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Research Paper

Power Plant Infrastructures Route Selection

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ABSTRACT: *Currently the assets of the electric power and gas industries consist of large and complex facilities. During the design phase of these facilities, low risks and cost are the goals. Usually, more than a route for the pipeline and transmission line are studied. Technicians are always concerned with choosing the best connect solution with a power plant. The route selection process get more importance due to the changes currently underway in Brazil. Such changes include the recent disclosure of Petrobras efforts in gas natural assets divestments according to your Business and Management Plan. It is an opportunity to explore new frontiers. Brazil is a very big country. Some states of the federation, such as Santa Catarina, although it appears as one of the ten largest consumers of electricity in Brazil, does not have natural gas consumption for the purpose of electricity generation. This scenario could serve as a motivation for further studies about gas-fired power plants. This paper it will discuss optimization practices in order to get the best routes of pipelines and transmission lines interconnected in gas-fired Thermal Power Plants (TPP) in Santa Catarina state, Brazil.*
Keywords: *Optimization, Pipeline, Power Plant, Route Selection.*

I. INTRODUCTION

The nature of power plant infrastructures route selection problems have a direct relationship with decision-making process. Engineering problems can usually solved by considering the focus on technological, parametric and structural levels. The usual approach to solving this problem is to consider the focus on technological, parametric and structural levels. Another characteristic of these problems is that infrastructures route selection sometimes occurs at different times and by different companies, regulators and institutions. The length of each auxiliary infrastructure will be greater or smaller and this can contribute to the reduction of such infrastructure investment costs and risks. The contribution of this paper is to propose a methodology of decision-making of route selection with low cost based on the use of optimization techniques.

Typically, the gas-fired power plants external infrastructure are gas pipeline, transmission line and water pipeline. At the beginning of the TPP design, there are many alternatives and doubts (as shown in fig.1).

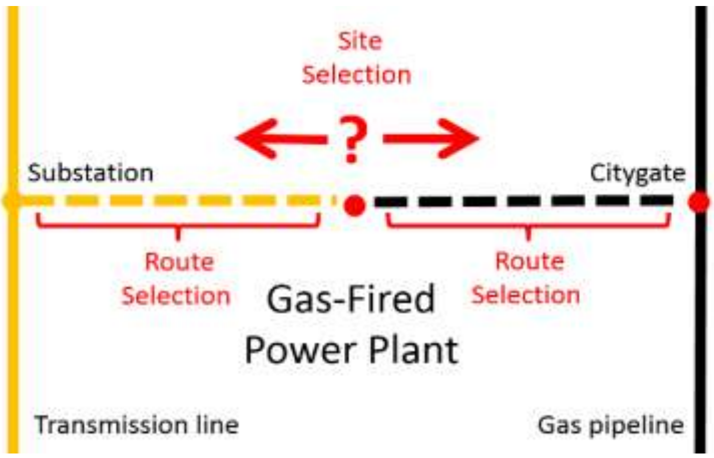

Fig. 1 - Gas-fired TPP main external infrastructures

Usually, several paths for the pipeline and transmission line can solve the infrastructures route selection problem of gas fired TPP (as shown in fig.2). Which one should we choose as the best solution? What criteria should we consider? In order to answer these questions it is necessary first to survey the literature on this subject.

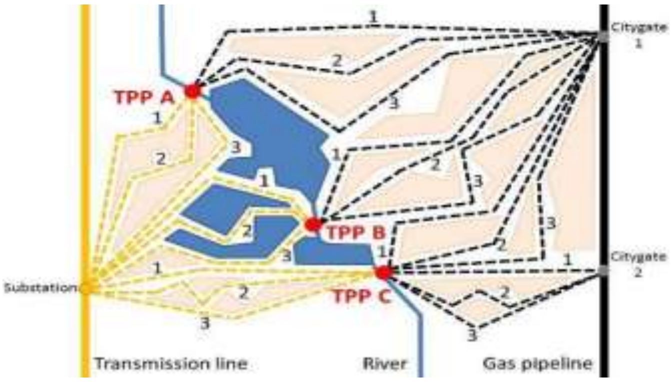

Fig. 2 - Gas-fired TPP external infrastructures

II. LITERATURE REVIEW

Sharma, Nikil and Attri [1] contributed to the study of identification of factors for site selection of thermal power plant. The important factors evaluated in this study were availability of resources, economic impact, environment concern and accessibility, among others. Water availability, land acquisition cost, road/rail/airport accessibility and electricity consumption point are relevant sub-factors. Akash, Mamlook and Mohsen [2] also contributed to the study of multi-criteria selection of electric power plants using analytical hierarchy process.

The State of Washington Energy Facility Site Evaluation Council – EFESC [3] proposed criteria for transmission line route and design. The important factors evaluated in this study were safety, available access, proximity and potential impacts of line route to residences, environmental impact and protection of wetlands and wildlife habitat. The Construction Manual for Transmission Lines of RAJASTHAN RAJYA VIDYUT PRASARAN NIGAM LTD. [4] describes the following criteria for transmission line: shortest length, required separation distance from railways and communication lines, avoiding lands subject to flood, mountain and wooded areas.

The book Pipeline Planning and Construction Field Manual written by Menon [5] describes the following criteria for pipeline route selection: shortest length, land acquisition cost, road/airport accessibility and avoiding lands subject to flood, mountain areas.

Gamarra [6] highlighted how the spatial information has always played an important role in the pipeline route selection process. Gamarra contributed to the study of route selection process using geo-processing models with the recent advantages in GIS technologies.

Some criteria have relationship (pros or cons) with one or more criteria. Nowadays there are techniques for comparison and measurement of route criteria using geographic information system (GIS) and Multiple-Criteria Decision Analysis (MCDA). However, there is no a single standard for pipeline and transmission line route selection. According to the location of gas-fired TPP the length of each auxiliary infrastructure will be greater or smaller and this can contribute to the reduce the project management and risk control scope

III. RESEARCH METHODOLOGY

From the viewpoint of process engineering, the natural gas-fired TPP are optimization problems and its solution consider the focus on technological, parametric and structural levels. In the case of the structural focus, the optimization solutions comprehend successive generation of alternative structures with different arrangements of gas pipelines and transmission lines, in order to obtain an optimal solution that has low investment cost and low cost of operation and maintenance, without compromising safety.

The basic premises for the development of a methodology in order to get the best routes of pipelines and transmission lines interconnected in gas-fired TPP includes: (i) Elaborate organized sets of unit costs and data of geographic coordinates of existing infrastructure, demand and supply; (ii) Calculate the distance between the existing auxiliary facilities and points of interest. (iii) Clustering data according to the location criteria infrastructures; (iv) Develop mathematical models related to the data collected, processed and calculated; and (v) Investigate the best paths of pipelines and transmission lines.

IV. CASE STUDY AND RESULT

This case study evaluate the optimization problem solution related to the decision regarding the location of gas-fired TPP in Santa Catarina (SC) state and the route selection of its auxiliary infrastructure. Brazil is a very big country, with 8,515,767.049 km^2. Santa Catarina state (as shown in fig.3), although it appears as one of the ten largest consumers of electricity in Brazil, does not have natural gas consumption for the purpose of electricity generation. The geographical coordinates of roads, rivers and transmission facilities (substations and transmission lines) are available in the Brazilian Electricity Regulatory Agency (ANEEL) databases [7]. Google Earth has made it possible to calculate distances between cities of interest and notable points.

As a boundary condition in this case study, electric power will be supplied to Canoinhas substation. Another boundary condition will be choose the site near roads to allow heavy equipment transportation. As criteria also will be chosen the site with abundant water to enable the cooling of TPP equipment. According with National Agency of Petroleum, Natural Gas and Biofuels (ANP) [8] there is enough natural gas available in the gas pipeline Bolívia-Brasil (GASBOL) to supply one TPP.

Fig. 3 – Brazil map and the Santa Catarina state (source IBGE [9])

In Santa Catarina, there are transmission lines of 500 kV and 230 kV. There are also 9 load centers with large substations. Figure 4 illustrates the electric power transmission infrastructure in the state of Santa Catarina and highlight the Canoinhas substation. The orange lines represent transmission lines of 500 kV. The green lines are those of 230 kV and the yellow ones of 138 kV.

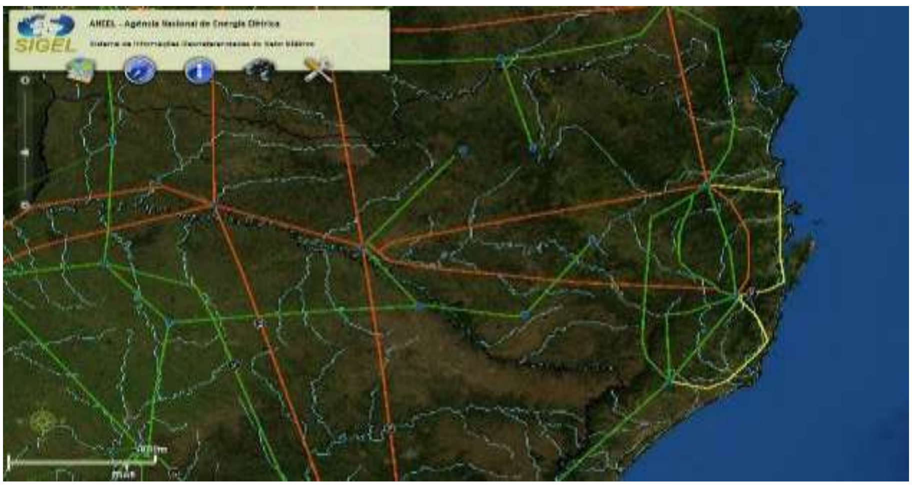

Fig. 4 – Infrastructure of electric energy transmission em SC (source: ANEEL, 2015 [10])

Near Canoinhas substation, interconnection points between highways, such as BR-116 road and BR-470 road, and rivers located in the southern region of the Santa Catarina state, such as the Negro, Canoas, Blumenau and Canoinhas rivers, are favorable locations (as shown in fig.5).

Fig. 5 – TPP alternatives near main roads and rivers of Santa Catarina state

There are 9 citygates that deliver natural gas to distribution pipelines in Santa Catarina. The closest citygates of Canoinhas (as shown in fig.6) are Guaramirim, Brusque and São Pedro de Alcântara. This citygates will need new equipment and measuring systems. This case study will evaluate 4 alternatives of TPP site selection and its infrastructure, as shown in figure 6.

Fig. 6 – Geographical coordinates of TPP alternatives near GASBOL city gates in Santa Catarina state.

The 12 interconnection possibilities are related to the 7 facilities of the model and are represented in Figure 7. This is a typical transport problem and will be solved using optimization techniques. Arcs are cost paths and nodes are the alternatives.

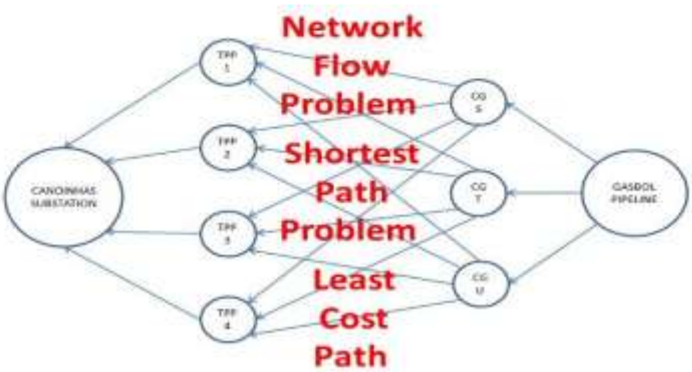

Fig. 7 – Diagram with the TPP infrastructures alternatives in this case study.

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The cost of investing in TPP infrastructure implementation is a function of several headings, such as engineering design, environmental licensing, acquisition of equipment and materials, management of the work, construction, assembly and commissioning. At this case study, cost will be limited to the acquisition of main equipment and materials. This study considers the following values of unit cost of pipeline infrastructure and transmission lines in Brazil, published on the internet and converted to march 2016 basis: (i) API 5L X65 pipe with 16": R$ 1,356.86 / meter [11]; (ii) Measurement System Equipment in the citygates: São Pedro de Alcântara (R$ 6 million), Brusque (R$ 9 million) and Guaramirim (R$ 3 million) [12]; and (iii) transmission line conductor cable (230 kV): R$ 287.55 / meter [13].

The distances between each of the facilities in this case study are in table 1.

Table 1 – The distances (in kilometers) between each of the facilities.

	TPP 1	TPP 2	TPP 3	TPP 4
CANOINHAS SUBSTATION	86	10	88	98

	TPP 1	TPP 2	TPP 3	TPP 4
GUARAMIRIM CITYGATE	105	126	97	162
BRUSQUE CITYGATE	130	141	94	160
SÃO PEDRO DE ALCÂNTARA CITYGATE	189	181	106	160

The distances and unit costs of infrastructures allow the calculation of the total costs for each of the interconnection possibilities as shown in table 2.

Table 2 – Total costs (in millions of R$) for each of the interconnection possibilities.

	TPP 1	TPP 2	TPP 3	TPP 4
CANOINHAS SUBSTATION	25	3	25	28

	TPP 1	TPP 2	TPP 3	TPP 4
GUARAMIRIM CITYGATE	142	171	131	219
BRUSQUE CITYGATE	177	192	128	217
SÃO PEDRO DE ALCÂNTARA CITYGATE	256	246	144	216

Based on the data above, this paper will study the following cost objective function:

Minimize: $3X_{12} + 9X_{13} + 6X_{14} + 142X_{25} + 171X_{26} + 131X_{27} + 219X_{28} + 177X_{35} + 192X_{36} + 128X_{37} + 217X_{38} + 256X_{45} + 246X_{46} + 144X_{47} + 216X_{48} + 25X_{5.9} + 3X_{6.9} + 25X_{7.9} + 28X_{8.9,}$

Subject to the following restrictions presented in table 3:

Table 3 - Problem Constraint Equations

$- X_{1.2} - X_{1.3} - X_{1.4} = - 1$	$+ X_{2.6} + X_{3.6} + X_{4.6} - X_{6.9} = 0$
$+ X_{1.2} - X_{2.5} - X_{2.6} - X_{2.7} - X_{2.8} = 0$	$+ X_{2.7} + X_{3.7} + X_{4.7} - X_{7.9} = 0$
$+ X_{1.3} - X_{3.5} - X_{3.6} - X_{3.7} - X_{3.8} = 0$	$+ X_{2.8} + X_{3.8} + X_{4.8} - X_{8.9} = 0$
$+ X_{1.4} - X_{4.5} - X_{4.6} - X_{4.7} - X_{4.8} = 0$	$+ X_{5.9} + X_{6.9} + X_{7.9} + X_{8.9} = + 1$
$+ X_{2.5} + X_{3.5} + X_{4.5} - X_{5.9} = 0$	Xi.j greater or equal to zero:

Dantzig [14] and Pizzolato [15] already classified this type of problem has as Transport Problem, Network Flow Problem, Shortest path Problem or Least Cost Path. The constraint are responsible to balance all nodes of the transport network.

This is a Linear Programming problem because it has integer linear variables and can be solved by the SIMPLEX search method available in software GAMS (CPLEX) version Win32 24.4.3 or in MS-Excel 2013 (LP Simplex Solver). Both software solve this objective function and calculate the same result.The minimum investment cost of the optimized solution of the problem is R$ 159 million. The optimized location of TPP and its infrastructures are in Fig. 8.The detailed cost is: R$ 3 million of the Guaramirim citygate new metering system; R$ 131 million for acquisition of main equipment and materials of the Guaramirim up to TPP 3 gas pipeline; and R$ 25 million for acquisition of main equipment and materials of the transmission line between Canoinhas substation and TPP 3.There are transmission lines and gas pipelines with lower costs, but the optimized solution did not contain these infrastructures, since separately they do not contribute to obtain the lowest cost, in this case study.Considering the restrictions established this solution is the best location of a TPP within 90 km distance from Canoinhas, which is the destination for the transmission line of the energy produced at the Plant. It is important to highlight that the results obtained are valid considering the restricted scenarios delimited in this case study.

Fig. 8 – Optimized location of TPP and its infrastructures

V. CONCLUSION AND SUGGESTIONS

The main conclusion is that project cost will only be as small as possible as the route selection problem is treated as an optimization problem. The institutions involved in the licensing and authorization process of natural gas thermoelectric plants should investigate together whether the costs of these projects correspond to the costs obtained in projects with optimized location. Conducting this study in advance allows the detection of mistaken design assumptions.

The reduction of total length of infrastructure can reduce the total cost of investment. Low lengths allows lower environmental cost and smaller quantity of river and road crossings.There are limitations and assumptions in the case study. The case study goal was not solve a complete natural gas supply problem, since it did not consider the cost of gas and tariffs. Fine adjustment to increase the amount of cost variables with the application of more localization criteria will increase the accuracy of results. It's important consider that pipe length can be greater, considering the need to meet future demands and subjective factors can influence the process of optimal decision-making, such as political risk.It is suggested development of a database of location criteria data and create models in GIS software to verify the gas-fired TPP paths located in other states and cities in Brazil.A tool to conduct the exhaustive search of the best locations for new gas-fired TPP would be of great value to all those interested in the strategic implementation of natural gas thermoelectric projects.

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