INDIRECT PROCESS CONTROL USING ELECTRICAL NETWORK PARAMETERS FOR ENHANCED AUTOMATION IN CHEMICAL TECHNOLOGIES

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Abstract – Automation and real-time monitoring are hampered by the fact that traditional methods of controlling operations in opaque reactors typically rely on expensive and invasive sensors. This work discusses a low-cost, non-invasive technique that provides useful insights into process dynamics using electrical energy analysis. We demonstrate the application of electrical parameter fluctuations such as power and current as indicators of significant process changes in opaque reactors. This method could be of great benefit to the High-Tech industry, where precise process control is required to produce consistent, high-quality products. In our evaluation of the advantages and limitations of the method, we emphasize how the approach can increase production efficiency while reducing the need for human intervention in process control [1].

Keywords – *process control, automation, chemical production*

INTRODUCTION

The pursuit of robust and reliable automation in chemical technology is based on the desire to minimize human intervention, improve process consistency and increase overall efficiency. However, achieving this goal often faces challenges because it is difficult to directly observe and control internal process variables. Many chemical processes occur in sealed, opaque devices, making direct monitoring difficult and requiring the use of costly and complex sensors.

This is particularly relevant in pharmaceutical production, where strict GMP (Good Manufacturing Practice) regulations require strict control of process parameters to ensure consistent product quality [2]. The need for precise control and the possibility of human error underscore the importance of reliable automation systems. While traditional approaches are based on the direct measurement of process variables, this article proposes a novel method for indirect process control that utilizes readily available electrical network parameters. By analyzing fluctuations in current, active power and apparent power, we can infer changes that occur in the “black box” of chemical equipment. This approach provides a cost-effective and potentially more robust method of monitoring and controlling processes and potentially results in:

• Simplified monitoring: reducing reliance on complex and expensive sensors.

• Reduced costs: avoid installation and maintenance of costly direct measurement systems.

• Increased reliability: utilizing redundant data streams from electrical network parameters for improved process control.

PROBLEM STATEMENT

Directly monitoring and controlling all critical process parameters in chemical engineering can be difficult and costly due to:

• Opaque equipment: most chemical processes take place in sealed and opaque containers, making direct observation of internal conditions impossible.

• Costly sensors: special sensors are often required to measure certain process variables, resulting in significant financial investments.

• Limited access: due to the nature of the equipment, certain process variables may be inaccessible or difficult to measure.

• Complex process dynamics: many chemical reactions exhibit complex dynamics, requiring advanced sensor systems to accurately capture all relevant parameters.

These problems show that we need different ways to keep an eye on things and make sure they work well, instead of just checking them directly all the time [3].

PROPOSED SOLUTION: INDIRECT PROCESS CONTROL USING ELECTRICAL NETWORK PARAMETERS

This work proposes the use of easily accessible electrical network parameters as indirect markers of process changes. This method justification is based on the basic idea that changes in electrical parameters are often associated with changes in the underlying process.

Take this example:

• Power: an increase in power consumption could be a sign of increased heat transfer motion or reaction speed in the device.

• Active power: changes in active power consumption can provide information about the efficiency of heat transfer or the progress of a reaction by reflecting changes in the energy requirements of the process.

• Apparent power: fluctuations in apparent power can reveal shifts in the overall electrical load of the process, reflecting the energy consumed by the device and reaction. We can derive process changes and initiate any necessary adjustments to maintain process stability and achieve desired product quality by examining trends and patterns in these electrical network parameters. This strategy offers a number of potential benefits.

• Cost effectiveness: using existing electrical monitoring systems means fewer specialized sensors are required.

• Increased robustness: the overall reliability of the control system is increased by the redundancy provided by multiple data points of electrical parameters.

• Adaptability: the method provides a flexible solution for process monitoring and control and can be easily adapted to a variety of requirements.

CASE STUDY: INDIRECT MONITORING OF A PHARMACEUTICAL CRYSTALLIZATION PROCESS

In our pharmaceutical production processes, we are investigating the task of controlling the crystallization process. For that we need to clearly identify the criteria of the end of the crystallization process. Pharmaceutical crystallization is one of the key steps in drug development that has an immediate impact on the purity, solubility and bioavailability of active pharmaceutical ingredients (APIs) during manufacturing. In conventional monitoring techniques that include often visual inspection or advanced analytical procedures for measurement, the use of equipment in crystallization processes may not be transparent and can interfere with obtaining reliable data. This study exemplifies the ability of some indirect monitoring strategies based on electrical network parameters to increase automation and control in a pharmaceutical crystallization process.

This involved real-time monitoring of electrical network parameters as well as input data from crystallization process units to analyze the relationship between energy consumption parameters (e.g., current, active power, reactive power) and the state of crystallization. The experimental system consisted of a standard batch reactor (200/250 liters) as typically used in pharmaceutical production, equipped with temperature sensor, INNOVERT IVD152B43E frequency converter, Cooling Thermostat VMT 24, and OWEN ME210-701 modules to record the electrical parameters applied to the system “Fig. 1”.

The values of total, active and reactive power are obtained by calculating according to the formulas given below:

Full power, VA—

$$S = V_{rms} \cdot I_{rms},$$

where V_{rms} – the root mean square (RMS) voltage; I_{rms} – the RMS current.

Active power, VA—

$$P = V_{rms} \cdot I_{rms} \cdot cos(\phi),$$

where φ – the angle of displacement between V and I.

The RMS voltage and RMS current are calculated by the following formulas

$$V_{rms} = K_V \cdot \sqrt{\frac{1}{T} \cdot \int_0^T V^2(t)dt},$$

$$I_{rms} = K_I \cdot \sqrt{\frac{1}{T} \cdot \int_0^T I^2(t)dt},$$

where V – the value of the phase voltage; T – the period; K_V – the voltage transformation coefficient; I – the value of the phase current; K_I – the current transformation coefficient

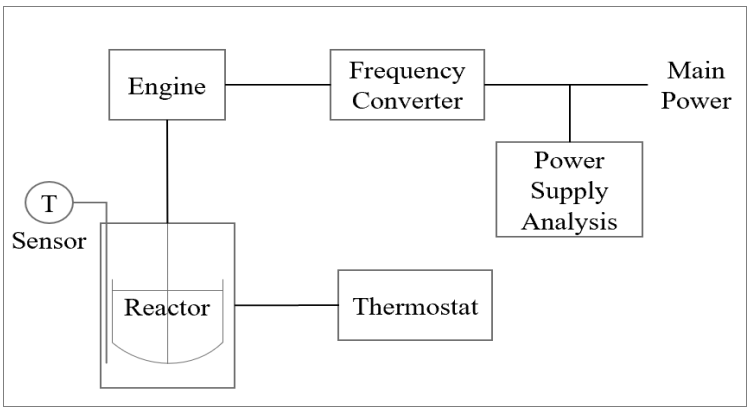

Fig. 1. Technical scheme of the experiment.

Significant patterns in the electrical parameter of active power were observed as the crystallization process moved through various stages “Fig. 2”. During the nucleation phase for example there was a consistent increase in electrical current which suggests that energy requirements increased because of increased agitation and mixing activities that are necessary for crystal formation. The sudden increase of active power is associated with a higher resistance that the stirrer of the reactor encounters due to the higher viscosity of the solution to continue stirring with the same frequency. On the other hand, as the system’s focus shifted to encouraging crystal growth rather than creating turbulence a stabilization in current consumption and a noticeable decrease in active power during the crystal growth phase suggested that the system had stabilized. By comparing these observations, we were able to conclude that power consumption was a good indicator of both energy expenditure and the dynamic changes taking place inside the chemical reactor. After establishing a trustworthy correlation between particular operational conditions and electrical parameters we created a calibration model that allowed for predictive control over the crystallization process thereby facilitating automated adjustments to maximize yield and purity.

In the current experimental setup, the initiation and termination of the crystallization process were determined through direct observation by chemical operators and analytical sampling during production according to the usual production procedure. These visual assessments were correlated with the corresponding measurement data obtained throughout the experiment.

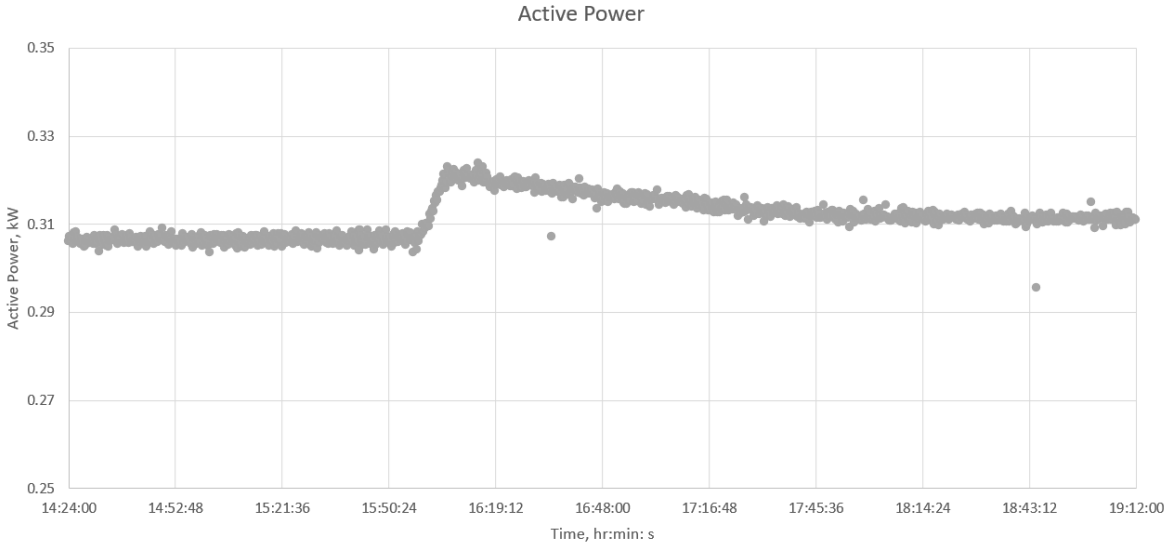

Fig. 2. Graph of the dependence of the active power during the crystallization time for the product VM1500A 905420724-2/7

CONCLUSION

Indirect monitoring of electrical network parameters can provide important insights into the dynamics of pharmaceutical crystallization processes, as this case study supports. Deriving process states without direct visual monitoring improves automation capabilities while optimizing operational efficiency. As monitoring of electrical parameters continues to be investigated, automated control techniques for a range of chemical processing technologies will continue to be developed. Future studies should focus on developing reliable algorithms to correlate electrical network parameters with specific process variables, verifying the methodology through experiments, and exploring the possibility of integrating this technique into already existing automation systems. Process control and optimization will improve significantly through this research, opening the door to more reliable, economical and efficient automation in the chemical manufacturing industry.

Applicability of this method, however, could be restricted by the intrinsic nature of the chemical system under investigation. Systems with negligible fluctuations in electrical demand across critical process phases such as initiation and completion may not yield unambiguous results. Future research has to investigate the versatility of this method to different chemical systems to define the limits of its successful application. Additionally, further research is required to assess the suitable sampling rate and signal processing methods for accurately monitoring crystallization processes with a wide range of kinetic profiles. In cases of extremely slow crystallization, active power trends are anticipated to be low-level and incremental electrical changes to be very slow, which would create an obstacle to distinguish from unrelated fluctuations or baseline noise.

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