Intelligent Planner for Electrical Substation Restoration

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Abstract: **-** This paper presents an application of functional modeling used for acquiring AI planning knowledge of substations, this knowledge will be used to generate restoration plans when a fault happens. It will be shown an approach to acquire the planning domain knowledge of substations plants based on Multilevel Flow Modeling (MFM), and how to map the MFM functions in a planning representation. And more, it will be shown the operation of an intelligent planner and its future applications in the automated supervision and control systems used in electrical substations.

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1 Introduction

The great increase of blackouts' number in Brazilian power system is a consequence of the system overload and the investment lack in the electric sector. Besides, the impact of prolonged blackouts on the consumer, economy, and on the power system itself makes rapid effective restoration very important [1].

An important part of power systems is the electrical substation, which assist the need of interconnection, transformation and control of the power system.

The restoration of the normal configuration of a substation, after a fault, is performed by intervention of a human operator. Considering the growing complexity in the arrangement of the substations, the probability of human failure, and the spent time in the execution of the restoration actions are large.

A decision support system that aids the restoration of a substation should have means for:

- evaluate the agent of the occurrence;
- define the defective area which was isolated by the performance of the protection;
- characterize the defect is permanent or transitory;
- identify the involved components and the affected ones [2].

This work consists of applying AI planning joined with multilevel flow modeling (MFM) to develop a software package capable to contribute with the decision making of the human operator of a substation in a restoration situation.

The application of AI planning in real engineering systems has been shown to be particularly hard due to the problem of acquiring robust task knowledge from human experts. Furthermore, this knowledge, when acquired, is rather domain dependent and the acquisition effort is very seldom reused in other applications [3].

The use of automated systems in electrical substation, as well as its technical viability, is already consolidated in Brazil, with several equipment being offered in the market, and countless applications in the sector. These systems are based in the automation of the supervision actions, control and protection.

This paper is organized as follows: Section 2 describes the built models for a simple bus substation (138kV), usually found in the power system, and the MFM functions used are detailed. Section 3 shows how it is derived the planning knowledge from the MFM model, and presents the operators ENABLE and ESTABLISH in a generic form. Section 4 overviews the structure of the developed system and its operation. Section 5 draws the conclusions and future applications.

2 Functional Modeling of Substations

Functional modeling techniques capture which functions the parts of the system can accomplish individually or together, and how these functions are accomplished.

A multilevel flow model constitutes a significant advance in abstracting the high-level functional description of a system from the low-level technical implementation details [4].

MFM uses the whole-part and means-end decompositions to represent a man-made engineering system.

The means-end decomposition seeks to identify the functions of the components and their relations to the goals of the system. The functions are ascribed to the system to achieve a specific goal and there is no meaning to specify functions which do not contribute to achieving goals.

The whole-part decomposition is used to describe refinements of a function in order to present more details of its realization. This process create hierarchical structures and new functions and goals are generated [5].

The construction process of a MFM model is highly dependent of the abstraction level desired. A system can be described in many different point of view, and it can define several representation levels.

In a substation plant, there is just energy flows, since it is not being considered information and mass flows. To build the MFM model of a substation plant it was necessary to split the substation in several structures: transmission lines, input bus, transformers, output bus and loads. Each structure has a MFM model that achieves a goal, this goal is a precondition for the following structure. In Figure 1, it is being shown a MFM model for the transmission lines of a *simple bus substation*.

The MFM model of a transmission line does not include the filter and the lightning rod, because they are not important for restoration task. The two balances BaN1 and BaN2 represents two nodes of the diagram. S11, D1 and S12 are joined in the transport TrDS1 because they work together and execute the same function.

These MFM functions have been defined to assist the objective G1, that is, energize the input bus. Kindred that the transport TrDS1 can work correctly the goal GD1 has to be achieved by the second structure.

A MFM model was not used for the protections, instead of this it was used a group of rules that gives a Boolean condition of operation. All protections foreseen for a transmission line and the differential protection commonly used in buses are inside of the second structure shown in the Figure 1.

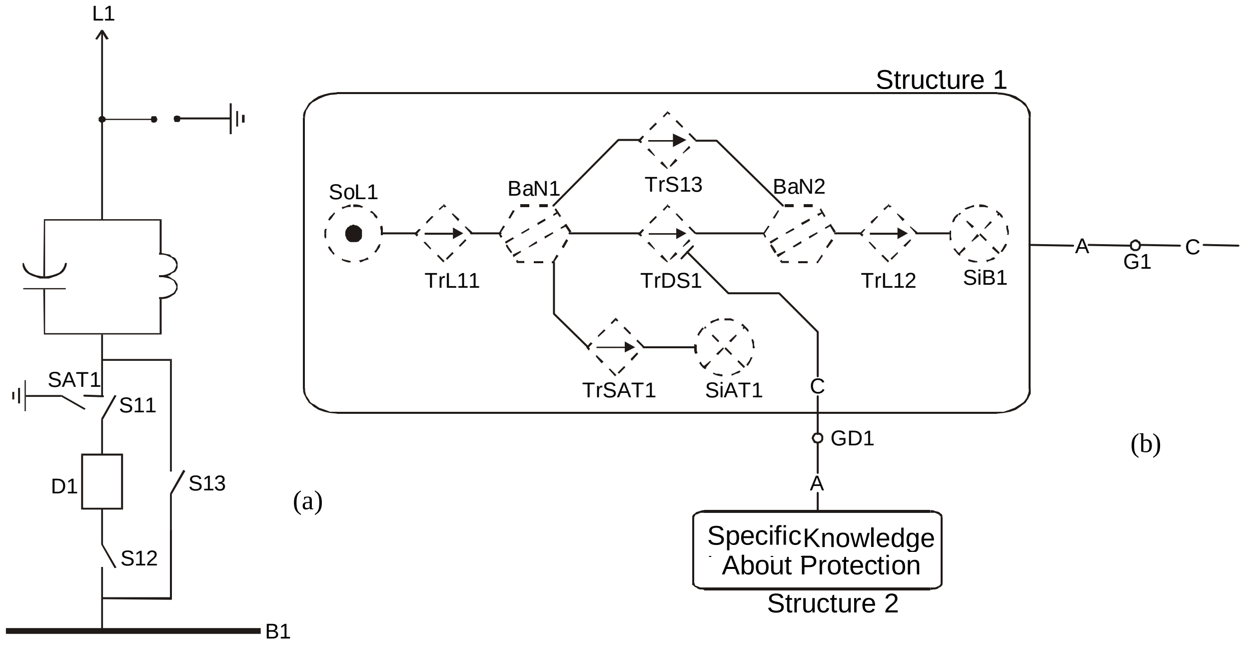

Fig. 1 - a) Diagram and b) MFM model for transmission line

In Figure 2, it is being shown a MFM model for the input bus. The function SoB1 is activated by G1, and it can have more than one structure shown in Figure 1 achieving G1 if it has more than one transmission line.

As the transformers have different current and voltage levels in the primary and secondary windings, the transformers were divided in two different functions: a sink function for the primary winding and a source function for the secondary winding.

Two transformers are had, T1 and T2, each one of them achieves a goal, G2 and G3, that are energize the secondary winding of the transformers.

In Figure 3, it is being shown a MFM model for the transformer T1. The function SoST1 is conditioned by goal G2. This structure achieves goal G4, that is energize output bus. The function TrDT1 is similar to the function TrDS1 in its operation. For each transformer a structure is had, as shown in Figure 3.

In Figure 4, it is being shown a MFM model for the load C1. The function SoBP is achieved by goal G4. This structure achieves no goal, since it's the last structure of the model. The function TrDC1 is similar to the function TrDS1 in its operation.

For each load we will have a structure as shown in Figure 4. The goal G5, that is energize transfer bus, is achieved by another structure that represents the connection of main and transfer bus.

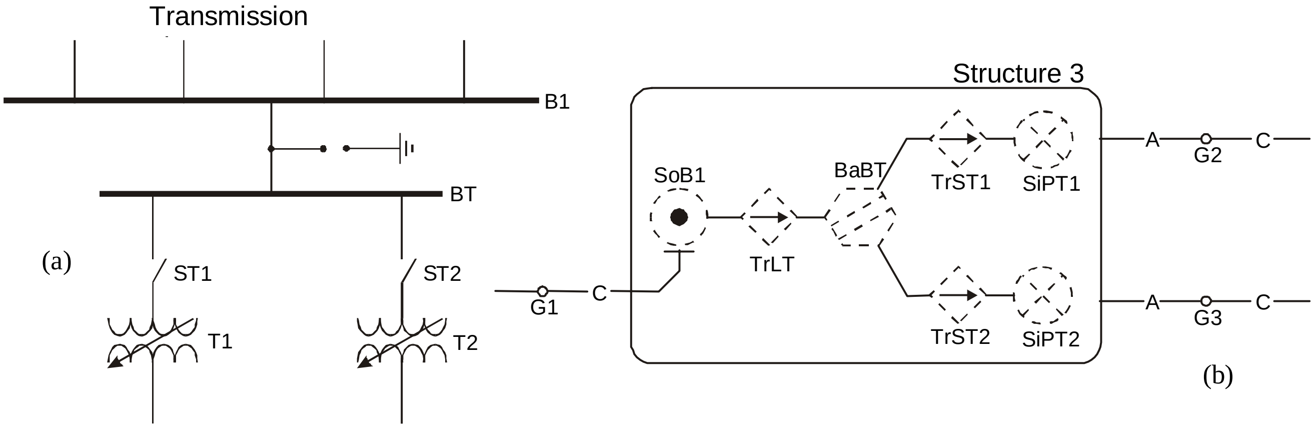

Fig. 2 - a) diagram and b) MFM model for input bus

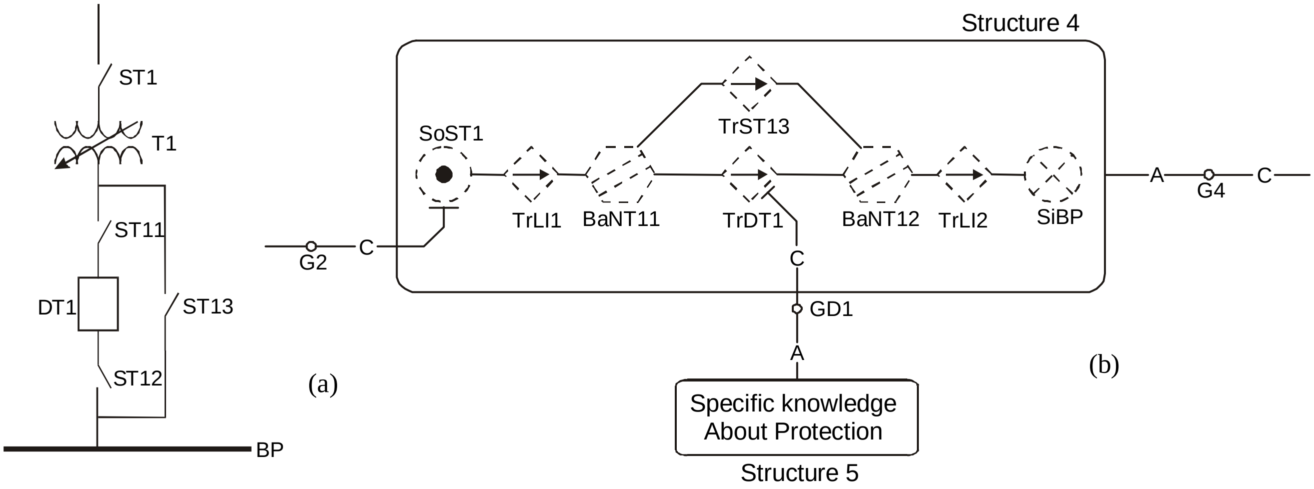

Fig. 3 - a) diagram and b) MFM model for transformer T1

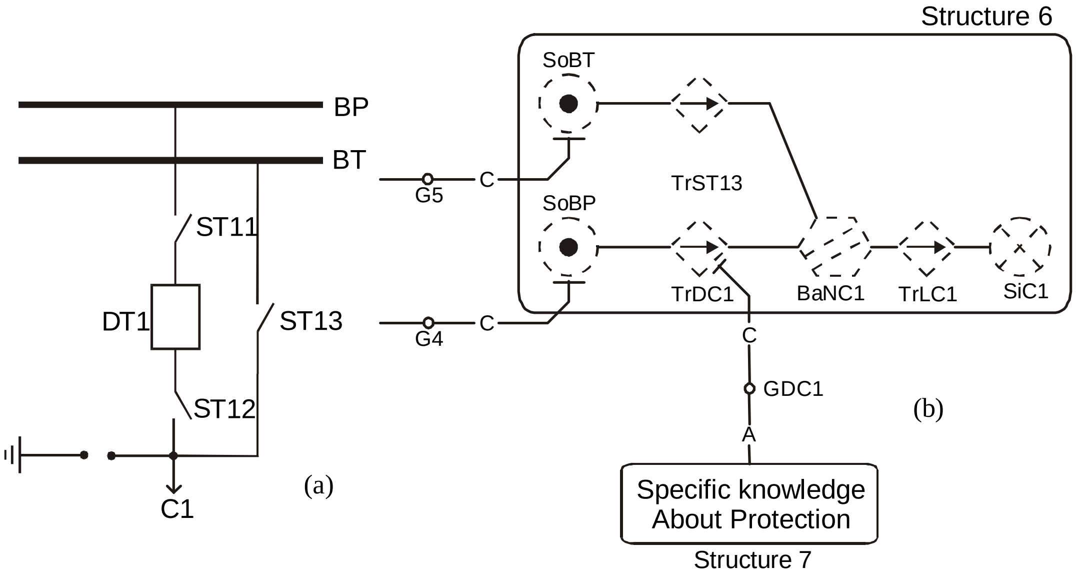

Fig. 4 - a) diagram and b) MFM model for load

3 Deriving Planning Knowledge from MFM

According to Larsen [6], the process of developing a start-up plan for a MFM modeled plant may be compared to the problem of establishing each function in the model.

A function can be established when both the underlying neighboring functions in the model are in states as intended by the designer and contribute to achieving the operational goals. Before establishing a function it must be enabled. A function can be enabled when it is ready to be integrated with other functions, that is, it is ready to provide an useful behavior but is not yet working.

Based on this concept, it was built a planning domain composed of generalized operators to enable and establish the MFM functions shown in Figure 5.

When the functions of the models are being enabled, the objectives related to the structures of specific knowledge about protections are processed at the same time. And, when the functions are being established, the objectives related to the junction of structures are processed at same time.

The mapping functions, defined in the interface on Figure 6, are responsible for defining the planning variables in agreement with the acquired and stored knowledge in MFM representation. It was used three types of precondition for mapping knowledge from an MFM model [7]:

- Preconditions that can be derived from the model topology;
- Preconditions to support the basic behavior of a MFM function, called process state preconditions;
- Preconditions associated to the human operator activities, called user task preconditions.

The topological structures describes the means-ends MFM relationships. For each function defined in the model the neighboring functions, previous and next functions, are identified and organized in structures.

The structures of process states capture the specific knowledge of a domain. A knowledge should be acquired as a process state when it represents a condition that should be satisfied kindred of supporting the basic behavior of a MFM function.

The solution of a planning problem consists of a sequence of actions that if executed it will take the system for an objective state. These actions are derived of the domain and they usually represent an user action. If an external action is requested to establish a MFM function, then the knowledge that represent that action should be acquired and stored in the corresponding structure.

4 Intelligent Planner

The proposed system is shown in Figure 6, and is divided in four parts: a knowledge acquisition interface, a modeling system, an interface and a planning system.

The knowledge acquisition interface generates a database of the parts and equipment of the substation, protections and user tasks. This substation database is divided in two parts, the second one is the substation's MFM model.

```
Operator ENABLE <F>
Var:
    <F> Function
    <NF> Next Function
    <PS> Process state
    <GD> Goal
Pre:
    Enabled <NF>
    Goal Achieved <GD>
    Structural-pre <PS>
Add:
    Enabled <F>
```

(a)

```
Operator ESTABLISH <F>
Var:
    <F> Function
    <PF> Previous Function
    <A> User Task
    <G> Goal
Pre:
    Enabled <F>
    Goal Achieved <G>
    Established <PF>
    Activity <A>
Add:
  Established <F>
```

(b)

Fig. 5 - Generic Representation of a Operator a) ENABLE and b) ESTABLISH

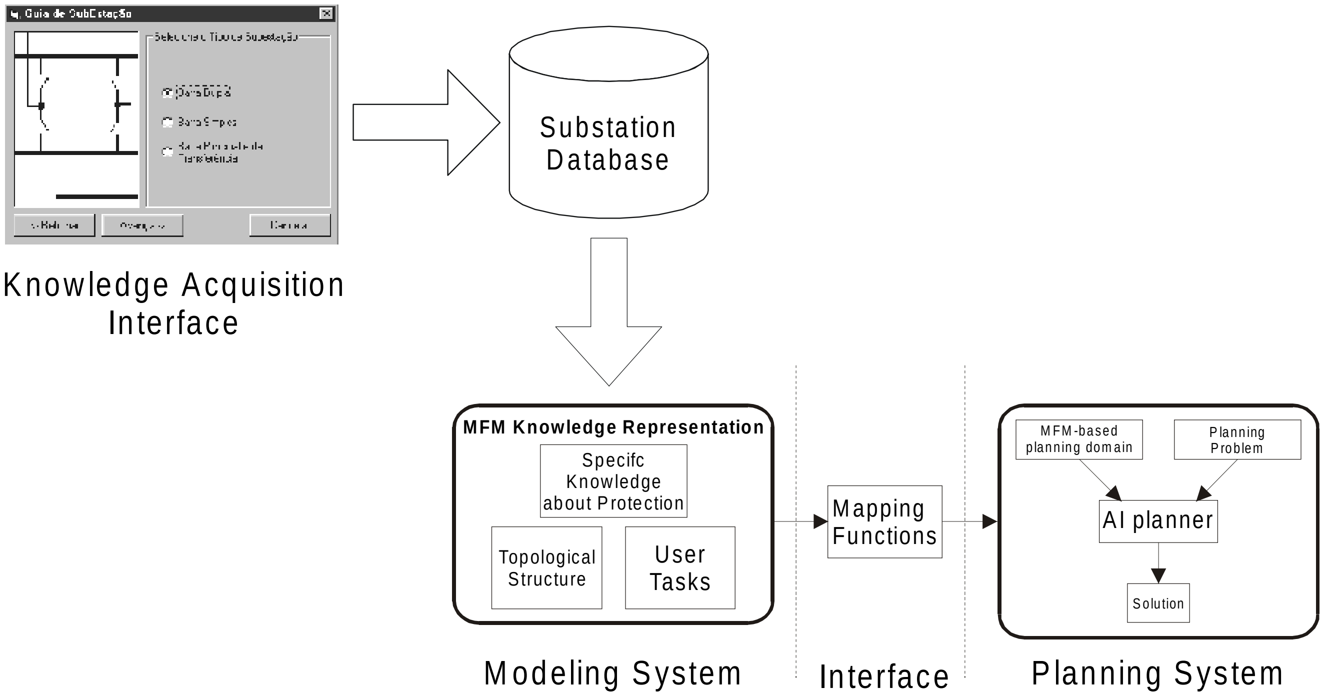

Fig. 6 - Integrated Framework of a Intelligent Planner for restoration tasks

The modeling system provides an intermediate step to acquire planning knowledge while maintaining an easy way to add or modify knowledge of each MFM function. This system uses the MFM database acquired and build the planning domain.

The interface between the MFM and the AI planner is realized by a set of mapping functions, that are responsible for initialize planning variables and operators. These functions maintain an independence between modeling and planning system.

And finally, the planning system is responsible for generating a series of complex plans based on the current state of the substation and according to the domain knowledge specified [3].

5 Conclusions

The MFM modeling technique has been shown appropriate to acquire planning knowledge, even so it is just efficient in relation to the knowledge of substation's topology. As the acquisition of knowledge is based on the MFM model, the obtaining of a good model is fundamental.

The planning domain based on MFM can be understood easily, even so it is necessary the development of specific operators according to the application. The necessary modification for application in another topologies of substations is internal to the structures, in the arrangement of the functions, facilitating the maintenance and offering flexibility.

For future development, the integration of the intelligent planner with an automated system of supervision and control of electrical substation is had, and also the application of diagnostic reasoning algorithms for: measurement validation, alarm analysis and fault diagnosis [8].

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