Intelligent System for Detecting "Hidden" Errors in Protection Settings

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Abstract- Due to many developments taking place within the electricity supply industry, the network and its operation has grown ever more in recent years, which brings significant challenges for power system protection engineers. Apart from the significant efforts that are required to ensure that the protection setting process is effective, work also needs to be carried out to check the validity of the settings after initial calculation and application. However, solely relying on personnel and procedures to assess the validity of the protection relay setting files may occasionally result in a hidden error (or errors) remaining undetected until an in-service mal-operation event is experienced. This may bring significant consequences, in terms of economic costs, potential safety hazards and damage to the reputation of the utility company. This paper will present the initial research of making use of artificial intelligence technology (expert system) to help protection engineers validate the protection settings. Existing expert systems for protection settings applications will be reviewed and a new intelligent system that can open a setting file and interrogate the protection functions and settings in the file will be introduced. The advantages of this novel intelligent tool over existing protection setting expert systems will be discussed.

Index Terms—Artificial intelligence, expert systems, power system, power system protection, power system relaying.

I. Introduction

The power network is developing quickly to meet the demands of the general trend for economic growth and is under pressure to meet increasing energy demand that will be required in the future, e.g. the increasing proportion of electric heating (as opposed to gas), growing population of electric vehicles, etc. Therefore, power system is expected to be more complex (e.g. with high penetration of distributed generation, storage, electric vehicles, smart meters, demand side management, FACTS, HVDC, possibly DC for lower voltages, etc.) with significantly increased load in the future. To meet these demands under existing network expansion constraints the system needs to be gradually transformed from a "conventional" system to a more intelligent and smarter system.

For power system protection engineers, the majority of work focuses on the setting of the protection system and its maintenance. It has been realised that solely depending on protection engineers for decision making in the setting of protection may lead to some undetected errors. These errors could result from the erroneous calculations, the engineers' misunderstanding or mistranslating of the setting policies, potential errors in the process of settings' application/approval, or network changes or events that may render the original (correct) settings erroneous under certain specific (unanticipated) circumstances. The field of power system protection engineering has increasingly been looking for methods to help solve current and emerging problems, and expert systems are a particular candidate technology that may be able to assist in this.

Expert system is a sub-discipline of artificial intelligence and has been popular since last two decades[2]. It is one of the most widely used techniques for protection setting applications. These applications normally focus on automatically carrying out protection settings. However, since protection settings depend largely upon the specific network configuration, and upon the nature of the protection scheme and the particular relays employed, these protection setting expert systems are either not very efficient or have limited applications. This paper will introduce a novel intelligent system, which detects hidden errors in protection setting files rather than carrying out the whole setting process. This is beneficial because it will save large amount of protection engineers' effort to verify settings. Other advantages of the new approach will be fully introduced later in this paper.

This paper is conducted into the following sections: Section II reviews the prior and existing research in the application of expert systems to power system protection settings. Section III introduces the proposed intelligent system and the last section will have a discussion of the advantages of the proposed intelligent system over traditional power protection setting expert systems.

II. Expert Systems For Power System Protection Settings

In parallel with the fast development of general computer science since the 1980s, artificial intelligence technology has also emerged and has been increasingly applied to solve real-world problems. There appears to be a trend towards increasing use of this technology in future years due to the fact that great efforts are being made to develop more intelligent products or systems and large motivation still exists to further reduce human labor in industry. Expert systems, as a sub-discipline of artificial intelligence, have been developed in many areas (including power system protection) to solve engineering problems, which, if implemented correctly, can be efficient, reliable and economical (e.g. less human labour may be required).

Reference [3] provides a very detailed description of the potential applications of expert systems in the area of power system protection. A large number of proposed areas of application have been developed and applied in recent years. Generally, there are four main application categories: protection performance analysis [4]; protection setting, and coordination [2, 5-8]; fault identification and location [9, 10]; and service restoration and remedial action [11, 12].

A. Expert systems for power system protection settings

As mentioned previously, the fast development of the power network has increasingly brought challenges to protection engineers. There are many publications over the last several decades which describe developed expert systems to automatically carry out protection settings[2, 3, 5-8, 13, 14]. References [2, 7, 8] report on the research into expert systems for protection settings of transmission lines. The work in [2] develops an expert system which provides comprehensive distance protection settings by generating all credible events that define the boundary limit of protection zones. Apart from zone reaches, zone time delay, the output of the system also provides optimal impedance characteristics, the fault detection settings and required relay sensitivity. This system is able to reliably calculate distance protection settings and also provides more advanced functions compared to traditional distance protection settings systems (which normally establish zone reach and time delay only). However, the method can only be applied to transmission system and is constrained to distance protection settings. Reference [4] introduces an expert system that applies a frame-based inference mechanism to achieve an efficient integration of frames and rules. It could successfully carry out basic settings for distance and over-current protection but lacks many practical functions and is constrained to certain relay types. The expert system developed in [5] is able to carry out both directional over current and distance protection setting, but is constrained to a simple loop system. Reference [13] looks at applying heuristic rules for setting protective devices in distribution systems. However, it focuses exclusively on the coordination of different protection devices such as relays, reclosers and fuses and only considers operating time as a coordination constraint. Furthermore, the coordination is based on the assumption that the relay setting is known. References [5, 6] introduce expert systems that deal with coordination of over-current and distance protections.

In conclusion, many existing publications introduce expert systems capable of automatically calculating protection setting but always constrained to some extent, either to certain type of network or protection scheme.

B. Expert system for protection setting error detection

In contrast, the proposed intelligent system is designed to detect the hidden errors in protection setting files. Currently, there is not a great deal of research that has been carried out to address this specific issue. From the literature review it is clear that the existing expert system applications concentrate on the settings calculation rather than verification. However, the automatic error detection techniques have been widely applied both in "daily life" as well as in many industrial applications. Typically, the most frequently seen examples are web-based form filling assistant applications [15], online shopping applications [16] and conflict detection techniques in some industrial applications [17]. Investigation of these techniques have been carried out by the authors and it was found that the mechanisms used for error detection in other domains are similar and could possibly be re-used for the protection setting application upon which this research will focus.

III. Intelligent Tool For Detecting Hidden Errors In Protection Setting Files

The objective of the intelligent tool proposed in this paper is to automatically check the validity of existing setting files against the National Grid settings policies. To achieve this goal, the system has to be able to open a setting file (from protection relays or setting file database) and interrogate the protection functions and settings contained in the file. Knowledge-based rules will be extracted and deployed within the intelligent tool in order to ascertain that no settings are erroneous. This includes checks that relay settings are correct and that no features are inadvertently enabled or disabled.

A. Rule-based expert system

Rule-Based expert systems can be considered the most widely applied in power system protection applications. Such systems apply a series of rules, which are typically extracted from the experts' knowledge and/or from supporting documents and other sources. Usually, the rules will be in the "If-Then" (or "When-Then") form, where "If" (or "When") defines the particular set of conditions or context and "Then" executes actions in response to the rule conditions being fulfilled (or partially fulfilled). Additionally, in order to clearly define each condition/context in highly complex situations, a hierarchical structure is usually applied. Sometimes this structure is also referred to as a hierarchical tree.

The proposed intelligent tool also applies a rule-based approach. The reasons to apply this approach is that: the majority of protection setting policies of most power companies are in the form of rule-style[7]. It is relatively easy to transform the policies into rules; rule-based expert system is one of the most mature and widely used artificial intelligence techniques. Its high efficiency has been proved in many successful applications in power protection domain (as introduced in Section II).

B. Proposed structure of the intelligent system

The intelligent system is expected to be able to accept setting files, "read" the settings, match the settings to related rules, and make the decision if the settings violate any rules or not. When an error or an inadvertent function feature is detected, warnings and appropriate suggestions will be given to the protection engineers. The warning message indicates the severity of the error and provides the relevant information about the specific policy or guideline being violated. The structure of the proposed intelligent tool is presented in Fig.1.

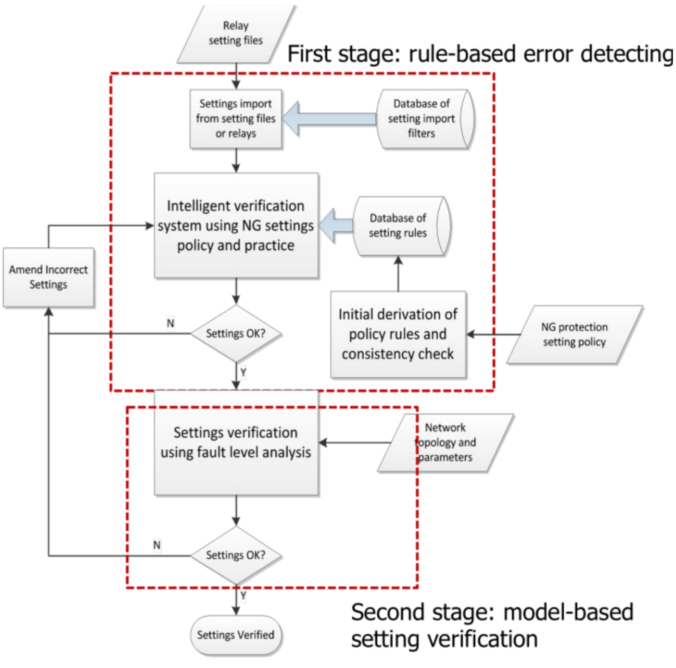

Fig.1. Proposed Structure of the intelligent tool

Fundamentally, there are two main stages in the proposed intelligent system. The first stage implements a rule-based approach to detect hidden errors while the second stage carries out a model-based verification of the settings. The internal structure of the first stage is shown in Fig.2.

The first stage could be treated as a sub-expert system of the intelligent tool. The rules extracted from protection setting policies will be stored in the production memory. The protection setting files imported from the protection setting database are called "facts" and will be stored in the working memory. The core part of this stage is the inference engine, which decides whether any hidden errors exist. The inference engine is the "brain" of the expert system and is in charge of matching the facts against the production rules. The process is called Pattern Matching [1] and is performed by the Pattern Matcher in the inference engine. In addition to this, the inference engine also has an agenda that decides the sequence of executing the rules.

There are two methods to execute rules: forward chaining and backward chaining. The rule system could take either of the approaches or both (called Hybrid Chaining Systems) [1].

The second stage represents a further development and is optional for the intelligent tool. It applies a model-based approach and provides extended means of setting verification which can be achieved using detailed fault level analysis and protection response. It is believed that the most accurate way

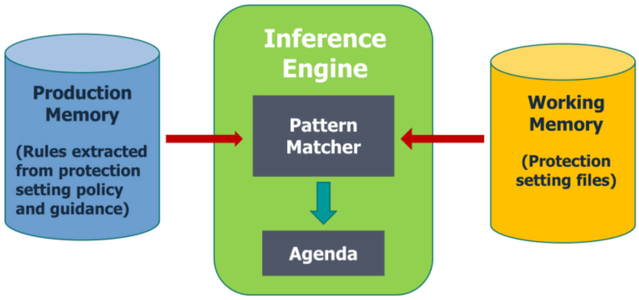

Fig.2. Structure of the rule-based sub-expert system [1]

of verifying the settings is simulation using dynamic protection system models. Although this stage is optional, the methodology which applies transient fault analysis to verify the settings could be very helpful when verifying the outcome of the first stage. Additionally, model based verification can provide additional guidance to the protection engineers in situations when although the settings conform to the setting policy but could be changed to improve system performance and security.

C. Drools – rule based development system

The main part of the intelligent tool is the rule-based error detection engine. The tool used for developing this stage is Drools [1].

Drools is a rule engine which can be used to implement any rule-based expert system. The algorithm that Drools implemented is Rete and the Drool Rete implementation is also called ReteOO which is enhanced and optimized by Drools for object oriented systems.

Reference [16] lists the advantages of using Drools for expert system development, but it is general for all users. For the specific application of protection setting error detection, the advantages are:

i) <u>declarative programming and understandable rules:</u> compared with normal codes, rules are much easier for the users to read, which helps to show the process of how a decision is made. In our application, by using rules, it could show the protection engineers at which step they made a mistake or which policy recommendation or rule the setting is not conforming to. Furthermore, when creating domain object models, Domain Specific Language [1] could be used which makes the rules very close to natural language. The rules could be made readable enough to be used as self-contained documents. When the rule base is built, the protection engineers might only need to check the rules without referring to the setting policies documents;

ii) <u>rules and data separation:</u> the rules extracted from the setting policies are stored in the production memory, which is separated from the working memory that stores the data (protection settings). This further helps in rule management and facilitates future modifications and updates when necessary. This is quite important aspect of the tool because the setting policies are likely to evolve when the networks become more complex with increasing presence of distributed generation. Flexible and straightforward rule management is therefore very beneficial;

iii) high inference efficiency: ReteOO provides high efficiency of matching the rules with the object data (protection settings). The high efficient inference engine is ready to use, which avoids a large amount of work otherwise needed to build an inference engine;

iv) tool integration: Drools can be easily integrated into other software tools such as Eclipse, which provides excellent user interface, making it much easier to edit and manage rules as well as to get immediate feedback and validation. In addition to that, when programming, it is essential to have efficient debugging facility available. Eclipse could well perform these functions;

v) Both Drools and Eclipse are free to use.

Additionally, the authors also chose to use Drools because it is based on Java which has good compatibility with most systems.

D. Difficulties in developing the setting error detection system

Although the proposed intelligent system does not need to consider the complex network topology, it still has a number challenging issues to overcome in development. The main challenges can be summarised as follows:

i) the protection relays in-service are of different types and different manufactures, which means that the protection setting files may have very different formats. For example, numerical relays normally have more protection functions than traditional electromechanical relays and both types are still used in the power network; different protection schemes have different setting parameters; different relay manufactures produce different file formats and their convention in naming protection setting parameters, some even have their own specific functions that others do not have. These all bring significant challenges for the intelligent system development. When the setting files are imported from the database, the intelligent system has to be able to extract the setting information from these files. This means that the system is not only required to "read" the setting files but also "understand" the content of the file so that it could correctly retrieve useful information;

ii) there are thousands of protection setting policies, which clearly define the requirements of the settings under each specific operating condition and protection scheme. Extracting these policies and accurately translating them into rules not only requires a large amount of work, but more importantly a good understanding of these polices. In addition, the large number of rules has to be easily managed to allow the engineers to update the rules when necessary;

iii) the built system is expected not only to be able to detect errors in a newly-set protection file, but also able to scan the databases to makes sure that the historical setting files are error free. This requires the system to have a very high efficiency of reasoning.

Apart from these, there are situations when the policies are not sufficient to decide whether the setting is acceptable or not. Usually, this situation relies on engineers' knowledge and experience. The system needs to identify these situations and incorporate the experts' knowledge to carry out the reasoning to some extent. This is quite difficult because there are new issues coming out when the network grows and changes. The system needs to be able to cope with these issues or at least not make any incorrect decisions.

IV. Advantages Of The Intelligent Tool

As mentioned previously, the main difference of the proposed intelligent tool over traditional protection setting expert system is that, rather than automatically carrying out the settings of a protection scheme, it checks and verifies the settings carried out by the protection engineers. Since the protection settings will depend largely upon the specific network configuration, and upon the nature of the protection scheme and the particular relays employed, most of the developed protection setting expert systems are constrained to certain network configurations and/or protection schemes.

The proposed intelligent system checks the settings against the rules extracted from the setting polices, so it does not constrains any network configuration or protection schemes. Furthermore, it is able to scan the protection database and check the validity of the settings. It is very important to do so reliably because those files are applied to devices in the field and are assumed to be correct. If there is a hidden error, it may only become apparent when an erroneous operation occurs (this has happened in the past on a number of occasions). Detecting errors in setting files may be impossible to achieve using existing protection setting expert systems, unless all settings are re-calculated, which is not a reasonable option.

V. Conclusion

This paper has briefly reviewed the application of expert systems in power system protection. Existing research in expert systems for protection setting is introduced with a brief discussion of the methodology of each system and its constraints. A proposed intelligent system that is able to detected hidden error in protection setting files is introduced and the advantages of this system over traditional protection setting expert system are discussed. Drools, the tool used for system development is characterised and the reasons to use it are discussed. Though the system has not yet been completely developed, the authors believe that this novel approach will change the way expert systems assist in the process of protection setting and if built successfully, it will reduce the work of protection engineers and reduce the protection system mal-operations.

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