2008년도 대한전기학회 전기설비전문위원회 춘계학술대회 논문집 (2008. 4. 18)

다수 변압기의 온라인 모니터링을 위한 실제 적용

윤 주호[1], 최 용성[1], 황 종선[2], 이 경섭[1]
[1]동신대학교 전기공학과, [2]전남도립대학

Practical Applications of Multi-Agent Transformer Condition Monitoring

Ju-Ho Yun[1], Yong-Sung Choi[1], Jong-Sun Hwang and Kyung-Sup Lee[1]
[1]Department of Electrical Engineering, Dongshin University, [2]Jeonnam Provincial College

Abstract - On-line condition monitoring is a useful tool for maintaining and extending the longevity of power transformers. An intelligent diagnostic system is desirable for operational safety and reliability. Bringing these concepts together results in a powerful support tool for engineers, reducing the volume of data to deal with, and making the data more meaningful. This paper describes how a multi-agent system for diagnosing the cause of transformer partial discharge activity was coupled with a method of UHF partial discharge monitoring, creating an on-line condition monitoring system. The challenges presented by the on-site environment are discussed, along with the implications for the cómplete system.

1. Introduction

Asset management supported by effective condition monitoring can result in improved performance and reliability of electric plant. In turn, this will reduce the costs associated with maintaining assets, and extend the longevity of individual items. The volume of condition monitoring data gathered by sensors rapidly becomes overwhelming for engineers to process. By coupling intelligent diagnostic techniques with data capturing systems, a valuable support tool is available to engineers, directing their attention to likely faults, and removing some of the data processing burden from personnel.

Recent research has shown the benefits of applying Ultra High Frequency (UHF) measurement of Partial Discharge (PD) to the task of power transformer monitoring [1].

This system creates a large amount of data, which has been processed off-line by the Transformer COndition Monitoring Multi-Agent System (COMMAS). The next logical improvement was to create a direct link between the two, allowing on-line diagnosis. Doing this highlighted issues which were not of prime consideration when COMMAS was operating off-line in its research and development environment. The computing resources available in a substation are limited, making processing efficiency of utmost importance. Additionally, the communications link with a substation-based UHF condition monitoring system is most often a modem attached to a telephone line, demanding efficient use of this resource also. When viewed in this way, certain aspects of COMMAS could be improved to create a system better suited to on-line operation.

2. Off-Line COMMAS

The original structure of COMMAS is a layered architecture, where the steps of fault diagnosis are separated into distinct modules [2-4]. The layers are:

- The data monitoring layer;
- The interpretation layer;
- The corroboration layer; and
- The information layer.

This structure maps the refining of information from raw sensor data to fault predictions. Coupled with the inherent multi-agent system property of service discovery, this architecture allows the easy addition of new analysis techniques and sensor outputs, such as dissolved gas analysis results, or knowledge-based interpretation of data. From the beginning, COMMAS has been designed with extensibility as the main requirement; this simplifies the task of incorporating the UHF measurement technology.

All four layers contain one or more agents, each of which performs a specific task. The full architecture is shown in Figure 1. The data monitoring layer is intended to reduce the need for engineers to check for sensor output. The off-line system reads sensor data from files, whereas in the on-line system, raw data is received directly from sensors and data capturing hardware. The data is then processed into a standard format for presentation to higher layers. This requires that the monitoring layer has intimate knowledge of the data aquisition techniques, making it very plant and hardware specific.

Data monitoring can be divided into two tasks, which are executed by two agents: a Feature Extraction Agent, and a Δt Calculation Agent. It has been shown that UHF sensors can be used to detect electromagnetic energy radiated by partial discharges, and from this raw sensor data, a phase resolved pattern of activity can be constructed [1]. The first of these agents takes in this phase resolved data, and extracts various features from it, which the interpretation layer uses to determine the likely cause of the partial discharge activity. The second agent uses the difference in time of arrival of the electromagentic signals at each sensor to determine where in the tank the partial discharge took place[2]. The interpretation layer contains multiple intelligent agents, each of which uses a different artificial intelligence technique to diagnose the cause of the partial discharge, based on the vector of features created by the data monitoring layer. This means that each agent in this layer takes in the same collection of parameters about the raw sensor data, and produces probabilities for each partial discharge cause: Bad Contact, Floating Component, Rolling Particle, Suspended Particle, Surface Discharge, or Protrusion. Even at this stage, the data produced is useful, and engineers can use it to narrow the focus of their investigations.

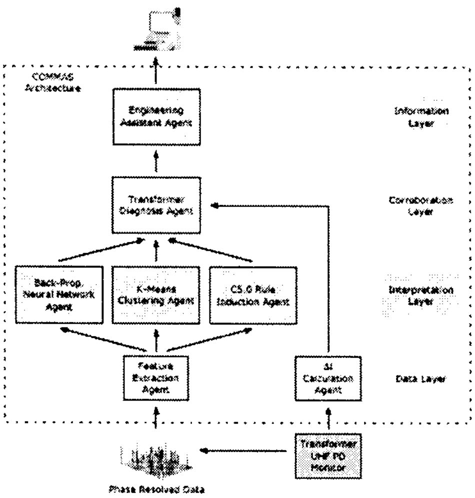

Fig. 1. Original COMMAS Architecture.

However, the most valuable information is provided by the corroboration layer, which takes in the various fault predictions generated at the interpretation layer, along with the Δt positioning data and a model of the transformer's internals, and makes a decision about the most likely source of the partial discharge activity. This is provided, along with a confidence factor, to the information layer.

The final layer gathers the data from the corroboration layer, and presents it to the user in an intuitive graphical format. It automatically updates whenever new fault data is received, removing the need for an engineer to continuously request information.

3. Results and Discussion

3.1Data Access and Agent Distribution

One feature of multi-agent systems is that agents can easily be distributed around various computers on a network. This spreads the processing load at the expense of extra network traffic. However, in many situations this negative is outweighed, such as when available computers do not have high specifications, or when many agents in the system have intensive computing requirements.

COMMAS was designed with this capability in mind, as the anticipated computing resources in a substation are not plentiful. However, all trials of distributing agents were made across a permanent Local Area Network (LAN). A major difference between this situation and that of a substation is that agents in a substation will generally only be reachable by dial-up telephone connection. If the modem link drops and partial discharge activity starts, the interesting data should be queued until the link is restored. This ensures no information is lost; when the connection resumes, the queued data is transmitted to the user end. Delegating this task to a separate agent in COMMAS is most appropriate.

A second consideration was how much data processing to do on site, and how much to perform at the user end of the modem connection. In this situation, the network traffic is as much of a concern as the processing power available at a substation. Keeping more layers of the system on site would reduce the amount of data transmitted over the telephone line, but increase the required specification of the computer on site. It was decided that the optimum distribution was to run the data monitoring, interpretation, and corroboration agents on site, and for the information layer to run where the user needs it. This limits the modem traffic to corroborated fault diagnoses, and any lower level data that the user specifically requests.

3.2 Stability

A major difference between using COMMAS for off-line processing and on-line operation is the length of time it will remain running. When recorded data was being analysed, COMMAS would typically run for a few minutes to quarter of an hour, as interesting raw data was fed in directly. In an on-line situation, COMMAS may run on site for weeks or months before partial discharge activity is detected, and the goal is to achieve permanent monitoring. This makes system robustness a priority.

Unfortunately, COMMAS originally used a multi-agent platform which was not amenable to this [3]. At the start of the COMMAS project, it was a well-featured platform with active support from its developers. Since then, maintenance has stopped, and other platforms have overtaken it in popularity and user flexibility. The platform did not support various standards which have been recognised and adopted since then. Additionally, serious memory leaks caused agents to run reliably for only an hour before system resources were irretrievably consumed.

Another agent platform was found to solve these problems [4]. It is actively maintained, with a large community of users, meaning any problems are likely to be fixed when discovered. It conforms to all current standards in agent communication[5], and is much less restrictive in terms of agent creation and design than the original platform. Converting COMMAS to use the new platform automatically increased the system's robustness, allowing agents to run without a time limit.

The Substation Manager sends a FIPA Query Ref message to the data provider, who responds with a FIPA Inform message, which either contains the requested data or an empty set if there is no data to send. This interaction is much faster than the Subscribe model, where Inform messages are delayed indefinitely until data is available. This responsive communication model enables the Substation Manager agent to monitor the other agents in the system, ensuring no agent gathers an unwieldy amount of data without it being archived. The complete on-line COMMAS architecture is shown in Figure 2, with the new communication paths highlighted in bold.

As the Information Layer of COMMAS is now located off-site, the Engineering Assistant Agent (EAA) is not as constrained in terms of computing resources. This gives more opportunity for providing useful features, such as a 3-dimensional model of the defect in a transformer, and gathering data from other sources such as maintenance records. This in turn makes the EAA a single point of contact for all information relating to transformer monitoring, allowing an engineer to make fast decisions based on complete knowledge, rather than manually gathering data.

The EAA can also manage multiple substations, each with multiple transformers. For a utility with over 100 substations, this is a major advantage. At run-time, the EAA requires the IP addresses of all substation-based computers, in order to contact the agent platform Main Containers. By querying each Substation Manager agent, the EAA builds up a list of monitored transformers, allowing the user to view details of each.

Whenever partial discharge activity occurs, and new fault predictions are generated, the EAA automatically updates to show the details. This is achieved by the EAA subscribing to corroborated fault diagnoses produced by the corroboration layer, using the FIPA Subscribe Interaction Protocol. The corroboration layer agents will thereafter notify the EAA whenever a diagnosis is available. The engineer can also initiate data retrieval, when the raw data or any intermediate data is required. Clicking a button on the EAA interface begins the FIPA Query Ref Interaction Protocol, where the Substation Manager agent is asked for any data it may have. An immediate response is given, indicating whether data is available, and the data itself. This is then displayed to the user, giving feedback in a matter of seconds. In this way, the EAA capabilities allow engineers to monitor multiple transformers across many sites, and access all pertinent information about transformers as faults develop. This supports any decisions needed with regard to asset management.

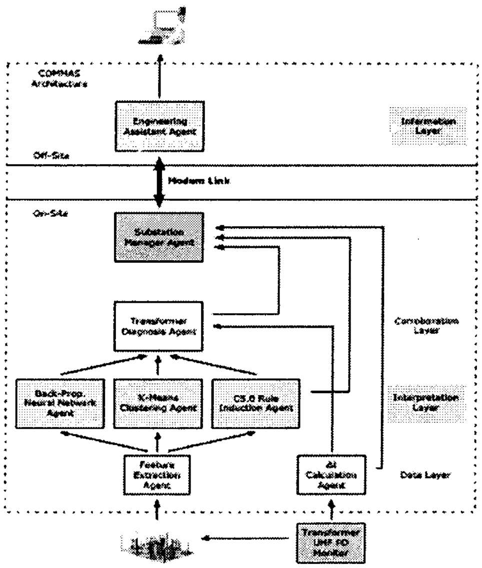

Fig. 2. Modified COMMAS Architecture.

4. Conclusions

This paper describes the transition of the Transformer COndition Monitoring Multi-Agent System (COMMAS) from an off-line partial discharge defect diagnosis system to an online one. The practical difficulties encountered along the way have been highlighted, and solutions outlined. The main issues were related to identifying fragility in the existing system, and making changes to the architecture to produce a more robust system. Additionally, considerations about the processing resources available on site and the communications links to the site influenced the decision to distribute individual agents across multiple computers. Adding a Substation Manager agent to COMMAS satisfies various requirements for data storage and accessibility, and serves as a gateway between the diagnosis side of COMMAS and the user interface. The system's stability was improved by moving to a newer agent platform, which brought additional benefits such as agent relocation abilities. By these means, COMMAS is now ready to be deployed on site, to perform on-line transformer monitoring.

[Acknowledgement]

This work was finally supported by MOCIE program (I-2006-0-092-01).

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