Abstract

Title: Intelligent supervisory control of a compressor system minimizing electricity consumption while ensuring a stable compressed air supply, in the context of Industry 4.0 principles.

Keywords: BiLSTM, screw compressors, load prediction, custom loss function, supervisory control, energy efficiency, asymmetric cost, Industry 4.0

Compressed air is one of the principal energy carriers in industry and often represents a considerable share of a manufacturing plant's operating costs. Directive (EU) 2023/1791 imposes an obligation to reduce electricity consumption, of which screw compressors are a substantial consumer. At the same time, Industry 4.0 encourages new ways of exploiting the process data that plants already collect and archive. One such use is to extend an existing control system with a predictive layer, whose purpose in this dissertation is to minimize the electricity consumed by compressed air systems.

To coordinate the operation of several screw compressors, manufacturing plants employ a supervisory controller that sequentially starts and stops machines, matching their number to the current demand for compressed air. These systems, commonly built on proprietary embedded controllers or on programmable logic controllers, have no knowledge of the cyclical behaviour or demand patterns specific to a given plant. As a consequence, and because demand varies considerably, machines may have to be kept running unloaded, drawing electrical power while producing no compressed air.

The dissertation proposes a predictive control layer that adds value to existing supervisory control solutions. It is based on a bidirectional recurrent network (BiLSTM) and predicts the load states of individual machines over a given horizon from the pressure trajectory and historical states. The proposed solution requires no additional instrumentation and relies solely on signals that are already available. The work introduces a four-component loss function that can be adapted to different demand characteristics, with emphasis on detecting critical errors, that is, those capable of compromising the stability of the compressed air supply, which serve as the criterion for validating the production model. The evaluation adopts indicators that, rather than relying on averaged deviation measures, assess the decisions that support switching a machine off once an unloaded state occurs.

The methodology was verified on twelve industrial installations belonging to three common classes of differing structure and demand. Production deployment was carried out on eight installations, four of which were not part of the previously studied set. An ablation study showed that bidirectional processing is a necessary condition, since unidirectional architectures may degenerate into predicting a single state. The deployments reduced unloaded running time by up to 83%, with two installations showing no statistically significant improvement. The limits of applicability of the method were also identified, together with the indicators that allow them to be recognized. The deployment further yielded an operational supervision indicator capable of detecting model degradation.

The contribution of this work comprises a loss function that links process cost to model selection, a set of evaluation indicators referred to decision events, together with criteria for qualifying an installation and a mechanism for operational supervision.