Substations Optimization
Foundations of a Decision Making System

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Abstract: The optimization of building processes for a power substation is based on the adopted configuration structure and includes a simulation of the methods for the mechanical, civil and electrical processes. Thus it is necessary to know the scope of the service area, the substation load and its connected transmission lines, the terrain topography, and the environmental impact, issues that will be only known after the choice of the area and the project details. The purpose of this work was to bring the foundations of a decision support system regarding the reduction of the structure weight and its concrete volume. A laboratory reduction model validated the work.

1 INTRODUCTION

For an electric utility, changes in legislation and the growth of energy use require the need for new tools and techniques, to achieve the highest level of quality of power supply to the consumer at the lowest cost and always preserving the environment. For this reason, the research carried out, combines mechanical civil and electrical engineering, and therefore makes use of different methodologies, depending on the area in which one seeks to optimize envisioning a decision support system (D'Ajuz, 1985).

The main objectives of this research aimed to develop possible solutions for optimization of construction of substations and consisted of:

1. Model and simulate the investigated metallic or composite structures by estimating their weights, aiming their reduction in the optimized Electrical System (ES).
2. Shape the foundations of the pillars concerned to the investigated metal or composite structures in order to .reduce the concrete volume.
3. Model, simulate and test the Electrical System on a reduced scale.

2 METHODOLOGY

2.1 Reducing the Weight Structure

Studies were undertaken in order to minimize the weight of the structure with three different situations, from the most traditional to the most innovative on the market with technical characteristics that meet the preliminary optimized substation. Three structures were investigated:

1. Lattice-like structures (traditionally used).
2. Tubular structures (used in our proposal).
3. Centrifuged Concrete Structures (steel and concrete).

These structures must be sized appropriately in order to resist traction forces, self weight, weight of equipment and wind acting on them. For the calculations is necessary to know precisely the topography of the region adjacent to the land and own land for the construction, the angular distribution lines related to the substation, and the climatic characteristics of the region, especially in relation to the wind, which at this stage project are not yet defined.

The computational tool (Bhati, 2005) used to model, simulate, analyze and estimate parameters in the three cases studied, was the Finite Element Method (FEM).

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2.1.1 Lattice-like Structures

Lattice Systems are those consisting of undeformable elements joined together by hinges, considered perfect, and subject only to loads applied to the joints or nodes. Thus the elements or bars are only subject to normal efforts, traction or compression. In the plane lattice, the set of construction elements, e.g. round bars, flat or angles, are interconnected under triangular form geometry, by pins, welding, rivets or bolts, designed to form a rigid structure in order to withstand only the normal efforts. Figure 1 shows part of the plant that was used for calculating the unilateral drift due to crosswind for a 138 kV Electrical Substation.

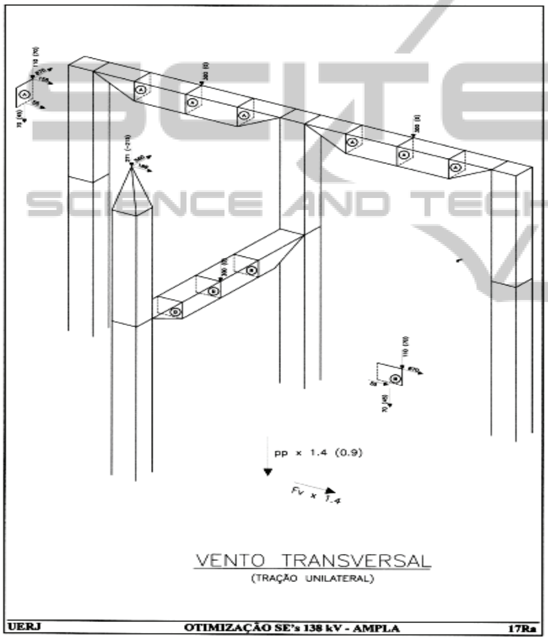

Figure 1: Unilateral drift due to crosswind for a 138 kV SE.

2.1.2 Tubular Structures

Tubular profiles can have three different geometries: circular, rectangular and square. The geometry of these profiles is their main advantage, because its closed section allows a significant increase in resistance. Besides, the effective reduction of the foundations structure yields huge savings for these buildings, and shows good integration to the environment.

The circular profiles provide a better distribution of stresses on the tube due to their geometry, in which all cross-sectional points are equidistant and therefore were investigated in our research. Figure 2 shows the FEM used in the 138 kV ES having tubular structure.

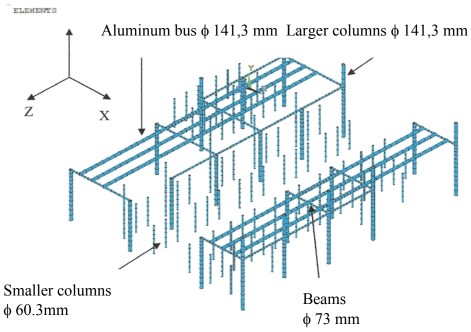

Figure 2: FEM modelling used for tubular structure.

2.1.3 Centrifuged Concrete Structures

The excellent visual integration with the urban environment, given the texture of the concrete and the elegance of the structure, allows the installation of centrifuged reinforced concrete in any area, minimizing the impact on the environment and landscape. Throughout this work simulations using FEM were performed indicating that the weight of the centrifuged reinforced concrete structure is much larger than that of the tubular steel and the same occurred with the lattice one. Consequently, the amount spent on concrete foundations using centrifuged concrete is much larger than the structures used in tubular steel and the same occurred with the lattice structure. Figure 3 shows a brief view of a 138 kV Electrical Substation with centrifuged concrete.

Tables I and II summarize some specifications, technical and economic characteristics and important peculiarities in these types of structures.

Table 1: Structures operational characteristics.

kV Class	Estimated Weight (kgf)			Av. Cost (US$/kgf)			Corrosion & Fire Resist.			Installation and execution of work			Visual Pollution		
	LAT	TUB	CENT	LAT	TUB	CENT	LAT	TUB	CENT	LAT	TUB	CENT	LAT	TUB	CENT
138	50260	12000	145000	>1.9 T	>4.5 NT	<0.6 T	1	3	4	E S	Ex S	F E S	4	2	0
69	38760	5980	200000												
34.5	14590	2250	40000												

LEGEND:
LAT – Lattice
TUB – Tubular
CENT – Centrifuged Concrete
0 – Very Low E- Easy
1 – Low F – Fast
2 – Medium Ex – Expensive
3 – High S – Safe
4 - Very High
T – Broadly tested in ESs
NT – Not Broadly tested in ESs

Table 2: Costs of the investigated structures.

kV Class	Structure Cost (US $)		
	Lattice	Tubular	Centrifuged
138	94935	54000	80556
69	72214	26910	111112
34.5	27559	10125	22223

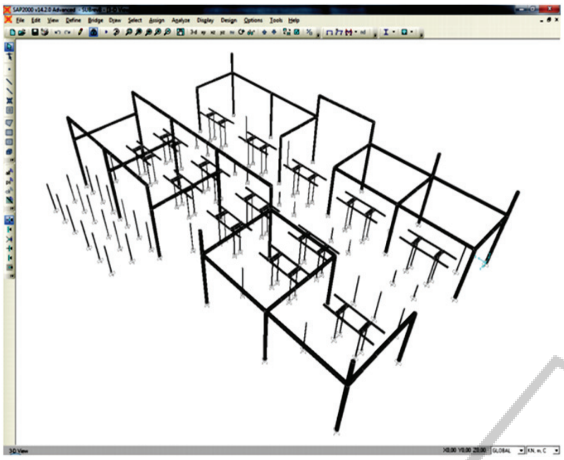

Figure 3: Centrifuged concrete structure for a 138 kV ES.

As far as the cost is concerned, the tubular structure is also very attractive, as evidenced in Table 2.

2.2 Simulation of the Concrete Volume

Generally, the foundations of substations can be classified as shown in Table 3

Table 3: Foundations of substations types.

Foundations							
Shallow			Pile				
Block	Shoe	Concrete Slab	Pre-cast Piles Steel, Concrete and Centrifuged Concrete	Piles moulded on site with a coating tube			
				Strauss	Franki	Helical	Pillar

To accurately estimate the type and volume of concrete foundations it is basically required to know the loads to be transferred to the foundations of the investigated structures, and evaluate the reports of the land survey for the construction of the ES. It is undeniable that there is an inevitable link between the geological conditions and the design of the foundations (Groenewald, 2009). Mentioned below are some needs which must be fully met during the detailed design of the project.

1. Definition of the loads to be transferred to foundations;
2. Important developments in geomorphology;
3. Geotechnical local site;
4. Data on slopes and hillsides on the ground;
5. Data on erosion, occurrence of soft soil on the surface;
6. Need to make cuts and embankments on the ground;
7. Compressibility and resistance in the survey;
8. The level of groundwater;
9. Executive feasibility;
10. Economic viability.

It can be seen, through simulation, that the tubular steel frame weighs less than 10% of the centrifuged concrete structure and less than 25% of the lattice structure, fact which would lead directly to its choice. The lighter the structure, the lower the concrete volume to be used, resulting in lower cost, as shown in Table 4.

Table 4: Cost of concrete.

kV Class	Concrete Cost (US $)					
	Lattice		Tubular		Centrifuged	
	30 MPa	50 MPa	30 MPa	50 MPa	30 MPa	50 MPa
138	30000	50000	15000	25000	30000	50000
69	18334	30556	1667	2778	11667	19445
34.5	13334	22223	1000	1667	7500	12500

2.3 Reduced Model Testing

The choice of the reduction coefficient of the reduced model was based taking into account not only the physical limitations found in the Laboratory of Structures and Materials (LEM) at PUC-Rio, where tests were performed, but also the equipment and instrumentation required to the tests, which followed a high technical accuracy required in these experiments and available on the LEM.

For the tests of the prototype scale model were considered reductions in the dimensions of the parts, taking into account the equivalence of physical resistance to the tubes easily available for purchase on the market. The height of the prototype is decisive for the calculation of the reduction coefficient under the penalty of exceeding the limits permitted in the laboratory tests, which led to the ratio of 1:6 (one to six).

The calculations of the reduced model were based on the original study design. The values of the geometric properties of the prototype, such as length, width and height of the structure, and external diameter and wall thickness of tubular profiles were taken from the design of the 69 kV ES performed using the structural analysis program SAP2000. Figure 4 shows the model with the actual dimensions.

All profiles are circular tubes with the following dimensions:

Columns

- \- outside diameter of 219.1 mm and 12.7 mm thickness;
- \- crossbeams - outside diameter of 219.1 mm and 12.7 mm thickness.

Longitudinal Beams

- \- outside diameter of 101.6 mm and thickness 5.7 mm.

As explained earlier, the reduced model was constructed using a reduction factor of 1:6. Figure 5 shows a schematic drawing of the dimensions of the reduced model.

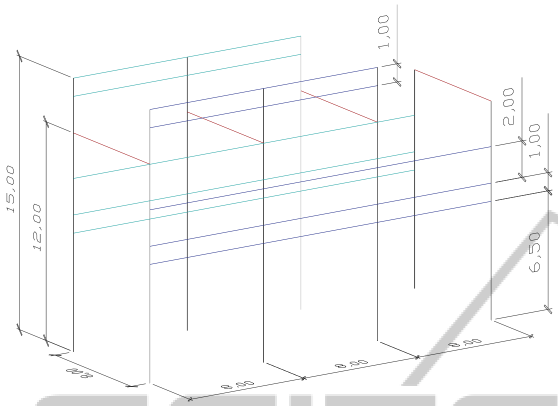

Figure 4: Actual dimensions of the 69 kV ES in meters.

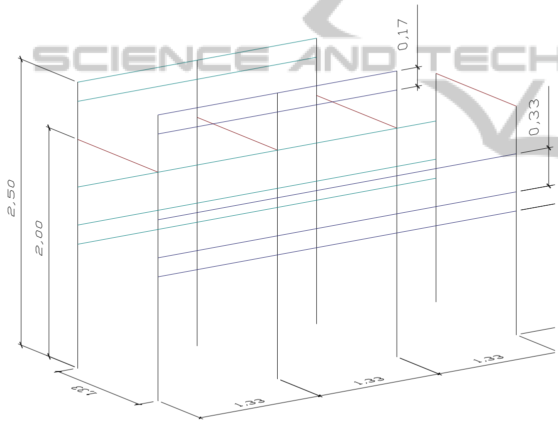

Figure 5: Reduced Model Dimensions of the 69 kV ES

3 CONCLUSIONS

Under the specific viewpoint of optimization of power substations, object of this research, the obtained results seem very promising. For future work it is intended to give more depth to the tubular steel structures and their respective founding, simulating more cases using finite element software, in addition to those already made in this research.

The test results of the reduced model indicate that the integrity of the structure was confirmed, considering the details of the boundary conditions of the investigated structures, loading and material, where there was no need for any reinforcement or modification of the original structure.

Finally, it was found that the optimized SEs were actually efficient from the studied viewpoint.

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