MV PLANNING APPROACH USING TEMPORAL SERIES, BILLING DATA OF MEDIUM VOLTAGE CONSUMERS AND SUBSTATION FEEDERS METERING

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ABSTRACT

This paper presents the methodology used by Daimon Engineering & Centrum Engineering Consortium to study CELESC's Joinville Regional Medium Voltage Distribution System (MVDS). To accomplish this Planning job, the consortium has used besides a load-flow programme called Interplan®, a set of other information, such as billing data of medium voltage consumers, substation feeders metering and SARIMA time series to characterize the system load growth and has performed load-flow studies for a 5 year period. As a result of this approach, the consultancy has been able to build a set of measures along the first 2 year period (short term study) and along the subsequent 3 year period (medium term study). The former presented alternatives, such as installation of air-break switches, feeders reconductoring, installation of capacitor banks, installation of voltage regulators across the grid. The latter presented alternatives, along with the ones of short term, such as the construction of new substations. All those measures have been taken to mitigate the conductors overcapacity, voltage drops and technical losses along the 5 year period.

INTRODUCTION

CELESC is an electric distribution utility, located in the southern region of Brazil which supplies approximately 2,700,000 customers (around 6,700,000 inhabitants), in the state of Santa Catarina, in Brazil.

One of the biggest regional divisions of CELESC is Joinville, which is composed by 6 cities: Joinville, Araquari, Garuva, Itapoá, São Francisco do Sul and Balneário Barra do Sul, which supplies approximately 265,000 customers (around 638,000 inhabitants).

Joinville Regional has a combination of very different load characteristics of its consumers, from heavy load industries to vacation homes on the coast.

The arrival of large factories in the Joinville Regional has been intensified by the tax reductions, the construction of industrial facilities, and also by the port areas of São Francisco do Sul and Itapoá, which has resulted in the market expansion of this region in recent years.

Joinville is a Brazilian city located in the southern region of the country, and is the largest city of the state of Santa Catarina, responsible for about 20% of the state exportation goods. It is also the 3rd industrial centre of the southern region of Brazil and the fifteenth largest municipal, state and federal tax contributors of the country. The city has a great deal of economic activity in the industry, especially the mechanical, textile, plastic, metallurgical, chemical and pharmaceutical areas.

The Gross Domestic Product of Joinville is also one of the country's largest ones, something around US$ 8.7 billion in 2012, according to IBGE (Brazilian Institute of Geography and Statistics) [1].

Due to high growth rates in the region in recent years, and on the other hand due to the increasing rigor of compliance and reliability parameters, established by ANEEL (Brazilian Electricity Regulatory Agency), it has been necessary to accomplish a comprehensive and detailed Medium Voltage Distribution System Planning Study to adequately meet their consumers.

The consultancy objective was to provide Joinville Regional Planning Department, detailed reports on the network performance in the short and medium terms, as well as a Plan of Works and Actions to optimize the performance of the existing network and meet market growth in the short and medium terms.

It has also been considered as an important guideline, the load switching from the 69 kV system to the 138 kV system, particularly in the central region of Joinville in order to relieve the load on the 69 kV system.

PLANNING STUDY

The study of Joinville Regional Division has been divided into five (5) steps: Acquisition and editing of topology data, analysis of the current MVDS market evaluation, MVDS planning and technical-economic study. The flowchart in Figure 1 shows the sequence of steps.

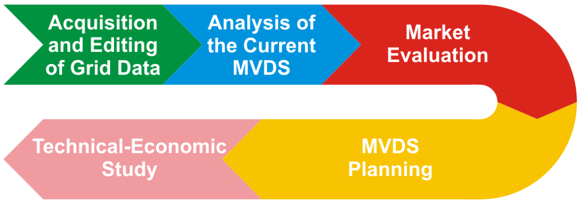


Figure 1 - Implementation Stages

Each step of the flowchart of Figure 1 will be detailed for a better explanation regarding the whole planning process.

Acquisition and Editing of Topology Data

The Interplan® Planning tool is a software which has been implemented in Joinville Regional and used for the acquisition and editing of topology data. The database of March 2013 has been adopted as the study reference network.

Although the database has already been suitable for conventional studies, it has been necessary to edit some information of the network imported in March 2013, in order to perform a more refined study, such as: i) insertion of new loads (new MV customers) and meet MV consumers load increasing requests, already in the portfolio of CELESC; ii) inclusion of MV consumers real power individual readings; iii) demand correction of distribution feeder at substations by the annual maximum capacity for each feeder; and iv) implementation of new substations and new feeders into the 2013 network base.

Adjustments in the data base of year 2013 have been necessary to incorporate as much as possible, the network imported in March 2013 with the field ongoing changes of the network.

The power flow has been calculated for the annual maximum demands of feeders, which in the vast majority concentrated in the months of December 2012 and February 2013.

Figure 2 shows the acquisition, editing of topology data and demand correction of the network imported in March 2013.

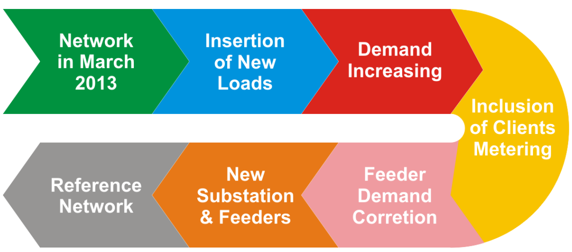


Figure 2 – Sequence of Steps for Acquisition and Editing of Topology Data

By the end of this process, the updated grid has been obtained and used as the basis for the studies.

Analysis of Current Joinville Regional MVDS

The evaluation of Joinville Regional MVDS has been accomplished using the March 2013 grid and adopting the annual maximum capacity of each feeder. This procedure has been necessary to identify the network transgressions in terms of voltage and capacity criteria.

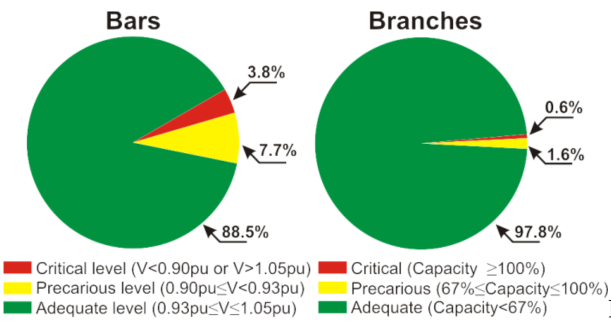
Feeders Maximum Capacity

For network dimensioning purposes, the months of feeders maximum capacity have been used to correct the feeder demands. The feeders maximum historical data used for the network evaluation comprise the period between March 2012 to February 2013.

It should be pointed out that there has not been a unique month with coincidence peaks regarding the maximum period of the feeders. In addition, one has observed a strong seasonality of feeders meeting coast regions due to the predominance of vacationer consumers.

Voltage Drop and Capacity of the Base Electric Network

Based on the reference months used to correct the feeders demand, i.e. from March 2012 to February 2013 and on the edited electrical network, the compliance study has been accomplished, observing the guidelines of Module 8 of the Electricity Distribution Procedures (PRODIST) [2]. The result of the power flow studies could determine the locations across the network where the transgressions overcame these guidelines. Figure 3 presents the analysis of bars (voltage drops) and branches (capacity) according to the Module 8 PRODIST criteria.



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igure 3 – Assessment of Joinville Regional Division: a) bar voltage drops; b) branches capacity

Construction Standards of The Primary Grid

The majority of the overhead primary network of Joinville regional division is formed exclusively by three-phase bare copper or aluminium conductors, although recently, portions of the urban network have been installed with spacer cable technology. This great amount of overhead lines with bare conductors is responsible for the difficulty that Joinville regional division has been facing to meet the reliability requirements of ANEEL, which becomes more and more restricted every year. Table 1 presents a data summary of Joinville regional division network.

Table 1 – Amount of Conductors of Joinville Regional Division Primary Network

	Predominant Conductor	Participation [%]
Feeder	336.4 MCM AC	67.9
Lateral	4 AWG CAA	69.1

One notes from Table 1 that the predominant cable of the network main feeders is 336.4 MCM AC, corresponding to 67.9% of the total amount. Regarding the laterals, 69.1% of the total amount of cables is made of 4 AWG CAA conductors. The rural distribution networks are characterized by having predominantly single phase 4 AWG ACSR conductors.

Additionally, 6 AWG copper conductor is present in most feeders, particularly in coastal regions, such as those fed by Ubatuba substation where this conductor represents 22% of the feeder´s conductors, making the system more vulnerable to the outages associated with broken conductors.

Market Forecast

In order to take into account the market variations, a predictive model based on time series of the maximum load of each substation has been adopted. This method has enabled to forecast market growth on the horizon of short and medium term.

It should be pointed out that this approach refers only to the vertical growth of loads (consumers load increase already connected to the network). Thus, the horizontal growth (new loads) has not been considered by this predictive method, with the exception of the new MV relevant loads, already committed with the utility.

Box-Jenkins Method

The predictive method based on time series, known as Box-Jenkins Method or SARIMA (Seasonal Autoregressive Integrated Moving Average) Model [3] has been employed. This method foresees future situations, based on what occurred in the past, using the concept of moving averages, autocorrelations and seasonality of the series. Table 2 shows a histogram of the substation's growth rates calculated by this method.

Table 2 - Histogram of The Substation's Growth Rates

Growth Rate (%)	Frequency
0 – 3	2
3 – 6	5
6 – 9	6
9 – 12	3

The substation's growth rates of Table 2 have been used as an input to the feeder's growth rates calculation. The method used to calculate each feeder's growth rate was based on the linear regression of a historical series of annual maximum demand feeder. Table 3 shows a histogram of the feeder's growth rates calculated by this method.

Table 3 - Histogram of The Feeder's Growth Rates

Growth Rate (%)	Frequency	Growth Rate (%)	Frequency
0 – 2,5	11	10 – 12,5	2
2,5 – 5	24	12,5 – 15	1
5 – 7,5	36	15,0 – 17,5	2
7,5 – 10	4	17,5 – 20	1

The feeder's growth rates of Table 3 have been used as an input for the power flow calculation for the short and medium term scenarios created in the next section.

Planning Study

The study of Joinville Regional Division Planning has been carried out to a five year horizon, with the first year set in 2014. Based on the growth rates set (calculated by the Box-Jenkins Method), the capacity and voltage drop of the network in future years have been simulated. The Planning study has been divided into short term, comprising the first two years of the study (2014 and 2015) and the medium term, comprising the last three years (2016, 2017 and 2018).

Over the two periods of Planning, a set of Actions and Works have been proposed to meet the compliance criteria, as shown in Figure 4 below.

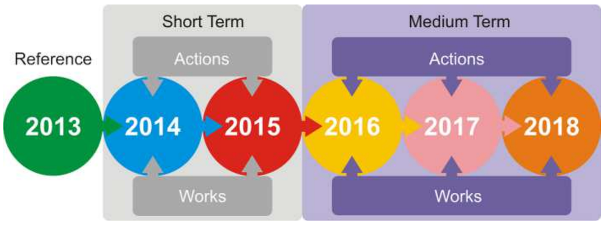

Figure 4 – Planning Implementation Flowchart

Corrective Proposals

Corrective proposals are divided in Actions and Works and can be defined as:
a) Actions: Set of measures such as load switching to adjacent feeders, network equipment relocation, connection point change, etc.
b) Works: Set of new assets, such as conductors replacement, network extension, capacitor bank installation, regulator voltage installation, installation of new substation/new feeders and new substation transformers.
The set of Actions and Works aims at meeting the voltage and capacity compliance criteria.

Short Term Planning

The short term Planning has prioritized the fulfilment of compliance criteria, proposing load switching between adjacent feeders (when possible), elaborating thus the Action Plan. It should be noted that the Works proposal in the short term period has only been considered due to the impossibility of meeting the compliance criteria through the Action Plan. For these situations, executive designs of corrective works have been carried out, which have comprised the short term works plan and whose implementation costs have been considered for the subsequent economic and financial evaluation.

Medium Term Planning

Similar to the short term Planning study, the medium term Planning aimed to meet the market expansion of Joinville regional division until the horizon year of 2018, maintaining the same quality criteria established in the short term study [2].

The particularity for the medium term study has been the usage of CELESC distribution network standard costs to estimate the work costs, since for these solutions, designs have not been proposed.

Summary of Actions and Works

Table 4 summarizes the set of actions and works which have been proposed to the short and medium term Planning of Joinville regional division medium voltage network.

Table 4 - Summary of Works and Actions of Short and Medium Term Planning

Planning	Network [km]		Installation		Relocation	
	New	Substitution	CB	RV	CB	RV
Short Term	36.7	29.7	10	9	0	4
Medium Term	17.6	28.4	11	2	5	4

Table 5 sums up the internal works in substations proposed in the short and medium term Planning.

Table 5 - Summary of Works and Actions of Short and Medium Term Planning

Planning	New Substation	New Feeder	Transformer Substitution
Short Term	2	7	0
Medium Term	2	8	2

Figure 5 shows the annual investment participation, as well as the relative sharing in the short and medium terms.

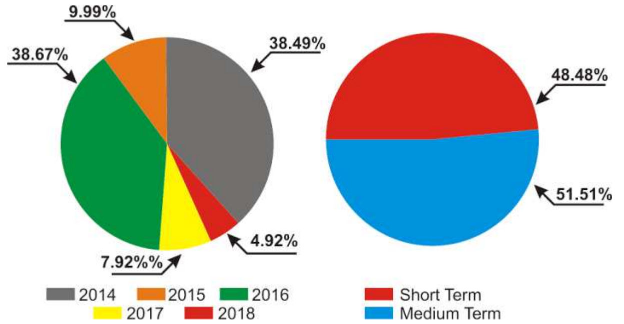

Figure 5 – a) Annual Participation in Investments; b) Planning Participation in Investments

Technical-Economic Study

The technical-economic study has analysed the benefits generated by the electric network investments and the economic viability of the proposed solutions. This study is divided in technical profits and investments return.

Investments

The total planned investments to implement the Action and Work Plans resulted in about US $ 30 million. Table 6 shows the annual investments.

Table 6 – Annual Investments

Year	2014	2015	2016	2017	2018	Total
Investment (Millions US$)	11.66	3.03	11.72	2.4	1.49	30.30

The following topics analyse the technical benefits and the regulatory profits of these investments.

Technical Benefits

The technical gains come from investments into the power grid and have been calculated from the reports generated by Interplan®. Gains are due to energy loss reduction, demand loss reduction and market gain.

a) Energy Loss Reduction: It is a consequence of the network efficiency increase, coming from the increase of conductors capacity, decreasing of feeders length, use of more efficient conductors, etc. Table 7 presents gains by reducing losses over the short and medium Planning term.

Table 7 – Energy Loss of Joinville Regional MVDS

Year	Planned Network	Reference (MWh/year)	Reduction (MWh/year)
2014	34,974	51,453	16,479
2015	36,116	58,559	22,443
2016	36,273	67,203	30,930
2017	38,664	77,566	38,903
2018	43,045	89,948	46,903

b) Demand Loss Reduction: Is the decrease of real power generated by the source, which can be mitigated in the same way of the energy loss gain. Table 8 presents gains of demand loss reduction over the short and medium Planning period term.

Table 8 - Demand Loss of Joinville Regional MVDS

Year	Planned Network	Reference (kW)	Reduction (kW)
2014	8,362	12,095	3,733
2015	8,904	14,052	5,148
2016	9,068	16,565	7,497
2017	9,710	19,357	9,647
2018	10,881	23,075	12,193

On Tables 6 and 7, Reference means the grid energy loss and the grid demand loss without the Action and Work Plan, respectively.

c) Market Gain: It is the consequence of the market growth due to the improvement of voltage level, after the investments. This benefit will only be considered in the first year of the investment, since this gain will be discounted by the X-Factor [4], when the annual tariff adjustment happens. In the first year of the study (2014), this gain is 18,141 MWh.

The technical benefits calculated above provide the financial gains presented on Table 9, considering the average life of electrical assets which are proposed in the Action Plan and Works.

Table 9 - Technical Benefits during the average life of electrical assets

Technical Benefits in Thousand US$ (PV)			
Energy Loss Reduction	Market Gain	Demand Loss Reduction	Total Technical Benefits
22,171	613	6,754	29,538

Investments Return

It corresponds to 2 items: the invested capital return and the reimbursement term due to the equipment depreciation.

a) Investment Revenue: It is the return on investment in the power grid. This value varies according to the weighing average cost of capital (WACC) [5], established in the year of the periodic tariff revision.
b) Regulatory Reintegration Quota: It corresponds to the depreciation of electric network assets, aiming at replacing them after the end of their lifetime.
Table 10 presents the investments return that are proposed on the Actions and Works Plan over the lifetime of the electric assets to be installed in the network.

Table 10 - Regulatory Benefits during the average life of electrical assets (Thousand US$ - Present Value)

Investment Return	Reintegration Quota	Total Assets Return
11,866	7,361	19,227

Economic Analysis

One should consider the total investments to be made over the five year period (2014-2018), the total returns due to the technical benefits and the total investment return, to accomplish an economic analysis (all of them brought to the present value). Table 11 presents a summary of these amounts.

Table 11 - Summary of Values in Thousand US $ (PV)

Investments	Technical Benefits	Investment Return
26,348	29,539	19,228

Based on the amounts presented on Table 10, it can be concluded that the set of proposed Actions and Works results in a 22.6% Internal Rate of Return, and in Benefit/Cost ratio of 1.85 and the Payback will happen in the eighth year (2022).

It is noteworthy that in this analysis, other benefits coming from the energy quality improvements, such as the reduction of operating costs and financial compensation paid to consumers due to transgression of reliability and voltage level standards, which would improve the economic results of proposed actions an works, have not been considered.

CONCLUSIONS

The Consulting job has presented an innovative approach in the assessment of Joinville regional division MVDS, incorporating measurement readings of each MV consumer for power flow simulations; and also the usage of SARIMA method, in order to evaluate the growth rate of the market fed by Joinville regional division substations and feeders, for the next five years. It has also presented an economic analysis of investments, taking into account not only the technical benefits to the electrical system, but also the economic effect of investments on the utility´s regulatory assets.

It should be finally pointed out that a job with the degree of detail and accuracy as that has been achieved, provides a systemic view to managers, enabling CELESC to foresee the system bottlenecks in time to take the adequate measures to keep the quality of power supply.

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[3] G. E. P. Box; G. M. Jenkins. Time Series Analysis: Forecasting and Control, 2nd ed. San Francisco: Holden-Day, 1976.

[4] ANEEL (Brazilian Electricity Regulatory Agency) Technical Note # 093/2011-SRE/ANEEL, issued on 13 April 2011.

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