A WEB-BASED INDUSTRIAL PROCESS MONITORING SYSTEM FOR ETHYLENE PRODUCTION

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Abstract Overview

In this work, a web-based industrial process monitoring system is proposed and a cracking unit for ethylene production is investigated for validation purpose. OPC sever is the beginning of unidirectional data acquisition, by which real-time operation data are transferred to the web system at different sampling frequencies according to the monitoring requirement. PCA based monitoring model system is developed for ever-changing operation states, even without corresponding historical data. Soft-sensoring subsystem is equipped for key parameters unavailable online and data reconciliation for ill-functioned measurement device. Root-cause reasoning is realized by accumulated Hoteling control chart, and cross validated by Signed Directed Graph (SDG). The system demo was tested in an industrial cracking unit and has continuously operated for two months. During the test phase, a sensor failure and nozzle mal-function were successfully identified, pipe surface temperature and cracking product components were also correctly predicted.

Keywords

Process monitoring, Fault diagnosis, Soft-sensoring, accumulated T^2.

Introduction

Distributed Control System, DCS, plays an important role in modern chemical industry. At the meantime it also provides a huge amount of operation data, which contain rich information of the process ready for further analysis. Data mining and pattern recognition technique have gained significant attention and are advanced rapidly in last couple decades (Qin et al., 2012), which are successfully applied to theoretical study of process monitoring and fault diagnosis, such as Tennessee Eastman process, TE (Downs et al., 1993), and simulated penicillin fermentation process, Pensim (Birol et al., 2002), but still challenged by the complicate situation of industrial practice due to its random disturbances, occasional instrument failures, constant switches of operation state, multiscale nature of process signal, strong correlation within/among measurements, and root cause reasoning under coupled control operation.

In this work, multiple operation state, novel root cause reasoning strategy, and interface for data acquisition and user are integrated into a web-based monitoring system and tested in an ethylene production process.

System framework

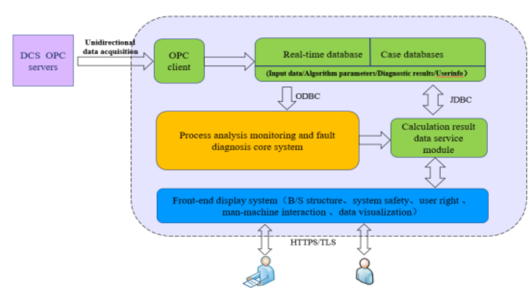


Figure 1. Monitoring results

The system framework is illustrated in Figure 1. An OPC sever is developed to obtaining data from DCS system at a designated sampling frequency. Three databases are established for temporal process data for analysis, fault case recording and result output. Subsystem of monitoring algorithm is communicating with three databases. User with different authorizations only interacts with result database.

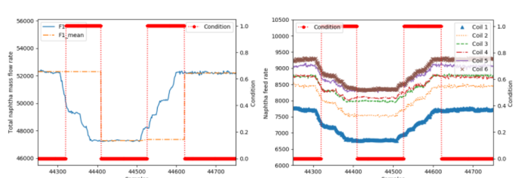
Application results

Data for a complete production cycle, from November 6, 2015 to February 6, 2016 are selected for system development and then the system was tested online.

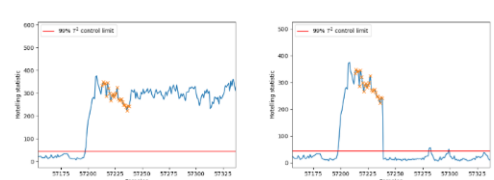
A. Fault detection with operation state change

A condition recognizer is developed for ever changing operation states in industrial practice. The monitoring model parameter will be automatically adjusted according to the output of condition recognizer (Han et al., 2017).

In Figure 2, for a known load adjustment due to the downstream reactor switching, the condition recognizer results, total naphtha mass flow rate, and naphtha mass flow rate among six coils are shown. In Figure 2 (a), straight line indicates total naphtha mass flow rate, dash dot line indicates the mean of subsequent monitoring model, and pentagonal mark indicates the condition recognizer results. When the condition recognizer confirms that the process parameters are adjusted by operators, the value is assigned to 1. Otherwise, the value is assigned to 0. It can be observed that process experienced operator adjustments during 44311th to 44387th and 44510th to 44604th sample.



(a) (b)



(c) (d)

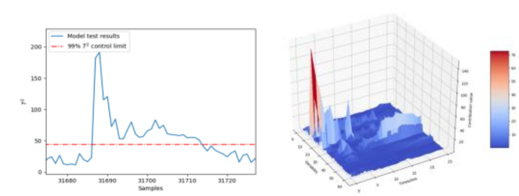
Figure 2. Condition recognizer results

The monitoring result for the complete production cycle (93 days) is shown in Figure 2. As known, cracking process cannot be kept identical for a long-term. In the process initial stage, parameters were adjusted in order to optimize operational condition. In later stage, parameters are adjusted due to the non-uniform coking condition of coils. It can be seen that the process monitoring results are in consistence with the actual process (Han et al., 2018).

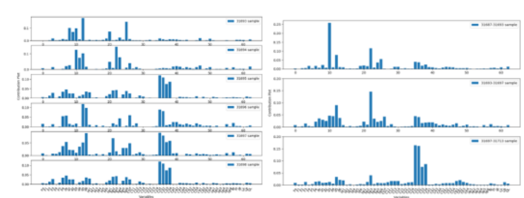
B. Fault diagnosis based on accumulated T^2

Traditionally fault diagnosis in PCA based monitoring is realized by contribution plot obtained by hoteling statistic. However, due to the rapid response of control system to process deviation, fault diagnosis result based on this contribution plot will change accordingly, which makes the root cause somehow mixed with the contribution of other manipulate variables.

In Figure 3, the contribution plot along time is obtained in (b) for an example of monitoring result as in (*a*). It can be observed that the variable with the most contribution is different for each sampling point. By proposed method, the contribution plot get more stable and only three dominate variables are shown, which is also accordance with practical situation.



(a) (*b*)

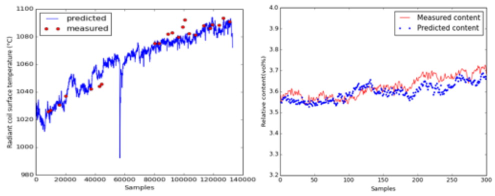


(c) (*d*)

Figure 3. Fault diagnosis based on accumulated Hoteling Statistic

C. Soft-sensoring

In order to obtain key parameters unavailable online and validate sensor function, soft-sensoring subsystem is developed based on multivariate method. In Figure 4 (a), prediction result for the surface temperature of cracking pipe. A sudden drop can be observed in coil surface temperatures of the first group. By discussing with engineers, this situation could be caused by fuel nozzle malfunction on the north side of the furnace. In Figure 4 (b), volume fraction of cracking products is illustrated. The relative error of both are below than 1% (Tian et al., 2017).



(a) (b)

Figure 4. Soft-sensoring result

System function and interface

In Figure 5, the main interface of the system is displayed, in which user can check both real time and historical monitoring result and corresponding root cause analysis. Soft-sensoring result are also available on this page. The system had been tested in a naphtha cracking facility for two months. Process deviations and measurement device failures are detected promptly and root causes are recognized correctly.

Figure 5. Main interface of the system

Conclusions

In this work, an online monitoring system is successfully applied on an industrial facility. Challenges from industrial practice, including constant switch of operation state, root cause reasoning under coupled control operation, are considered and corresponding strategy is proposed. The system is continuously improved based on online test feedback.

Acknowledgments

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References

Qin S. J., (2012), Survey on data-driven industrial process monitoring and diagnosis. Annual Reviews in Control, 36(2):220-234.

Downs, J. J., Vogel, E. F., (1993). A plant-wide industrial process control problem. *Computers & Chemical Engineering*, 17(3):245-255.

Birol G., Undey C., Çinar A., (2002). A modular simulation package for fed-batch fermentation: penicillin production. *Computers & Chemical Engineering*, 26(11):1553-1565.

Han, X., Tian, S., Romagnoli, J. A., Zhan, Y., Sun, W. (2017). The Real-time Multiple Operational Condition Monitoring of Ethylene Cracking Furnace Based on the Principal Component Analysis. *Chemical Engineering Transactions*, 61: 517-522.

Han, X., Tian, S., Romagnoli, J. A., Li H., Sun, W. (2018). PCA-SDG Based Process Monitoring and Fault Diagnosis: Application to an Industrial Pyrolysis Furnace, *IFAC-PapersOnLine*, 51(18): 482-487.

Tian, S., Han, X., Romagnoli, J. A., Ma, L., Sun, W. (2017). Coking analysis based on the prediction of coil surface temperature in radiation section of ethylene cracking furnace. *Chemical Engineering Transactions*, 61: 505-510.