AUTOMATION AS RESOURCE FOR DISTRIBUTION SYSTEMS PLANNING

Marcos R. GOUVÊA, Daniel P. DUARTE, Antônio P. CUNHA
Escola Politécnica da USP/PEA/ENERQ – Brazil
gouvea@pea.usp.br, daniel.duarte@pea.usp.br, apcunha@pea.usp.br

Ivo T. DOMINGUES
AES/Eletropaulo - Brazil
ivo.domingues@aes.com

ABSTRACT

Usually the planning of distribution systems is accomplished using conventional criteria, which foresee an excess in reserve capacity due to the redundancy of the installations for maintaining the supply in case of first contingency.
On the other hand, there is an increasing trend for the incorporation of automated resources in the distribution network. As a matter of fact, many automation devices already in operation are seldom considered during the planning of the network expansion.
This paper presents a Distribution Planning methodology that takes into account the automation as an alternative to the conventional work, like the construction of a new feeder or the installation of an additional transformer in an existing substation.
The purpose of such methodology is to replace some reserve capacity by automation resources, increasing the utilisation factor of the installations without loss of supply quality.
The balance between installations reserve and automation can be estimated for the single contingency condition using failures rates, mean times to repair and interruption costs. The sensitivity of the solutions to the economic cost of non-supply shall be also considered, since it is a key factor for the optimisation of the reserve capacity.

INTRODUCTION

Background

As a consequence of the so-called N-1 criterion, the traditional rule for planning of distribution systems, a certain reserve capacity exists in order to maintain the power supply during a contingency.
Under a price cap regulatory model, as adopted in Brazil, other ways to keep the continuity of the service need to be evaluated for restricting the capital expenditures within acceptable limits.
Distribution automation can be an alternative to more expensive assets, like transformers or feeders. Furthermore, reserve capacity affects customers alike, while automation can be used to prioritise them.
However, automation is currently used by utilities mainly as an operational tool, while the aim of this work is to introduce automation resources in the planning of the distribution system expansion.
With the consideration of automation since the beginning of the process some investments in reserve of capacity are expected to be replaced, or at least deferred, improving the economics of the utility while still providing a good supply service.

Reserve capacity cost

When adopting the N-1 criterion there is an implicit cost for the reserve capacity. Making such cost explicitly known can be a motivation for an optimised planning of the system.
Let the following typical figures for a substation transformer:
- cost including associated equipment: 30 US$/kVA;
- average unavailability: 1 h/year;
- load factor: 0.6;
- power factor: 0.9;
- utilisation factor: 0.8;
- capital recovery factor: 0.11 (10 %, 25 year lifetime).

Using the previous data the cost of the reserve capacity (*CRC*) can be estimated as approximately:

$$CRC_{Transformer} = \frac{30 \times 0.11}{1 \times 0.8 \times 0.9 \times 0.6} \cong 7.7 \quad \text{US\$/kWh}$$

A similar rationale can be made for overhead feeders, which are loaded with about 70 % of their maximum allowable current rating. In this case, assuming a cost of 2 US$/kVA/km and an unavailability of 0.25 h/km/year, the cost yields:

$$CRC_{Feeder} = \frac{2.0 \times 0.11}{0.25 \times (1-0.7) \times 0.9 \times 0.6} \cong 5.4 \quad \text{US\$/kWh}$$

At this point it's interesting to compare the interruption costs with reserve capacity ones.
According to references [1] and [2] the economic consequences to a customer of an interruption in Brazil is in the range from 0.75 to 6.95 US$/kWh, with an average value of 1.54 US$/kWh, depending on type of customer and outage duration.
Therefore, as a rough first estimation, the reserve of capacity has a cost ranging from the same order of magnitude to ten times more than the cost of an interruption, with an average of four times. In other words, the most of customer outages are avoided at a higher cost than the generated prejudices.
Obviously this does not means that customer outages must be tolerated in larger extents than they are presently, but that more economical alternatives to reserve capacity have to be sought.

METHODOLOGY

Planning considering automation

In order to accomplish the previously described targets, automation needs to be formally introduced in the present planning procedures.
The flow chart for distribution planning, with automation included, is shown in the figure 1.
At first, automation is simply added as another resource to be considered for generating alternative solutions to comply with pre-established performance criteria like maximum voltage drop, loading and contingencies. However, the treatment for evaluating this new alternative requires some additional concepts, as presented hereinafter.

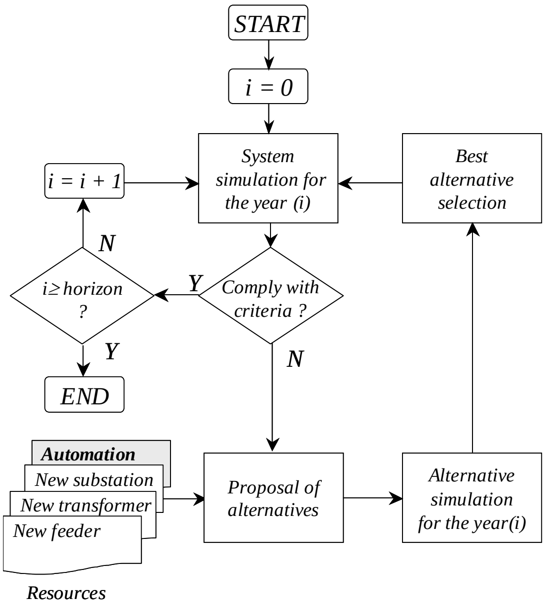

Figure 1: Distribution planning including automation.

Analysis of automation alternatives

Automation functionalities

Under the single denomination of distribution automation there are many functions related to voltage control, load switching, fault location, remote meter reading, etc.
But, for the purposes of this work, the functionality of primary importance is the feeder automation, i.e., the automatic sectionalising for fault isolation or switching for load transfer, since they can replace some reserve of installed power or avoid the necessity of a new feeder.

Automation resources

An automation resource is, in fact, a set of devices or components that operate together to accomplish the desired functionality (automatic feeder sectionalising or switching in the case).
This set includes basically sensing elements for detecting voltage or current, switching devices able to open the circuit under dead or loaded circumstances and communication means for connecting components among them or to a control centre. Sometimes such components can be integrated in a single equipment.
Anyway each element has a cost to be taken into account. Therefore, the complete characterisation of an automation resource shall consider all its components for calculating the total cost, including the installation service.
Furthermore, for communications the cost usually has a fixed part and a variable one, the latter being affected by the distances of allocation of the components.
In order to make the planner activities easier, some standard automation resources have been proposed as part of the methodology, in spite of the possibility for creating new combinations of elements.
Examples of such standardised automated resources are shown in the figure 2.

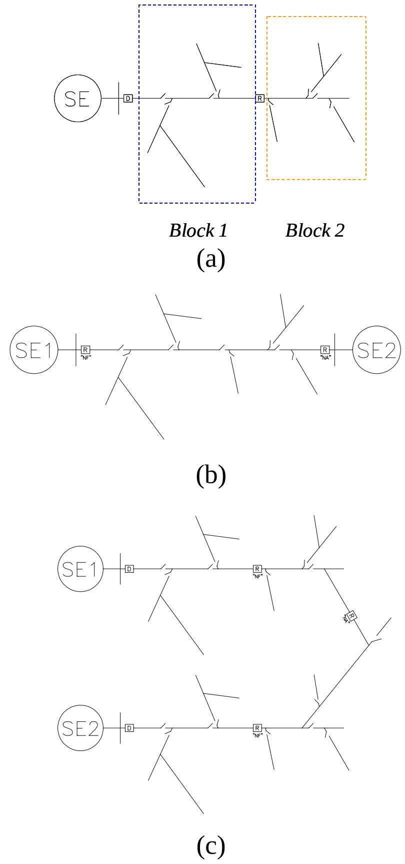

Figure 2: Standardised automation resources.

The main features of each resource are shown in table 1.

TABLE 1 – Standard automation resources.

Resource	Function	Equipment	Commun.
a	Restore block 1 for a fault in the block 2	1 NC recloser	No
b	Load transfer	1 NO recloser 1 NC recloser	Optional
c	Restore at least 50 % of total load of one substation	1 NO recloser 2 NC reclosers	Yes

Benefit associated to the automation

The basis for the computation of the economical benefit is the saving of non supplied energy [3], that can be obtained between the situation with and without automation, i.e.:

$B_a(i) = TCI_{woa}(i) - TCI_{wa}(i)$ (1). With:

$$TCI_x(i) = \sum_{j=1}^{n} \left[\lambda_j \sum_{k=1}^{m} (r_k D_{\max k} lf_k CI_k) \right] \quad (2)$$

Where:

$B_a(i)$: benefit associated to the automation for the year *i;*

$TCI_x(i)$: total cost of the interruptions for the year *i* (US$);

x: condition (*wa*: with automation, *woa*: without automation);

n: possible contingencies for the year *i*;

λ_j: expected failure rate for contingency *j* (year^{-1});

r_k: mean time to repair to restore power to bus *k* (h);

m: number of the system buses;

$D_{max\,k}$: maximum demand of the bus *k* for the year *i* (kVA);

lf_k: load factor associated to the bus *k*;

CI_k: cost of the interruption for the bus *k* (US$/kWh).

Benefits related to labour reduction were not considered.

Allocation of the automation resources

The same resources can generate different benefits and costs depending on their relative position with respect to each other, important load blocks, main substations, etc. Hence, the possible allocations of the switching element for each automation resource are subjected to some rules like the restoration of large load blocks or critical customers, as well as the maximum allowable rating of the feeders.

Estimation of parameters

In addition to the usual data related to demand, growth and load factors, the application of the equation (2) requires the knowledge of some network performance parameters, like failure rates or mean times to repair. Such data should be based on operational information.

Among the alternatives for obtaining them are the use of typical data by geographic area and type of system/feeder (bare, covered, underground, etc) or the estimation from local indexes of average interruptions frequency and duration. The second approach was judged suitable for this work.

Another fundamental parameter is the cost of the interruptions to be associated to each bus.

Initially is necessary to classify the bus according to the kind of customers connected to it. The proposed groups are: residential, commercial, industrial, public and other (for those highly sensitive as, for instance, health care facilities). A specific cost is then associated to each rate and applied to all the demand of the bus. This clearly involves an approximation for buses with mixed types of customers.

Proper values for the cost of interruptions should be obtained through surveys designed to gather this information.

Analysis of automation alternatives

The previous considerations for analysing an automation alternative can be seen in flow chart of the figure 3.

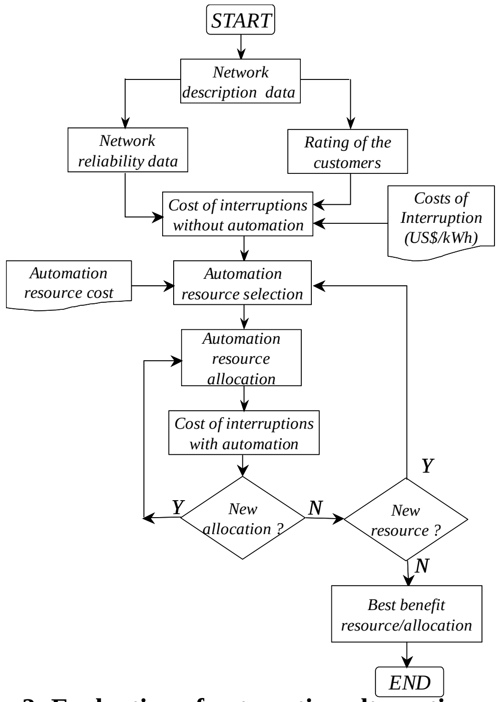

Figure 3: Evaluation of automation alternatives.

Best alternative solution

For every year of the planning horizon, with at least one violated performance criterion, alternatives of solution shall be proposed and evaluated. The least cost solution can contain a mix of automation and conventional work.

EXAMPLE OF APPLICATION

Description and alternatives of improvement

A simple application of the previous methodology has been made for the network of the figure 4. In the initial situation substations ST1, ST2 and ST3 are not interconnected to each other. The contingency of transformer TR1 of substation ST1 requires transferring loads S1, S2 and S3 to TR2, while disconnecting less sensitive loads S5 and S6 for reasons of maximum allowable power.

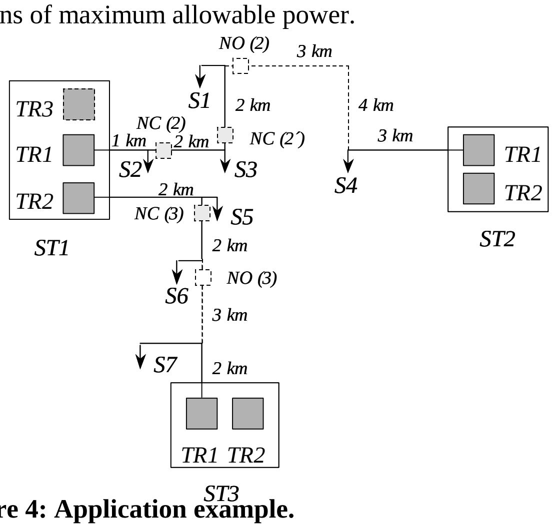

Figure 4: Application example.

The load data are shown in table 2. The unavailability is supposed to be 0.25 h/km/year and the load growth rate is assumed as 3 % to all feeders and loads, respectively.

TABLE 2 – Data of the application example.

Load		Type	Load factor	Cost of interruption (US$/kWh)
Id.	MVA			
S1	2.5	Health care	0.8	6.0
S2	4.0	Commercial	0.6	4.0
S3	2.0	Residential	0.5	2.5
S5	4.5	Commercial	0.6	4.0
S6	3.0	Residential	0.5	2.5

The proposed alternatives of improvement are:
- alternative 1: installation of transformer TR3 in ST1;
- alternative 2: building a feeder tie between ST1 and ST2 with normally open and normally closed reclosers;
- alternative 3: building feeder ties between ST1 and ST2 as well as ST1 and ST3, both with NO/NC reclosers.

The non distributed energy of each alternative is associated to the supplied and non supplied loads as per table 3. Note that alternative 2 involves in fact two conditions (2 and 2´), depending on the allocation of the NC recloser.

TABLE 3 – Loads supplied or not for each alternative.

Alt.	Supplied load	Non supplied load
1	S1, S2, S3, S5, S6	0
2	S1, S3, S5, S6	S2
2´	S1, S5, S6	S2, S3
3	S1, S2, S3, S5, S6	0

As an additional simplificative assumption, no penalties have been supposed for the non supplied loads.

Alternative costs and sensitivity analysis

Considering the costs shown in the table 4, the following net present values have been obtained:
- alternative 1: 444 kUS$;
- alternative 2: 32 kUS$;
- alternative 2´: 62 kUS$;
- alternative 3: 111 kUS$.

The results are, in fact, negative contributions to the cash flow (costs) with a clear influence of the initial investment. Hence alternative 2 is the best one. The difference between 2 and 2´shows the importance of the allocation. On the other hand, alternative 3, although more expensive than previous ones, provides the same service quality of the reserve capacity of alternative 1.

TABLE 4 – Capital expenditures and costs.

Alt.	Capital expenditure (kUS$)	Maintenance cost	
		(kUS$/year)	(%)
1	600	12	2
2 and 2´	180	7	5 (*)
3	280	10	5 (*)

(*) feeder tie only; reclosers are assumed maintenance free.

Since the economical consequences of an outage can be subjected to a relatively high uncertainty depending on the type of the customers involved, a sensitivity analysis is recommended.

The sensitivity of the NPV values of the example to the cost of the interruption of load S1 can be seen in the figure 5.

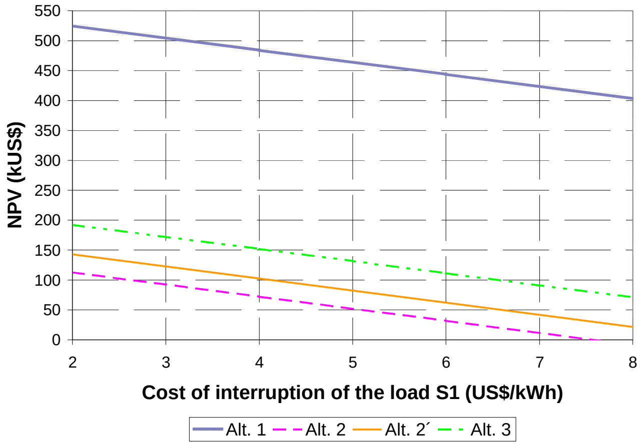

Figure 5: Sensitivity analysis.

FUTURE WORK

A pilot application is foreseen as part of the current project in order to gather real data regarding the operation of the network and to compare the benefits with the calculations. This can be used to validate the model as well as to show the need of further refinements.

CONCLUSIONS

The proposed model for Distribution Planning with automation as additional resource allows a differentiate treatment of more sensitive loads, without increasing the reserve capacity for a large group of customers.

Modifications in the current distribution planning process and reliability data collected from real operation are necessary to accomplish the required evaluation tasks.

In many situations the automation of distribution feeders can be used as a cost competitive alternative to conventional reserve capacity solutions like transformers and feeders.

In order to deal with the uncertainties in the cost of interruptions attributed to the customers, a sensitivity analysis is recommended before the choice of the final alternative.

REFERENCES

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