

ELECTRIC POWER CONTROL USING A GLOBAL HYBRID APPROACH

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ABSTRACT

There is strong evidence for the need for software systems capable of efficiently and robustly automating diagnostic and control tasks related to the generation, transmission and distribution of electrical power. Although researchers and developers have recognized the need for such a device, the vision, as yet, has not been realized. Two requirements, integral to the success of a global power controller, have represented major obstacles to be solved in realizing this objective. These are 1) the problem of automatic decision making in the face of complexity in the system being monitored, and 2) the problem of making power control decisions very quickly as well as reliably. This is because a power system is typically complex, and its behavior is a product of many interacting parameters. Techniques from artificial intelligence have been successfully utilized by others to advance the state of the art in automatic diagnosis and control. It is our firm belief that the best means of overcoming the technical obstacles will be the application of AI in the form of *model-based reasoning*. This belief is justified by concrete research results. Yet, the predominant sentiment among researchers in model-based reasoning is that significant innovations must still be made to the model-based paradigm before it can be effectively applied to the electric power systems domain. In this paper, we describe the concept of hybrid reasoning, where

traditional model-based reasoning techniques are combined with qualitative reasoning to achieve the greatest possible simplicity and, therefore, speed.

INTRODUCTION

To correctly anticipate the behavior of a power system for diagnosis and control, a controller must possess an accurate and robust representation of the behavior of the system (a *model*). Furthermore, in order to be effective, the controller must also possess the ability to very quickly respond to unanticipated events, including taking necessary control actions, in time to protect the device from permanent damage, while maintaining flow of power to all critical loads. Such a response time is typically very short (in the order of a few hundred milliseconds).

These two requirements are conflicting in nature and thus quite difficult to overcome together; the inherent complexity of a power system will result in the need for more computations in the process of executing control strategies, thus making fast response time more difficult to achieve.

Our work has centered in applying a conflict-oriented approach to the problem. This approach is fully

described in [McKenzie, 1994]. Briefly, it consists of creating sets of system components whose collective behavior could not explain the discrepancy detected. By comparing the makeup of the various conflict sets, not only among themselves but also against the list of components which are not on any conflict set, most of the normally-behaving components can be definitively identified and exonerated, leaving only the failed component as the culprit.

This technique has the advantage of simplicity and speed. It does not require the computationally-expensive constraint and observation propagation necessary in the constraint suspension technique. It also does not require the a-priori fault definitions inherent in fault modeling techniques. However, it has some drawbacks which must be compensated before an intelligent power controller is a commercial reality.

Exceptions in the Conflict-based Controller

Using the simplest type of model available makes for few computations and maximum speed of operation. A model which only models the current flow through the circuit would be the simplest model for a power distribution system. Such a model makes certain assumptions about the state of the power system that may be true under most normal circumstances (i.e., constant voltage). However, the ability of the Conflict-based diagnoser to identify faults in a power system is as good as the model being used to represent the monitored system. Therefore, the sphere of effectiveness of the existing controller prototype (called the *intelligent power controller*, or IPC) is currently limited to:

- 1) Radial distribution systems
- 2) Passive loads (i.e., loads that do not act as sources during a fault)
- 3) Faults where the number of resulting discrepancies is small.

Limitations 1 and 2 are quite acceptable in power distribution systems. These systems are, with few exceptions, radial in structure, and the typical motor load is too small to act as a generator during the few cycles after a fault. However, the third limitation can be quite restrictive and compensation for it may be required.

One example of the third limitation occurs in the case of hard faults where primary local protection is either not available or fails. In these, the voltage is likely to decay significantly in the buses that are electrically near the fault. The reduced voltage will cause reduced current through the lower level branches, and result in a current discrepancy. If

the system impedance is low, this voltage collapse may be widespread, resulting in numerous discrepancies being reported. The Conflict-based reasoner with the simplest current-only model will be led to erroneously identify the top level component as the location of the fault. There are two means of solving this problem from a theoretical point of view: 1) using a robust model which includes all the parameters measured and compared which are inherent in a power system, and 2) switching to a hybrid reasoning technique which can use a new model that incorporates voltage as well as current in its calculations.

The first alternative is more theoretically robust due to the attractiveness of maintaining only one model active at all times. However, the more complex the model, the more computationally expensive it becomes. Therefore, there is some attraction to using the simplest model possible at all times, and switch to a more complex model only when it becomes necessary to do so.

The simplest available model, by necessity, makes some assumptions about the state of the system. In a normally operating power distribution system for example, an assumption of nearly constant voltage throughout can be made. When that assumption, or any such other one, is determined to be invalid, then an alternate model is activated whose greater complexity allows it to not have to make that assumption. This is the multiple model approach, where different models account for various aspects of the power system being monitored. We call this approach Aspect Modeling [Morris, 1993].

Yet, replacing a simple model by a more complex one may slow the process of identifying and isolating the system fault to the point of being too long. Thus, the reasoning mechanism may have to also be simplified in order to speed up the process. Another feature of the proposed approach is the use of qualitative reasoning to identify the faulty component. We refer to the combination of these two techniques as the hybrid approach.

In order to better describe the approach being proposed, we discuss the example of the voltage collapse exception of the Conflict-oriented approach.

Example of Exception - Voltage Collapse During a Fault

Figure 1 shows hard fault in a bus for which there is local primary protection. The sensor discrepancies seen by the IPC (after fault interruption) are in the branches indicated by X's in the circuit breakers. Those below the fault are discrepant because the circuit breaker above them

has tripped, isolating these loads from the power source. Those above are also discrepant because currents measured won't add up to the value expected by running the model. This is, of course, due to the open loads downstream. This situation can be easily diagnosed by the current Conflict-based diagnoser using a current-only model.

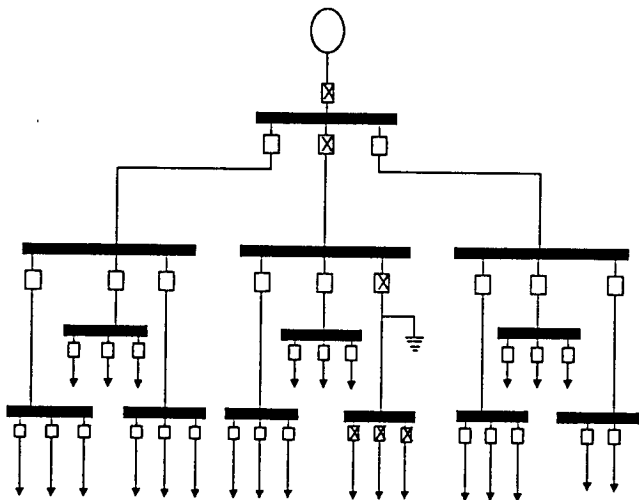


Figure 1 - Discrepancies for a Hard fault with no Voltage Collapse

Likewise, Figure 2 depicts a soft fault at the same location. An important assumption, as will be seen later, is that the voltage levels at the busses remain unchanged, or nearly so. Discrepant branches are once again indicated by X's in the appropriate circuit breakers. In this type of situation, the loads downstream from the soft fault will continue to operate normally since there is no voltage decay. Therefore, discrepancies will only exist in branches originating from the fault all the way to the source. This type of situation will also be easily diagnosed by the Conflict-oriented diagnoser with a current-only model.

Nevertheless, an uninterrupted soft fault is not the same as an uninterrupted hard fault because the latter may cause a voltage decay throughout the circuit. This decay may result in loads pulling less than rated current, and thus appearing to be discrepant, as shown in Figure 3. This is not representable within the current-only model, and conflict-oriented algorithm. Since all paths in the system may be affected by this hard fault, it may not be able to isolate the

culprit element. Even if it does, it may be too slow to be effective as primary protection.

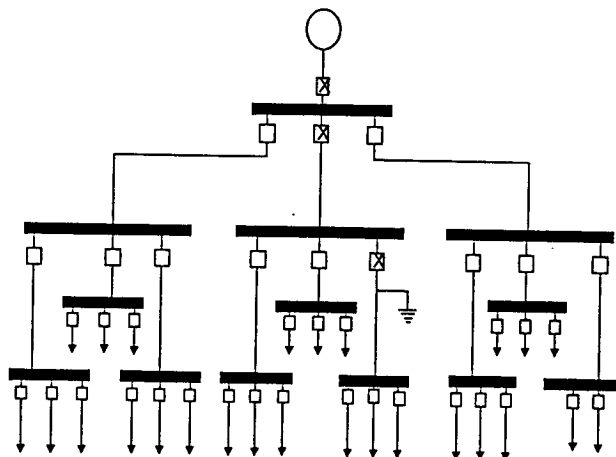


Figure 2 - Soft Fault with no Voltage Collapse

HYBRID REASONING WITH MULTIPLE MODELS

The solution may lie in the use of a robust modelling capability to diagnose, and not merely to detect discrepancies. In order to do this, three enhancements to the current Conflict-based IPC diagnosis technique may be required:

- 1) Ability to use a more complex model which includes monitoring of voltage levels throughout the circuit.
- 2) The use of some general heuristics to determine in which branch the fault is taking place.
- 3) Implementation of fault models derived from the quantitative models to facilitate matching of conditions in the circuit to the heuristics.

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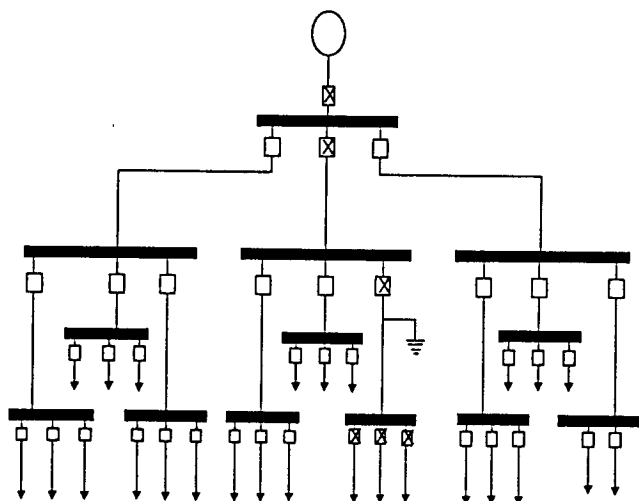


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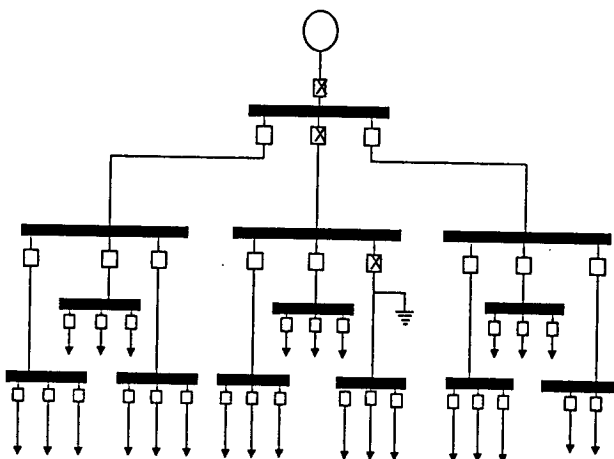


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The more frequent use of the model may further require the implementation of a distributed computing

environment where the model execution is done by one processor while the diagnosis is done in another.

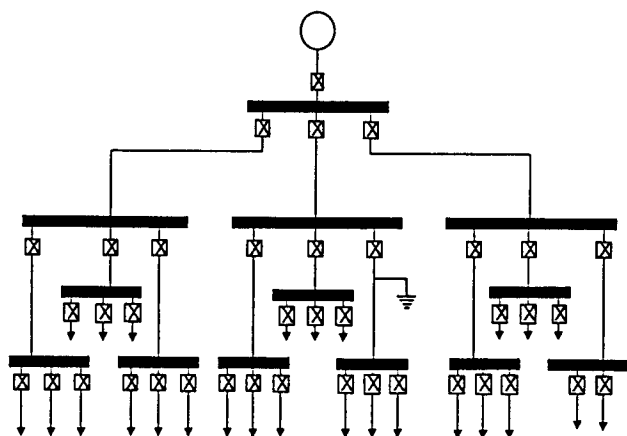


Figure 3 - Discrepancies during a Hard Fault with Voltage Collapse

The operation of the enhanced IPC would operate as follows for faults in radial power distribution systems:

During normal conditions, the monitoring function would continue as it does presently. Upon detection of a discrepancy in a current sensor, the IPC would examine the voltage sensors for evidence of a significant reduction in voltage. If none is found (i.e., no discrepancies in the voltage sensors), the IPC would operate as it presently does, to diagnose the fault, isolate it and provide an alternate path for power to critical loads, if any.

If, however, a discrepancy is registered in a voltage sensor, this would indicate that the voltage level at the busses has collapsed to some degree, and all current sensors below that voltmeter will be discrepant. In this case, a more complex model of the system being monitored, one which includes the voltage parameter, must be activated and used. Otherwise, the multiple (erroneous) discrepancies with the current-only model will invalidate the use of the Conflict-based diagnoser.

At this point, three options will exist: 1) Using the more complex model of the power system, re-calculate the discrepancies and apply the Conflict-based diagnoser, 2) use

fault models to identify the true discrepancies and neglect the others, allowing the Conflict-based diagnoser to operate correctly, and 3) use fault models to identify the fault location, bypassing the Conflict-based diagnoser altogether.

If the discrepancies can be represented correctly by the more complex model, then Option #1 is clearly viable. However, the added complexity of the new model may inhibit the speed of the diagnoser and thus compromise the effectiveness of the controller.

Option #2 has the advantage of using the first-principles reasoning inherent in the Conflict-based diagnoser. If the particular fault present is not accurately modeled by any fault model, the controller may still be able to include the correct component in its diagnosis. However, this process may be even slower, as it has to operate two models in sequence.

Option #3, called *fault modeling*, promises to be faster than the first two. The use of qualitative states can reduce the diagnostic process to simply matching system characteristics to those of various pre-defined fault models. These fault states can be cached off-line at the time of model generation, and would only need to be modified whenever any modifications are made to the system. This option will be the main topic of discussion in this paper.

Fault models have been used by other researchers to facilitate the search involved in model-based diagnostics that use a structure-and-behavior approach to modeling the monitored system. By being able to describe a-priori how a fault will manifest itself in terms of the system observations, the fault location can be more easily identified. Their disadvantage, however, is that they are not dependent on first-principles, as is the conventional model-based reasoning approach. When a fault model cannot be found that matches the situation, the culprit may not be identified, and control action will fail to isolate the fault.

One drawback to this technique is the potentially large numbers of fault models that would be necessary to encompass any non-trivial distribution system. One solution to that is to define these models as generally as possible, and be able to draw conclusions based on these general models. For that reason, qualitative models, which simply describe the current and/or voltage levels in relation to their normal or previous levels, may be the ideal solution.

For example, in the instance of the hard fault and corresponding voltage collapse, there will be three kinds of readings (see Figure 4):

- sensors measuring the current input to the loads directly downstream of the fault will read zero or nearly zero.

- sensors directly upstream of the fault to the source (or the infinite bus) will read very high values of current.

- sensors that are not in the branch of the fault will read decreased levels of current. In some extreme cases, they may also read zero, but that is not likely, as there will be some impedance in the lines between the source and the fault will support some voltage at the non-faulted branches.

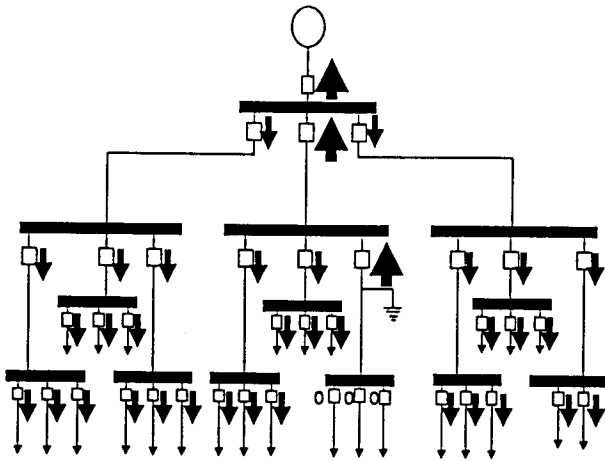


Figure 4 - Qualitative Description of Hard Fault with Voltage Collapse

These qualitative readings can be integrated into a qualitative model of the circuit's behavior under the fault conditions. Using these, it would be possible to very quickly isolate the branch in which the fault is located and initiate any recovery action through the same mechanism as for the Conflict-based diagnoser.

QUALITATIVE MODEL ALGORITHM FOR HARD FAULTS

Using the heuristics discussed above which can serve to describe an uninterrupted hard fault, the following two-step algorithm can be applied to the problem.

Step 1 - DETECTION

A) When the first discrepancy is detected, make readings in sibling buses to determine whether there is a collapse of voltage in the system

IF some readings are discrepant go into the qualitative fault model diagnostic algorithm.

ELSE use the standard Conflict-oriented approach.

Step 2 - DIAGNOSIS

A) Point to the highest level bus in the monitored system.

B) Make list of immediate downstream elements from the pointed bus.

i) Loop: Until list is empty:

IF: the measurement at the element is increased (+) Call this diagnostic algorithm recursively, pointing to this element as the new top level bus

ELSE: Discard branch from suspect list.

ii) END of Loop

C) IF culprit has not been found, THEN top system node is culprit

This algorithm will search out the branch where the current levels are much higher than normal. This will indicate the faulted branch. All other branches where discrepancies exist will exhibit current levels that are lower than normal, and are neglected by the algorithm, as they will not lead to the fault. As the algorithm searches depth-first down the suspect branch, it will stop when the current levels are no longer higher than normal. When this happens, the lowest level bus will contain the breaker to trip in order to interrupt the fault.

CONCLUSIONS

Conflict-oriented model-based diagnosis can successfully be used to protect a power distribution system from soft faults and recover loads which are therein defined as critical. However, in cases where the model of the monitored system does not account for certain behavior, the conflict-oriented approach may not work. In an attempt to remedy this situation, we describe a hybrid system based on conflict-oriented diagnosis and on qualitative fault models. This system is based upon the conflict-oriented diagnostic approach, but will quickly switch to an alternative mode comprised of qualitative fault models when the original approach will not suffice due to model deficiencies. An algorithm for handling hard faults is presented.

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- [McKenzie, 1994] McKenzie, F. D., "Using Robust Models to Represent Global Behaviors in Model-based Diagnosis", Doctoral Dissertation, University of Central Florida, 1994.
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