way.

Failures in underground and submergible transformers is not usual, but those occurrences offer a small advantage to the network system because the loss of a transformer with this topology doesn't implicate in interruption, in other hand any other configurations there will be service interruption. The interruption just affects the consumers supplyed by the transformer with defect and it is prolonged for the period necessary to connect a generator, permanently available for that purpose in Eletropaulo.

The failures in secondary nets can be seen in way similar to transformers: advantage to the network system, continuity practically absolute of service because of redundancy and network protectors. However, advantage is not a lot significant, because even if the time of failure location in the other configurations is relatively long (the average can be in 4 hours), the failure tax of secondary underground cables is short, the affected area is relatively restricted and the possibility of installation of emergency service to the affected consumers start from way boxes guarantees the radial configurations.

**Economical Acting**

The Economical Evaluation of alternatives of configuration was considered the implementation in several net configurations proposed, that differential costs of each alternative were calculated.

In this work an important point was the orientation of study for real nets and loads of Eletropaulo, where traditionally network system has been operated, with all the associated structures. Thus, in a searching to an appropriate solution to expansion of nets or revitalization, considering the possible alternatives of patterns innovation.

Therefore, it is necessary to considered outline conditions different from a theoretical study, where application is generic and uncommitted with existent structures, and the possibilities of innovations. Considering the work mentioned above, many elements of underground system are common all of the types of proposed configurations, where there are differences of patterns that it can be neglectful in a comparative economical analysis.

It was studied the nets: network, primary selective and hybrid net, once the radial net with resource can be seen as a case peculiar of the primary selective, since there is no load limitation in the primary net, as in case of Eletropaulo.

The common elements in the network system, primary selective and hybrid net, they are shown in the next illustration:

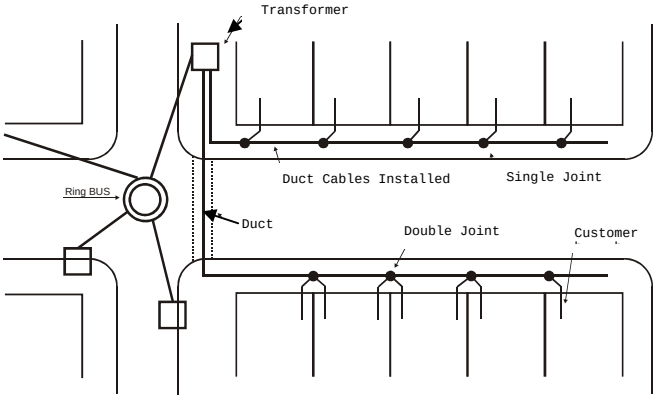


Illustration 6 - Elements common to all of the configurations of considered Net.

The structural difference among those 3 configurations is in the transformtion capacity and the civil structures, in switching and protection equipments associated to the transformers: network protector and automatic switch transfer.

The differential economical among those configurations it is defined for the facilities. The redundancy of transformers in the network system requests a transformer capacity superior in primary selective and hybrid net too.

Considering typical configurations and medium costs of submergible transformers also, network protectors, underground vaults and switch transfer ; the relationship of facilities cost among the configuration network and primary selective it locates around 2, varying of 1,4 in preservative situations to 2,9 in more optimistic conditions.

The difference among the costs of two net configurations, ally to the failures taxes in underground nets, indicate the largest reliability level than the configuration network offers in the primary selective.

## PILOT NET

The area to the implementation of the experimental pilot net is in the old São Paulo downtown (Square of the Cathedral and adjacencies) supplyed network system, with 4 feeders from the Riachuelo Substation in voltage out of pattern (3,8 kV), that it will be converted to 21 kV and supplyed by Miguel Reale Station with the following characteristics:

a. Approximated area: 0,36 km2;
b. Consumers in low voltage: 4200;
c.100 transformers of 500 kVA and 750 kVA;
d. Installed capacity: 53 MVA

## CONCLUSIONS

The technical and economical analysis of configurations alternatives of underground nets allows concluding for the viability of gradual transformation of network system to the configuration selective primary system, constituting the Hybrid System.

Migration is accomplished through the radialization of secondary nets supplyed by transformers in primary net and automatic transfer switch. The simultaneous operation of two types of configurations in secondary nets - in mesh with network protectors and radial with conventional protection - supplyed by the same system of primary feeders was shown appropriate.

The opportunity of improvements was verified in that system, that motivates future developments, such as:

- Searching for inexpensive fuses to protect low impedance failures;
- Nationalize of transfer switch;
- Optimize transformers loading and the quantaty of units supplyed by the same transfer switch;
- Development of economical systems of automation and supervision with the use of failure indicators.

All of the analyzed configurations assist the established technical requirements, secondary in mesh - network - it presents larger reliability level and cost.

## REFERENCES

[1] Rural Electric Research – National Rural Electric Cooperative Association.
[2] Underground System Guide – Reference Book - Edison Electric Institute – 1957
[3] National Electrical Safety Code, IEEE - Institute of Electrical and Electronics Engineers, Inc - 1993
[4] Improving URD Reliability Using Predictive Techniques - Marti T. Bishop, Chis A. McCarthy, Dennis A. Walder - Cooper Power Systems 1998
[5] Overcurrent Protection Alternatives for Underground Distribution Systems - Marti T. Bishop, A. G. Jones, W.F. Israel - IEEE 1994 – Transmisión and Distribution Conference
[6] Innovations in use of Microprocessor Relays and Controls for Improved Reliability on the Distribution System - J.C. Appleyard, D. A. Myers, J. K. Niemira - IEEE 2001 – Transmission and Distribution Conference
[7] IEEE standard requirements for over-head, pad-mounted, dry-vault; andsubmersible automatic line seccionalizer for AC systems; Switchgear Committee of the IEEE Power Engeneering Society, USA – 1997
[8] Design of electrical interface: utility to critical load facility; - Kusko Alex; Ayoub Jean - INTELEC Internacional Tele Energy Conference – 2000
[9] High voltage automatic transfer switch, Going beyond normal distribution solucion- Simmons-RA Salem-FJ - Ninth Internacional Conference on Harmonics and Quality Power An application of high speed automatic transfer switch - Grebchenko NV Nuri-A; Elektrichestvo july 1997
[10] Overcurrent protection alternatives for underground distribution systems Bishop MT; Jones AG; Israel WF - Cooper Power Systems, Franksville,WI USA