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“Suggesting an Agent Based Design Methodology for Condition Monitoring of High Voltage Apparatus”
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"Multi-Agent Systems for Power Engineering Applications-Part I: Concepts, Approaches, and Technical Challenges"
by S. D. J. McArthur; E. M. Davidson; V. M. Catterson; A. L. Dimeas; N. D. Hatziargyriou; F. Ponci; T. Funabashi,
in the IEEE Transactions on Power Systems, Vol. 22, No. 4, November 2007, pp. 1743-1752

"Multi-Agent Systems for Power Engineering Applications-Part II: Technologies, Standards, and Tools for Building Multi-agent Systems",
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Suggesting an Agent Based Design Methodology for Condition Monitoring of High Voltage Apparatus

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***Abstract*— Condition monitoring of high voltage equipments has always been a central part of condition based maintenance programs which is highly preferred by generation, transmission and distribution companies. Through their development there has been a great deal of changes in condition monitoring systems aimed at providing systems of high reliability, modularity and adaptivity as well. Multi agent systems with the aforementioned features can be appropriate means of implementing distributed, modular and intelligent monitoring systems. In this paper designing of a high voltage monitoring system based on multi agent system will be considered in which tasks are distributed among different levels where the tasks and purposes of each level are defined according to the whole goals of the system. It finally results in an intelligent multi agent system combined of different levels.**

Keywords; Condition monitoring, Partial discharge, Multi-Agent systems, JADE, Ontology

I. Introduction

Maintenance is among the most substantial issues that electrical generation and distribution companies are encountering in their life time. The heart or central part of condition based maintenance is condition monitoring which comprises data acquisition, data processing and analysis, inference, and information extraction units.

Considering the importance of condition monitoring as a corner stone of condition based maintenance, various methods have been exploited in condition monitoring system's design and implementation. Regardless of the system hardware (sensors, converters and other data acquisition components), those issues that designers are challenging with are: voluminous data obtained from the equipments and the difficulties in their analysis, lack of expert for interpretation of the acquired data and the needs for intelligent analysis methods, dispersal of the physical equipments and appliances from location point of view and the requisite for using communication and computer networks to get access to the whole system, and also the necessity of modularity and adaptivity of the monitoring system are those to name a few.

According to the aforementioned properties that a monitoring system should entail, multi agent system can be an appropriate option for monitoring system implementation [1]. A multi agent system comprises of some software agents which possess aspects such as: autonomy, communicability and reactivity [2].

Among all of the equipments in a power system, transformer is more important. That is because of its cost and vital role in the power system, so it is indispensible to monitor the transformer's status quo. Partial discharge (PD) measurement and monitoring has the greatest focus in the topic of transformer condition monitoring, because of its significant influence on condition of a power transformer's insulation system. The reminder of the paper is organized as follow: In section II, agents and Multi-Agent systems will be given. Section III deals with condition monitoring system basics, and in section IV condition monitoring design methodology based on Multi-Agent system will be discussed, and section V will conclude the article.

II. Agents and Multi-Agent Systems

The term 'agent', or software agent, has found its way into a number of technologies and has been widely used. According to Wooldridge [1], an agent is merely "a software (or hardware) entity that is situated in some environment and is able to autonomously react to changes in that environment." An agent which displays flexible autonomy, i.e., an intelligent agent, has the following three characteristics: Reactivity, Pro-activeness and Social ability.

A multi-agent system is simply a system comprising two or more agents or intelligent agents. It is important to recognize that there is no overall system goal, simply the local goals of each separate agent. In recent years, the Foundation for Intelligent Physical Agents' (FIPA) standards has become the de facto standards used by MAS developers [3]. FIPA standard consists of different parts and aspects:

- Multi-Agent System Architectures
- Agent Communication Languages
- Content Languages and Ontologies

The FIPA Agent Management Reference model [4] defines the normative framework within which FIPA agents exist and operate. It establishes the logical reference model for the creation, registration, location, communication, migration and retirement of agents. Under the FIPA model, Fig. 1, an agent resids on a particular agent platform which provides some sort of message transport system to allow the agents to communicate. Each agent platform includes two utility agents: the agent management service (AMS) agent, which is compulsory, and the directory facilitator (DF) agent, which is optional. The AMS acts as white pages, maintaining a directory of agents registered with the MAS platform. The DF acts as yellow pages, maintaining a directory of agents and the services they can offer other agents.

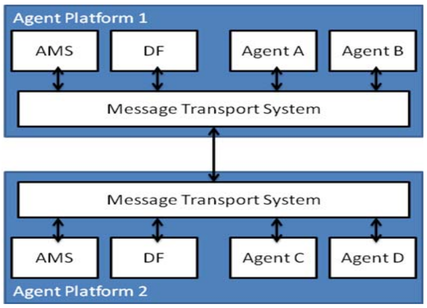

Figure 1. FIPA Agent Management Reference model

Mechanisms for the communication between agents underpin their sociabilities. Early multi-agent systems used proprietary communication languages. The content of a message comprises two parts: content language and ontology. The content language defines syntax, or grammar, of the content. The semantics or lexicon is drawn from the ontology. The choice of content language is important, as the chosen language will shape how a given ontology is expressed. The ontology describes the concepts of a domain and the relationship between those concepts in a structured manner. For example, ontologies for use with the Java Agent Development Framework (JADE) [5] contain a class hierarchy of concepts, predicates, and agent actions. Agents use the ontology for the passing of information, formulating questions and requesting the execution of actions related to their specific domain.

JADE is among distinct programming packages which is used in multi-agent systems implementation, supports FIPA protocols and standards. JADE is a software platform that provides basic middleware-layer functionalities which are independent of the specific application and simplify the realization of distributed applications that exploit the software agent abstraction. A significant merit of JADE is that it implements this abstraction over a well-known object-oriented language, Java, providing a simple and friendly API [6].

III. CONDITION MONITORING SYSTEM BASICS

Before explaining the design steps of condition monitoring system, some important aspects of a simple transformer condition monitoring system will be discussed.

A. *Overall Structure of a Condition Monitoring System*

This prototype transformer condition monitoring system consists of different parts as depicted at Fig. 2.

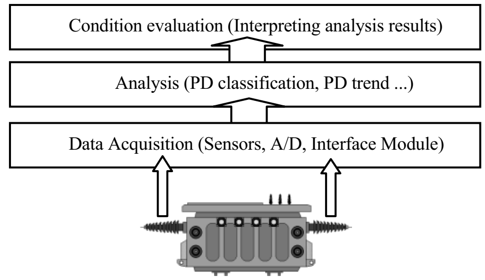

Figure 2. A Simple Condition Monitoring System Structure

Data acquisition section consists of sensors, A/D converters, and interface module for contacting with analysis section and software modules. In this application desired sensors are PD sensors. Analysis and condition evaluation section contains some software modules designed to manipulate and interpret data acquired by data acquisition section. Type of PD sensor can influence the analysis. But it is possible to extract and select some features from acquired PD data that make the analysis independent from the structure of acquisition system.

B. *Partial Discharge Analysis and Monitoring*

Partial discharges are localized electrical discharges that only partially bridge the insulation between conductors which can or cannot occur adjacent to a conductor [7]. PD pulses have useful information about the condition of the equipment where they stems from. The most basic quantities of PD activities are apparent charge, q, inception voltage, V_{inc}, and phase position of PD pulses with respect to applied test voltage, φ, which are used for interpretation purposes of the under test insulation system. PD can be initiated by different causes and sources and each source has different effect on insulation. Therefore it is important that partial discharge signals classified based on their sources. Corona, surface, and void discharges are most frequent discharge types insulation systems of HV equipment.

However, the above mentioned quantities cannot be sufficient for a perfect diagnostics. So, heuristically there have been introduced lots of features derived from basic quantities termed as deduced and statistical operators [8], which can be used for defect identification and evaluation. Conventionally, nearly all interpretations were based on visualized pattern of PD characteristics, Elliptic Patterns, Phase Resolved Partial Discharge (PRPD), and so forth, mostly on oscillographic devices [9].

PRPD is the most applicable PD pattern for defect classification and insulation condition evaluation. Researchers develop various methods to classify PD defects through their features and by means of classification methods (i.e. fuzzy and expert system, neural network…). Also PD Trends represent the changes in insulation quality and its increment can be a sign of insulation degradation. With combining above analysis (i.e. PD classification, PD trend), an expert is able to extract some IF-THEN rule which by means of them the condition of equipment insulation can be evaluated. Fig. 3 shows a schematic of aforementioned information about PD.

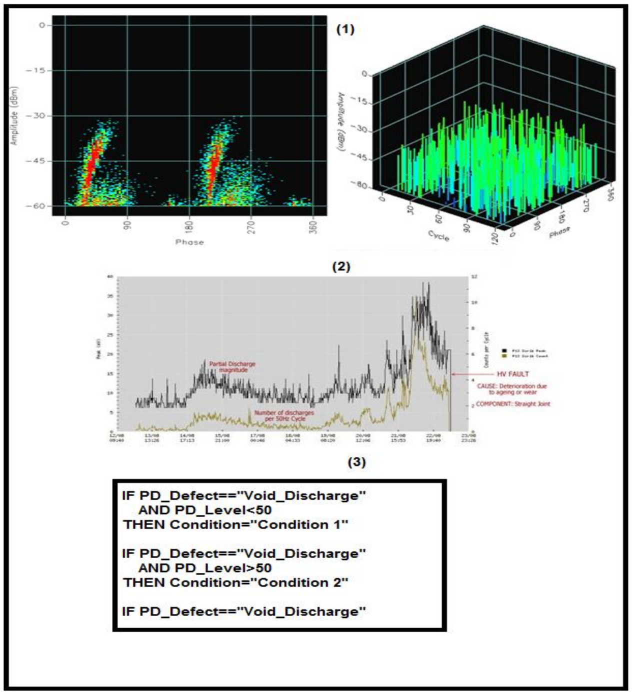

Figure 3. PRPD (1), PD trend (2), PD IF-THEN Rules (3)

IV. CONDITION MONITORING DESIGN METHODOLOGY BASED ON MULTI-AGENT SYSTEM

In preceding sections all of required information for designing a multi-agent based condition monitoring system is presented. This section specifically appertains to introduce a design methodology for establishing a prototype condition monitoring system. All of multi-agent concepts (ontology and so on) are based on JADE's specifications.

A. Design Steps

In following steps, it is attended to be more general and applicability of the resultant system is considered thoroughly. Applicability of the system means that it can be applied for wide range of similar applications notwithstanding existing differences. These steps are followed:

1) Parameter Selection and Anlysis Methods:

Among the most important parameters considered in high voltage equipment monitoring systems are; PD (partial discharge) signals, DGA(dissolved gas analysis) results, temperatures, vibrations, voltages and currents of the equipment to name a few.

2) Task decomposition & distributing the tasks among agents:

The structure of monitoring system should be decomposed into suitable smaller components in order to be specified as a distributed system. There are two different decomposing methods; physical decomposition and task decomposition. In physical decomposition, the whole system is broken down into its comprising stand alone components. In task decomposition methods, the task and operation are considered to be the component of the system and will be decomposed based on them. Tasks can be categorized as general and special ones where the special tasks depend on the equipment itself. For example, the different analysis of the PD data is considered to be special tasks. General tasks do not depend on the type of the equipment, whereas they are the same across the whole system.

3) Ontology Design

Ontology designing likewise agent type determination and designing is an important step in designing multi agent systems. Ontology describes the fundamental aspects pertinent to a domain and their relations [10]. The main parts of ontology designing are: (a) classes or concepts, (b) properties of each class defining features and attributes related to each class or concept, sometimes called slots, roles and predicates, (c) applied limitation on slots (facets), sometimes called 'agent action limitations' in JADE.

Ontologies in JADE package have three main subsets: Concepts, Agent Action, and Predicate. Ontology designing is one of the controversial topics in implementing of Multi-Agent systems. There is an increasing need for ontology standardization in power system applications where generalization and combination of the designed multi agent based systems are intended [11]. Considering the descriptions above, a typically suggested ontology in condition monitoring of power transformers is presented in Fig. 4. For simplification,

4) Agents Designing and system architecture

Designing of agents is a kind of three step process: specifying the tasks of agents, designing of agent's life-cycle, determining the agents' connections and interactions. Using JADE package, agent task can be defined as different types of behaviors. Structure of multi-agent based condition monitoring system depends on types and connections between different agents. For better understanding, it would be better to divide the structure of the system into several levels regarding agent task hierarchy. This will be broadly explained in the following section.

B. Case Study

Considering the aforementioned steps, a system for monitoring of PD activities in a transformer has been given as an example in this section representing a multi-agent based mentoring system.

Step 1: Here a typical conventional data acquisition module using say capacitor sensor, is exploited to acquire PD data; transferring to host computer where the recorded fields would contain time tags, voltage, charge and phase position of PDs. Then, they are analyzed by means of the following methods (depicted in Fig. 3): (a) PRPD analysis for classification purposes [8], (b) PD trend analysis for insulation status quo, (c) Expert system.

Step 2: In this application, the main tasks are: Data acquisition, PD analysis including PD classification & trend analysis, result interpretation & condition evaluation, interaction with user. This task will be delegated to different agents.

Step 3: For ontology designing system's physical components, their interconnections and also acquired parameters by hardware units have to be considered. The ontology has been considered to contain only common PD features of a transformer which makes it to be applicable in other similar condition monitoring systems despite the likelihood differences might be in between data acquisitions and hardware configuration of the system. Common features of PDs should to be merely considered. Fig. 4 shows the structure of the mentioned ontology.

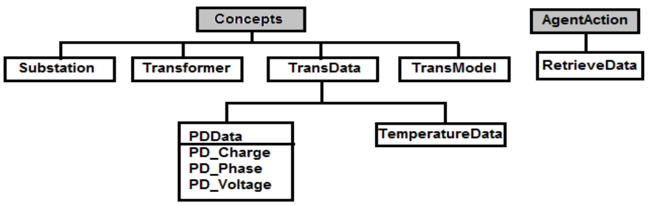

Figure 4. Condition Monitoring Ontology

Step 4: As it depicted in Fig. 5, this system is divided into four levels, and agents of each level have access to agents of lower levels. More details about agents of each level are as follow:

1) Data acqisition Level:This level contains only one type of agent (i.e. Data Acquisition Agent). Data acquisition agent is responsible for transferring PD data from data acquisition hardware to the proprietary software component where the transferring is done as soon as the agent receives requests from other agents.

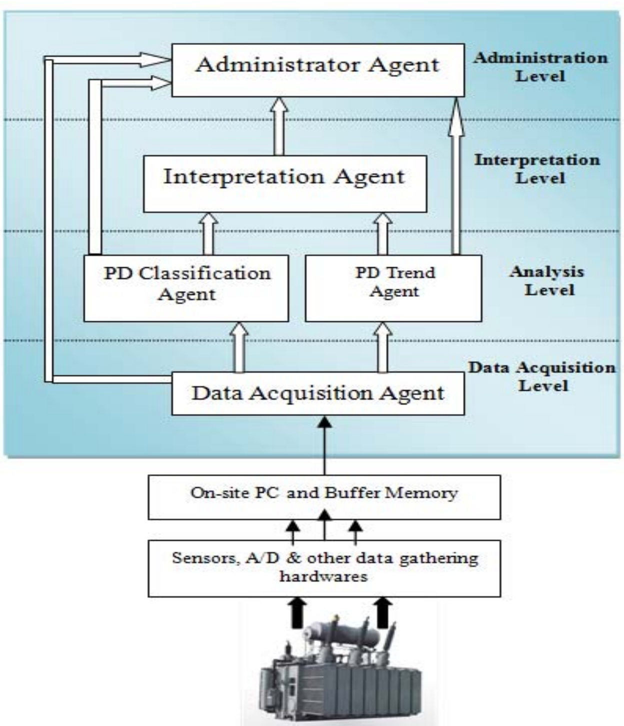

Figure 5. Multi-Agent based Transformer Condition Monitoring System

1) Analysis Level:PD Classification Agent and PD Trend analysis agent are two types of agents which are located in this level. These agents' tasks (analysis) can be performed in a cyclic manner or receiving requests from administrator agent.

2) Interpretation and Condition Evaluation Level:As matter of facts, Interpretation Agent in this level performs as an expert. This agent applies IF-THEN rules so as to interpret the received analytical results from the lower hand levels.

3) Administration Level:This level contains Administrator Agent which plays the role of user interface for the monitoring system. This agent helps the user to interact with the system: send request to the system, and observe the analysis results. Also, this agent has the ability to communicate with other multi-agent based systems in the power system. In this sense, when two systems intend to communicate with each other, they ought to have a common or mapping ontology [11].

V. CONCLUSION

This paper presents a design methodology for designing a prototype condition monitoring system. The four mentioned design steps in the text can be applied for wide range of condition monitoring systems regardless of the type of equipment or hardware configuration of the exploited data acquisition system. Generality and applicability of the resulted condition monitoring system is considered thoroughly where ontology designing and its standardization in condition monitoring applications is discussed. The prototype condition monitoring system was designed based on the propound design methodology.

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