Computers and Mathematics with Applications 61 (2011) 715–721

Contents lists available at ScienceDirect

Computers and Mathematics with Applications

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

Algorithm for cataloging topologies in the Common Information Model (CIM)

Imre I. Lendak [a,*], Aleksandar M. Erdeljan [a], Dragan S. Popović [b]

[a] *Faculty of Technical Sciences, Trg Dositeja Obradovića 6, 21000 Novi Sad, Serbia*

[b] *Telvent DMS Llc, Sremska 4, 21000 Novi Sad, Serbia*

ARTICLE INFO

Article history:
Received 26 August 2009
Received in revised form 29 October 2010
Accepted 10 December 2010

Keywords:
Catalog of topologies
Graph isomorphism
Smart Grid
Common Information Model

ABSTRACT

This paper presents a novel algorithm for finding the catalog of topologies in a power system's model in the Common Information Model (CIM) format. The algorithm prepares the models of complex, large-scale power systems (e.g., Smart Grids with renewable energy sources) and allows analytic Distribution Management System (DMS) functions to achieve high performance and optimize the power system operation in real time. It utilizes the Ullmann graph isomorphism algorithm to find unique topologies. In addition, it is optimized for parallel execution on 64-bit, multi-processor computers. Its ability to handle large amounts of data was verified on detailed, real-life electric power system data.

1. Introduction

Modern human society depends on the continuous services of large-scale critical infrastructure systems such as electric power and water distribution systems. Power systems are becoming increasingly significant for the continuous operation of an increasing number of secondary services, e.g., telecommunication, heating, and finance. Utility companies producing, transmitting and distributing electricity are under constant pressure to produce more and at lower prices, while taking into account environmental impacts. There are various ways to enhance power system operation: improve energy efficiency, install renewable energy sources (e.g., using wind power or solar panels), design better electric equipment or improve the control of existing power systems. These enhancements can all take the system closer to a truly Smart Grid [1].

Engineers assisted by powerful software solutions installed in control centers can optimize system utilization by sophisticated analytic functions for Distribution Management Systems (DMSs), e.g., optimal network reconfiguration [2], voltage/var control [3], and fault location, isolation and supply restoration (FLISR) [4]. Optimal network reconfiguration allows engineers to optimize operation by connecting some network loads to different supply paths without direct investment in hardware. Voltage/var control optimizes transformer and capacitor bank control, thereby maintaining the voltage profile within acceptable limits and reducing losses. FLISR automatically locates the sources of faults, isolates them and restores supply without operator intervention.

These analytic functions contain intensive calculations run in a closed loop, and they require an optimal representation of the power system (i.e., a model). Modern computers have the necessary computing power and are capable of running these calculations in real time. As far as system representation is concerned, a well-known model is the International Electrotechnical Commission's (IEC's) Common Information Model (CIM) [5], which defines an object-oriented model of electric power systems and represents resources as classes and associations between them. In the CIM, the power system is represented with a graph: pieces of conducting equipment (e.g., fuse, section, transformer winding) are the edges and

* Corresponding author. Tel.: +381 63 855 0 744, +381 21 6350 992; fax: +381 21 458 873.
E-mail addresses: lendak@uns.ac.rs, lendak@gmail.com (I.I. Lendak), ftn_erdeljan@uns.ac.rs (A.M. Erdeljan), dragan.popovic@telventdms.com (D.S. Popović).

0898-1221/$ – see front matter
doi:10.1016/j.camwa.2010.12.021

Table 1
Example branch weights and symbols.

Equipment	Abbreviation	Weight
Breaker	BRK	2^0
Disconnector	DIS	2^4
Fuse	FUS	2^8
Power transformer	TRF	2^{12}
Induction motor	MOT	2^{16}
Busbar	BUS	2^{20}
etc.	...	$2^{4(n-1)}, n \in N$

connectivity nodes are the vertices. A potential problem in the CIM is the fact that it needs relatively large numbers of abstract entities (connectivity nodes and terminals) for modeling connectivity [5].

Field experience shows that power systems contain identical equipment connections which occur in multiple places. The description of these repetitive connections can be centralized into the catalog of topologies. The current version of the CIM does not contain an implementation of this concept, although there is an initiative to introduce it [6]. If the CIM data is extended with it, then considerably less computing power is necessary to find the power system's bus/branch model [5]. This in turn enhances the analytic function performance and allows power system optimizations in real time.

This paper presents a novel algorithm which populates the catalog of topologies. The algorithm's input is a power system's data model in the CIM format. The catalog of topologies is found in multiple steps: representing the power system with a mathematical graph, breaking it down into subgraphs, and then finding unique subgraphs by the modified Ullmann graph isomorphism algorithm [7], which was extended with support for weighted graphs and optimized for 64-bit computers and parallel execution. The proposed algorithm was successfully verified in the preparation of real, large-scale power system models for real-time calculations and optimizations of Smart Grid DMS analytic functions.

Following this introduction, this paper is organized into four further sections: Section 2 describes the proposed algorithm, Section 3 discusses the achieved results, Section 4 expands on the scalability of the algorithm and Section 5 concludes the paper.

2. The algorithm

The catalog of topologies contains preprocessed metadata which extends the power system's switch/node model [5] and allows topology analysis to build the bus/branch model faster. This paper proposes an algorithm which populates the catalog of topologies. It accepts a power system's model in the CIM format as its input and generates a catalog of topologies as its output. It consists of three complex steps: representing the power system with a mathematical graph, decomposing the graph into subgraphs, and de-duplicating the subgraphs.

Step 1: *graph representation*

The input of this step is an electric power system's switch/node model in the CIM format. The output is a mathematical graph formed from the input. As large power systems usually consist of thousands of connected substations, which in turn contain multiple pieces of conducting equipment, even their simplified views would require large diagrams for their representation. Therefore a simplified high voltage substation will be used as an example throughout this paper—see Fig. 1(a), which shows one such simplified substation.

The power system's model is represented with a weighted [8] graph $G = \{V, E, W\}$, in which

1. V is the set of vertices which is formed from the set of connectivity nodes (instances of the CIM's ConnecitivityNode class)—one vertex is created per busbar (full circles in Fig. 1(b));
2. E is the set of edges, and it is formed from the set of conducting equipment instances, e.g., switches, fuses, sections, transformer windings, etc. The algorithm can work with a single edge per transformer (for two winding transformers) or with an edge for each transformer winding. In the latter case, an additional vertex should be inserted at the core of each transformer;
3. $w(e) \in W, \ \forall e \in E$—unique edge weights are assigned to each edge based on the type of the corresponding conducting equipment.

Fig. 1(b) shows graph G, which represents the simplified substation shown in Fig. 1(a). Weights are represented by three-letter abbreviations chosen for each CIM type: e.g., BUS for busbars, MOT for motors, etc. While these equivalents were introduced to make the figure easier to understand, the implementation of the algorithm uses the numerical weights listed in the third column of Table 1 (calculated by the formula $2^{4(n-1)}, \ n \in N$, as explained later). These type codes are not fixed; neither is their number, nor their assignment.

The algorithm shows how to form a machine-interpretable, weighted graph from CIM data. As the connectivity nodes in the CIM do not differentiate inputs and outputs – i.e., all equipment terminals attached to them are treated the same – the resulting mathematical graph is undirected. Due to the nature of power systems, where the order of set V can be very large and the number of edges connected to a vertex is small (usually less than 10; busbar nodes have the most), graph G is sparse.