Electric Power Systems Research 143 (2017) 163–173

Contents lists available at ScienceDirect

Electric Power Systems Research

journal homepage: www.elsevier.com/locate/epsr

Practical tool to aid the planning of complex electrical industrial systems—Oil and gas industry

Welton Verly, Leandro Ramos de Araujo*, Débora Rosana Ribeiro Penido

Department of Electrical Engineering, Federal University of Juiz de Fora, Juiz de Fora, MG, Brazil

ARTICLE INFO

Article history:
Received 2 June 2016
Received in revised form
22 September 2016
Accepted 10 October 2016
Available online 22 October 2016

Keywords:
Cable thermal modeling
Electrical losses
Genetic algorithm
Industrial electrical systems
Substation
Oil refinery

ABSTRACT

This paper presents an integrated computational method that supports design engineers with the elaboration of industrial distribution network projects during the conceptual and basic design phases. The method proposes various electrical topologies based on studies of electrical power flow and short circuit analysis and provides the specifications of the main electrical equipment (cables, transformers, and panels). The method also provides a technical and economic analysis of the presented solutions. In addition, the paper proposes a general method that accounts for the intrinsic thermal effects of the cables in any electrical system, which can have a significant impact on the electrical system results. An example of a complex and large scale oil refinery planning is presented.

1. Introduction

Planning of industrial electrical systems is a complex process that entails multiple variables and constraints that are not always well-modeled and/or clearly identified. Relevant examples include geographical constraints, electrical constraints, policies, economic aspects, and reliability issues. Identifying these constraints can be useful when planning distribution systems and large industrial systems [1–3].

Several methods are proposed in literature for planning and designing urban electric distribution networks; [4–12] however, very few studies discuss or analyze the planning and sizing of industrial electrical systems, especially, large-scale systems [13–16]. The primary distribution network topology is widely discussed in literature, typically focusing on urban distribution networks. The main objectives of this paper is to discuss the planning and sizing of primary distribution network topologies and to apply these methods to large industrial networks, such as oil refineries. In this context, the proposed algorithm merges the mathematical modeling and design rules that are currently applied in the petroleum industry.

In spite of the occasional crisis-related outliers, the ever-growing demand for oil products and the continuous modernization of oil processing units amplify the need for electric power during petroleum processing, which inevitably increases the complexity of a refinery's electrical system. Accordingly, the number of large electrically driven machines is soaring at the expense of steam driven systems, with the increasing number of units required for processing and internal generation. Such complications and consequent interconnections complexities present a great challenge while planning industrial electrical systems of oil refineries.

Based on studies of electrical power flow and short-circuit analysis, this paper presents a versatile technique that tackles various electrical network topologies to provide specifications for the main electrical equipment (cables, transformers, and panels) within a network. The technique adjusts the cables' thermal effects and load variations while providing near-optimal substations allocation. This technique is proposed due to the need to reduce equipment and operational costs and incorporate technical and economic analysis for the provided network solutions.

2. Basic aspects in the planning of electrical industrial systems in the oil & gas industry

Oil refining is a complex process that requires high reliability to prevent large potential profit losses, as interruptions to a processing unit present substantial financial losses. To put matter into scale, small refineries estimate loss values of US$ 100,000.00 per hour per unit stop. Therefore, the reliability of the relevant electri-

* Corresponding author.
E-mail address: leandro.araujo@ufjf.edu.br (L.R. de Araujo).

http://dx.doi.org/10.1016/j.epsr.2016.10.027

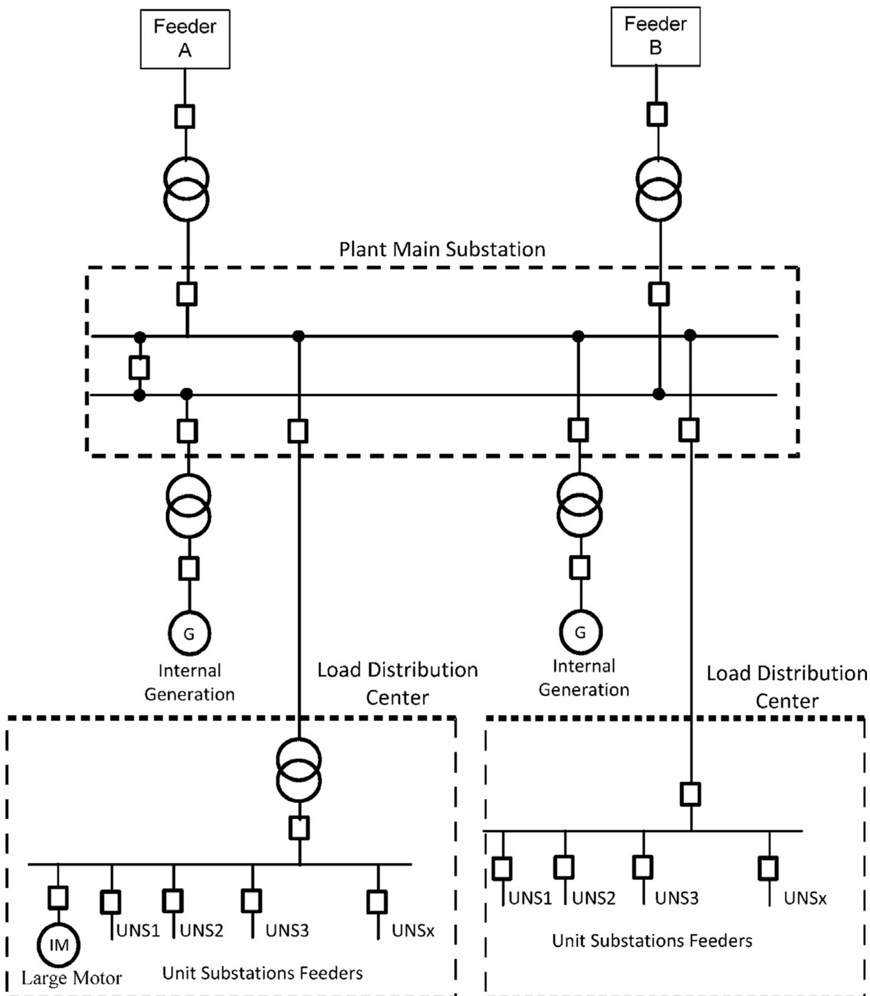

Fig. 1. Main substation and distribution centers.

cal systems is critical, i.e., a failure of electrical equipment should not impact the continuity of the process. This condition is usually met by the existence of redundancy equipment in oil refineries, which complicates the electrical planning process [1,2].

The electrical demand of an oil refinery is supplied through the combination of self-generation and the utility electrical system. Many refineries are electrically self-sufficient, but retain connection to the utility network for reliability enhancement. Fig. 1 shows a typical topology for an electrical distribution system of an oil refinery, and highlights the self-generation and connection to utility (through Feeders A and B).

The Plant Main Substation is the coupling point between the industrial system and the utility system.

The Load Distribution Centers (LDC) are also called Power Islands, they are a power source for unit substations (UNS). The LDC normally do not present generation and they are connected directly to the main substation (Fig. 1). The main function of the LCD is delivery power to the loads (large motors or/and unit substations) and not physically overloading a single substation.

The UNS are responsible for power supply of loads and process units. The topology used in this work is shown in Fig. 2. For reasons of reliability and operational flexibility, the topology of the substations are selective secondary [1]. As can be seen in Fig. 1, each unit substation (Fig. 2) is powered by two feeders.

The loads can be powered through two separate feeders in the secondary selective configuration as shown in Fig. 3. In II-configuration, each feeder energize approximately half of the loads in the secondary busbar. In the L-configuration, a feeder energizes all the secondary load. This operating condition is usually associated with a contingency and has the highest voltage drops. In U-configuration, the two feeders energize the total load in the secondary busbar. Despite a lower voltage drop and lower losses, this condition is generally avoided because it has large short-circuit current values.

The 440–460 V induction motors up to 55 kW are allocated to Motor Center Control (MCCs) and induction motors up to 130 kW are allocated to Load Center (LC) as shown in Fig. 2. These values are a design premise and can be modified.

It should be noted that the electrical systems of the oil industry facilities are usually large and complex, for example, for an installation with electric power of 100 MW, it is necessary to the sizing approximately 70 transformers, 400 MCCs, 350 LCs cubicle, 40 km of medium voltage power cables, besides the location of substations and substation voltage levels. During the stage of the basic design is necessary to evaluate several substations location, voltage level alternatives and realize the sizing of the principal equipment for technical evaluation. For each alternative is necessary realize the studies of power flow, electrical losses, short-circuit, besides the financial aspects. An estimated amount of 500 man-hours for completion of the basic design is necessary even using the existing tools on the market [17,18]. These commercial tools, although aiding the development of the basic project, do not allow the optimization and analysis of various electrical aspects. The proposed method performed the optimization and plant sizing in a few minutes.