Real-Time Diagnosis for a Large Gas Turbine Based on a Deep Model of the Controller

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Abstract

The ESPRIT project 6862 TIGER addresses the development of a real-time knowledge based diagnosis system for two gas turbines: a large scale industrial gas turbine and an auxiliary power unit for aviation. The project will combine the qualitative model based with the rule based diagnosis approach.

This paper describes the rule based approach taken in the development of a real-time diagnostic system for a large scale gas turbine. Deep models will be automatically extracted from the deterministic knowledge embedded within the controller ladder logic diagrams. Heuristic knowledge will be extracted from the domain expert and engineering manuals.

1. Introduction

One of the objectives of the TIGER project is to develop a rule based system that continuously acquire data from the gas turbine controller, identify possible malfunctions, search for their cause and suggest corrective actions.

Heuristic knowledge acquisition is the major bottle-neck in rule based system development. It is a time-consuming task to extract knowledge from a domain expert and incorporate it into a large knowledge base. Furthermore, the availability of domain experts impose further restrictions and limitations which may affect the success of the task. Therefore, the TIGER diagnosis system will also use deep models extracted from the process controller ladder logic and control loops. A study has shown that these models contain design and engineering knowledge in a more usable form compared to that held in the minds of the designers themselves [Caldeira-Saraiva 91]. Thus, the objective of this work is to build an automatic translator from ladder logic description language to expert rules that can be used to make intelligent diagnosis of the turbine based on the deterministic knowledge embedded within the Process Control *contact network.*

One of the major drawbacks with classic expert system technology is the prohibitive and often unbounded response time which makes it difficult to meet real-time constraints. The chosen expert system, Kheops [Ghallab 88], tackles this problem by compiling the knowledge at the chaining and control level by rewriting a set of declarative rules into a deterministic network whose traversal gives an upper-bound on the response time of the system. Given the value of all attributes in the input space, a typical Kheops reasoning consists of deducting the value of all attributes in the output space by propagation through the Kheops network.

This papers describes the target process and the knowledge acquisition task.

2. The process

The Fife Ethylene Plant is a 650000 tones a year gas cracking facility located in South East Scotland, and jointly owned by Exxon Chemical Company and Shell Chemical Company. The major product of the facility is high grade ethylene for use in the plastic and butyl rubber industries in both the UK and on the continent. The feed stock is ethane gas obtained from the Shell/Esso off-shore facilities in the North Sea. The process is continuous with the ethylene products being transported by both ship and pipeline top end users in the UK and on the continent. The gas turbine is a 28 mega-watt General Electric Frame Five two shaft supplied by John Brown Engineering, this is used to drive the primary compressor for the Fife Ethylene Plant. It is a vital item of equipment for the plant. If the turbine fails the entire plant must shut down. This turbine is typical of large scale industrial gas turbines.

2.1. Gas Turbine

This section summarises the structure of the Fife Ethylene gas turbine. A deeper description of gas turbine behaviour and structure can be found in [Cohen 72].

The first significant element of the gas turbine is the *air intake* (figure 1) which brings in the outside air. It has filters to keep the compressor blades clean. The air is compressed from 1 bar to 12 bar through the *compressor*. The air compressor is of the axial flow type. There are 12 *combustion chamber* in a circle around the compressor output. Here, the fuel is introduced with the high pressure air and they mix and burn to produce hot exhaust gas which will drive the turbine. The *turbine* has two stages at different speeds. These stages are referred as LP and HP for low pressure and high pressure. The turbine is driven by the expansion of the exhaust gas across rotating buckets. Approximately 60% of its power is used to drive the compressor. About 35% of the power is available as useful work to drive an output device. The difference is lost due to inefficiency. Finally, the *air outlet.* The exhaust gases are sent to a heat recovery device to increase the turbine efficiency. The turbine is *controlled* by a Speetronik Mark IV control system.

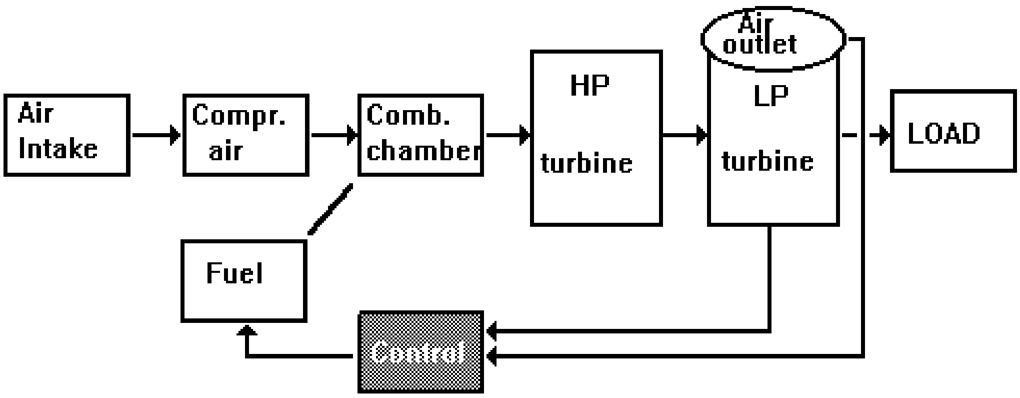

Figure 1: Gas turbine schematic

2.2. Control system

The turbine is principally controlled by startup control, speed control, and temperature control. Sensors monitor the turbine speed, temperature, and compresor discharged pressure to determine the operating conditions of the unit. The operation conditions are accomplished by modulating the flow of fuel to the turbine. Protection systems are provided to prevent abnormal conditions which could result in damage to the turbine. The critical operating information monitored by the protections systems is: temperature, speed, vibration and flame. Overtemperature and overspeed systems are part of the redundant temperature and speed control system.

The Speedtronic system [Johnson 83] is a micro computer control system which provides the analog and digital signals required to control and protect the operation of the gas turbine. Operating conditions of the turbine are sensed and utilised as feedback signals to the Speedtronic control system. Figure 2 shows the basic bloc diagram of the Speedtronik Mark IV system. The three control sections R, S and T are called <RST>, signifying that they are identical yet completely independent processors. They perform redundant functions to increase the reliability of the system. Each of them has inputs and outputs, and each has its own power supply. The fourth section is called <C> for communicator and it is in communication with <RST>.

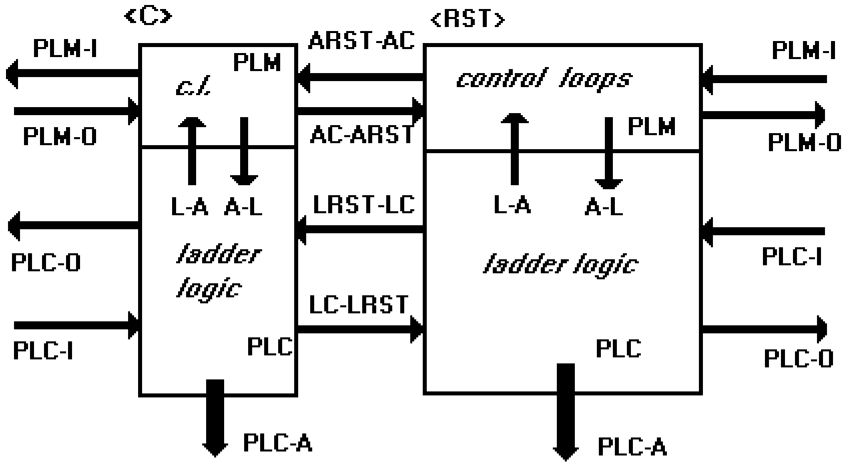

Figure 2. Data communication interfaces in the <RST> and <C> processors.
PLC-O: output logic data
PLC-I: input logic data
PLC-A: logic alarms
LRST-LC: logic data from the <RST> to <C>
LC-LRST: logic data from the <C> to <RST>
L-A: data from the logic to the control loops.
A-L: data from the control loops to the logic

Critical sensors that are used for both control and diagnostic functions are also redundant or are connected in such a manner that equivalent redundancy is provided. Diagnostic features are coded in a ladder logic description language and control features are coded in a high level language (PLM86).

3. Knowledge acquisition

Fife Ethylene gas turbine is a critical item in the plant. If a problem develops leading to a trip, the associated cost can be very high (up to $0.01 million/hour). As a result there is a need to detect at an early stage, developing problems. When an alarm does occur, the Speedtronik alarm messages themselves are not useful to operators. The engineers must also perform more detailed diagnosis to determine the exact cause of the alarm.

There are up to 256 diagnostic alarms. Usually, when an alarm is detected, the plant engineer has to trace through the ladder logic diagram using data available from the controller to determine its cause. This is a time consuming task since the ladder diagram has about 2100 elements, 288 input variables and 460 internal variables. Moreover, understanding of the ladder and of its structure is needed to trace it. Thus, one of the goals of the TIGER project is to develop a rule based system that could help the plant operator or engineer in the diagnosis task and in consequence, reduce the time in which the plant is halted or avoid a plant trip by taking appropriate actions.

The approach that is being used to build the knowledge based system is:

1) Generate a rule-base explicit representation of the ladder diagram (deep model). This representation will emulate the Speedtronik diagnostic system and will be used to detect the exact cause of the alarm in an automatic manner.
2) Add heuristic knowledge extracted from plant operators and available information. This knowledge includes temporal constraints and qualitative reasoning which will extent the diagnostic capabilities of the Speedtronik.

A compiler is being developed to translate the Ladder Logic Description Language software provided by the plant engineers into an equivalent rule-based explicit representation. However, though a straightforward ('blind') translation could be attempted, the final success is dubious since there is little knowledge about the structure and completeness of the source ladder logic data. Therefore, the compiler is being extended in order to analyze the topological structure of the ladder and to make a more efficient and structured translation of the embedded knowledge into expert rules.

At present, the compiler is able to translate the ladder logic description language into an object ladder digraph. Graph based algorithms can be used to transverse the digraph. These algorithms allow or will allow, for example,

1) Create a rule based model for a specific alarm.
2) Generate a list of the inputs needed to evaluate the status of an alarm.
3) Sort the alarms according to its computational complexity. This parameter is the number of elements that are needed to evaluate an specific alarm.

The primary goal is automatically generate a structured rule-based model of the Speedtronik control logic and inform about the inputs that will be needed in real-time to emulate the real process.

The ladder diagram is mostly a combinational switching network, though it also has sequenciality and timers that have to be considered in the analysis of the ladder. The combinational ladder section is being analyzed using classic graph theory which provide powerful means to determine the input-output behaviour of the network (switching function). Thus, simplified alarm rule based models could be created using the switching functions.

The object digraph not only preserves the topological structure of the ladder but it also maintains the semantics of the source ladder logic code. Thus, an alternative approach to determine the behaviour of the ladder is to simulated propagating forward the input states through the graph and the cause of the alarm can be determined traversing the graph backwards. Therefore, this tools can also be used as an off line tool that will act as an aid to the troubleshooting and diagnostic engineers.

4. Conclusions

Down time costs of the critical turbines in the petrochemical industry are prohibitively high. Moreover, diagnostics of complex turbine problems calls for individuals with analytical skills and experience which are not always available. Therefore, there is a need for rapid means for diagnosis and troubleshooting.

The expected result of this ESPRIT project task is a prototype tool for knowledge acquisition that automatically extracts the deterministic knowledge embedded within the turbine process controller ladder logic and generates Kheops rule based deep models that can be used for real-time diagnosis.

5. Acknowledgments

The work described in this paper is part of the ESPRIT II 6862 **Tiger** project, and we are thankful to all the partners who make it possible:

Prime contractor:	Intelligent Applications Ltd. Edinbourgh (UK)
	John Brown Engineering, Glasgow (UK)
	Exxon Chemicals, Fife ethilene plant (UK)
	Dassault Aviation, Paris (F)
	LAAS-CNRS, Toulouse
	Dept. ESAII, Univ. Politècnica de Catalunya (E)

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