Introduction

The area of fault detection and diagnosis is one of the most important aspects in process engineering. This area has received considerable attention from industry and academia because of the economic and safety impact involved. Fault diagnosis is the first step in Abnormal Situation Management (ASM). The aim of ASM is timely detection, diagnosis and correction of abnormal conditions. The main objective is to avoid plant shutdowns. Furthermore, early diagnosis can reduce the loss of productivity during an abnormal event if it is performed when the plant is still operating in a controllable region.

The maintenance of yield and quality in a process strongly depends on Fault Diagnosis (FD). In order to install an ASM in a chemical plant, the design of an intelligent real-time operator support system seems to be the best choice. Such a system can perform automated control actions as well as to give support to operators for decision making.

Nowadays, the implementation of such systems in real plants present a variety of difficulties which can be considered as practical challenges: complexity of modern plants design and control systems, lack of useful process models, different sources of knowledge, efforts required to maintain the system and operators' adaptation.

In the area of plant-wide control at the supervisory level, the Fault Diagnosis System (FDS) plays a key role. The FDS includes the identification of the root causes of process upsets (fault diagnosis) and can provide recommended corrective actions to restore the process to normal operating condition (fault correction). In this regard, real-time appropriate actions must be taken in present chemical and petrochemical manufacturing. The technical personnel in most of these industries is responsible for process monitoring status, detecting abnormal events, diagnosing the source causes, and administering proper intervention to bring the process to normal operation. But, the complexity of the supervision tasks has increased considerably due to the high level of development in process design and control. A decision support system is needed to assist process operators in understanding and assessing process status, and responding quickly to abnormal events, thereby enabling processing plants to maintain operational integrity and improve product quality at a reduced cost.

Troubleshooting in chemical process plants is one area where computer technology can now provide substantial benefits. Computers are powerful enough to handle meaningful systems. It is now possible to deliver large-scale knowledge-based systems directly to the end-user. Furthermore, current chemical plants save large amount of data containing valuable information about the processes.

Methods of FD are currently a matter of extensive research. A number of knowledge-based expert system (KBES) approaches have been proposed in the literature for automated FD. The main drawbacks of these approaches are the difficulties in knowledge acquisition, this being necessarily a lengthy procedure since there is no easy way to incorporate learning into the system, and because of the unpredictability of the system outside its domain of expertise. Historical based methods like Artificial neural networks (ANNs) require no explicit encoding of knowledge unlike KBESs. However, ANNs do not incorporate the process deep knowledge in a structured form, as KBESs do. Therefore ANNs cannot offer insight into the problem-solving process.

In this context, the use of combinations of historical based methods and knowledge-based techniques for fault diagnosis in chemical plants shows promising results. Research is focused on the simplicity of implementation and the optimal performance of such systems.

1.1. Abnormal situation management in chemical plants. The role of operators

Operators have an important role for the adequate functioning of chemical plants. Their activities have evolved from dangerous actions (e.g. to open valves manually in hazard areas) to hierarchical activities in a control room. Operators are only humans and human perceptive and cognitive capacities have not increased. Hence, the reality of current chemical plants that contemplates complex processes, sophisticated control strategies, highly integrated plants and million of data collected every second is a challenge impossible to overcome without a support. The development of such supports does not imply the replacement of humans, it implies a wise assistance useful for them.

Automation technology is increasing in complexity continuously. Therefore, operators are faced with increasingly complex decisions to manage abnormal situations. Abnormal situations include start-ups, shutdowns and transition changes between operating states. Process disruptions also have different sizes. Control system cannot cope such situations and plant operation personnel have to intervene to correct the problems.

Sometimes, abnormal situations result in fires or explosions. But most of times they have minor consequences that are expensive, too. For example, schedule delays, equipment damaged, environmental hazards and poor product quality. Economic losses of about $20 billion annually in the petrochemical industry alone are being produced due to the inability of the automated control system and plant operation personnel to manage abnormal situations.

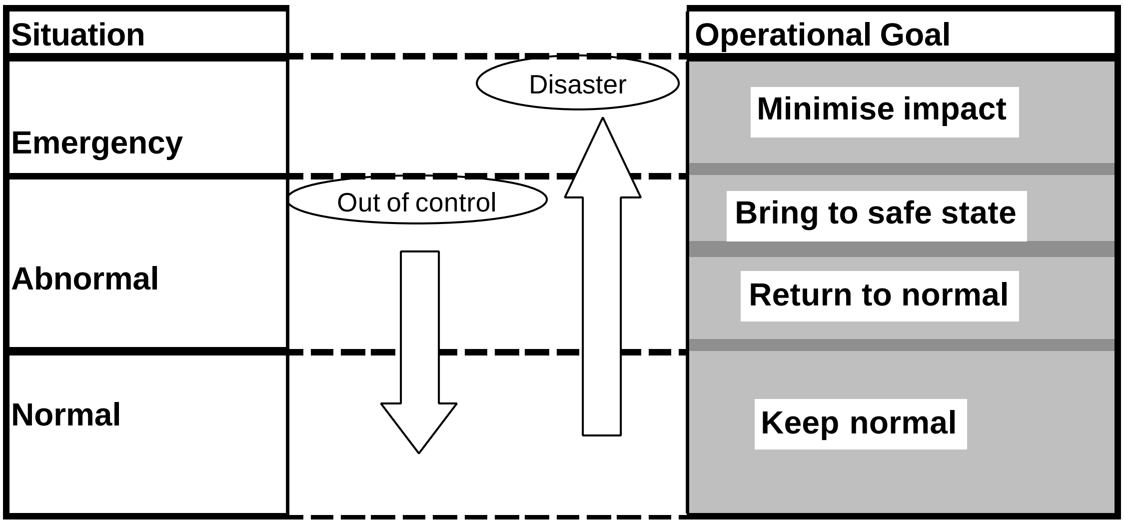

Figure 1.1. Operational goals according to plant status

Figure 1.1 shows a scheme that addresses the location of abnormal situations in the operation of chemical plants. A range of normal conditions can be identified, where the operational goal is to keep the plant in such situation. When the plant goes to abnormal conditions the objective is to return to the normal state. If the abnormal situation has arrived to a point that the return to normal operation is not possible, the goal changes. It consists in bringing the plant to safe state. If this goal cannot be reached, an accident or even a disaster can occur. This extreme situation is an emergency and the objective of operators and managers should be to minimise the impact of such situation.

ASM systems are designed to assist operation personnel and to take diagnostic and compensatory actions autonomously.

1.2. Fault diagnosis in batch chemical plants

The complexity of process control in present batch chemical plants affects the execution of the supervision tasks making it very difficult. Therefore, operators need a support for decision-making when a deviation from the normal operating conditions occurs. This support is also necessary at the upper levels in the decision-making system as is the planning and scheduling level. Due to its inherent flexibility, batch plants can operate efficiently under different scenarios if the consequences of abnormal situations can be anticipated. A robust Fault Diagnosis System (FDS), that timely provides the fault information to the scheduling level, allows to improve the efficiency of the reactive scheduling, to update the schedules in the most effective way. It is necessary to examine the implications of linking the process monitoring and diagnosis functionalities into a comprehensive manufacturing control system.

1.3. Terminology

Terminology in the field of supervision, fault detection and diagnosis is not consistent in the literature. Therefore, the following definitions have been adopted (Isserman and Ballé, 1997). They are consistent with the considerations made by the SAFEPROCESS Technical Committee (International Federation of Automatic Control).

Fault: An unpermitted deviation of at least one characteristic, property or parameter of the system from the acceptable / usual / standard condition.

Failure: A permanent interruption of a system's ability to perform a required function under specified operating conditions.

Malfunction: An intermittent irregularity in the fulfilment of a system's desired function.

Error: A deviation between a measured or computed value (of an output variable) and the true, specified or theoretically correct value.

Disturbance: An unknown (and uncontrolled) input acting on a system.

Perturbation: An input acting on a system, which results in a temporary departure from the current state.

Residual: A fault indicator, based on a deviation between measurements and model-equation-based computations.

Symptoms: A change of an observable quantity from normal behaviour.

Fault detection: Determination of the faults present in a system and the time of detection.

Fault isolation: Determination of the kind, location and time of detection of a fault. Follows fault detection.

Fault identification: Determination of the size and time-variant behaviour of a fault. Follows fault isolation.

Fault diagnosis: Determination of the kind, size, location and time of detection of a fault. Follows fault detection. Includes fault isolation and identification.

Monitoring: A continuous real-time task of determining the conditions of a physical system, by recording information, recognising and indicating anomalies in the behaviour.

Supervision: Monitoring a physical system and tasking appropriate actions to maintain the operation in the case of faults.

Protection: Means by which a potentially dangerous behaviour of the system is suppressed if possible, or means by which the consequences of a dangerous behaviour are avoided.

Analytical redundancy: Use of two or more (but not necessarily identical) ways to determine a variable, where one way uses a mathematical process model in analytical form.

1.4. Fault diagnosis system requirements

An ideal FDS should have the following features:

- *Fastness of detection and diagnosis:* the early detection and diagnosis means a quick response to an incipient fault. The main difficulty to reach this goal is that signals of false diagnosis can appear during normal operation if the FDS is designed to be so sensible.

- *Resolution:* the ability of a FDS to isolate, that is, to discriminate among different faults is an important attribute. It is also required the so called "completeness", that is, to have a complete list of hypothesis and the actual fault(s) as a subset of the proposed list. Therefore, there is a trade-off between resolution and completeness.
- *Robustness*: the correct diagnosis in presence of noise and uncertainties has to be balanced with a tolerable performance. The thresholds has to be chosen conservatively in presence of noise.
- *Novelty identifiability*: an important requirement of a FDS is to determine if the abnormal condition detected is a known one or not. Sometimes, the FDS could associate a new, unsuspected fault with a suspected one. Otherwise, the FDS could associate the new unsuspected fault with a normal condition. An ideal FDS does not have these two behaviours. It is desirable that the FDS be able to recognise the occurrence of normal faults and not misclassify them as others known malfunctions or as normal operation.
- *Multiple fault identifiability:* the ability of diagnosing multiple faults can be performed by a FDS if it is designed for all the possible multiple combinations. However, this design is computationally prohibitive for large processes. Hence, an ideal FDS should model the combined effect of the faults.
- *Explanation facility:* the FDS should provide explanations to the operator on how the fault is originated. This requires ability to reason about cause-consequence relationships in a process. A FDS output should give a list of justified recommendations.
- *Adaptability:* the FDS has to be capable of easy adaptation during use. This is important taking into account the changing operating conditions of present chemical plants.
- *Reasonable computational requirement*: the complexity of the computational system could affect FDS performance. On the other hand, simple FDS with less computational requirement might need high storage requirement to have tolerable performance.