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Design and Implementation of Compressor Controller Using an Optimized VSD Algorithm

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Abstract

Considering the high consumption of the air compressors, a control system of screw compressor is designed and implemented to deal with energy saving and localization of the mentioned compressor. In this paper the variable of speed drive (VSD) control algorithm based on proportional-integral-derivative (PID) controller is optimized to decrease power consumption and gain a more stable motor speed and outlet pressure. Automatic PI factors adjustment according to system behavior is the goal of this control system. To show the validity of the proposed algorithm, we simulated P and I changes. The results of simulation and practical test on a GA111 Atlas Copco compressor were established which demonstrate that the proposed algorithm provides system stability improvement, and as a consequence the depreciation reduction and energy saving were achieved.

Keywords: Compressor Controller; VSD algorithm; reducing of electrical energy; optimizing

1. Introduction

Energy management is the key to survival for all types of industries. This would require planning and operation of energy production and consumption units. But to do this, we should implement a substantial infrastructure. So a solution would be to extend both optimization and energy saving culture and consultative organizations.

The concentration of this paper is on air compressors. As the air compressors are widely used in industries and consume above 65% of total electrical power (about 50% of energy) of the world, optimization and improvement of air compressor systems leads to high energy saving and production cost reduction because the air compressors expend about 32% of total electro-motors' consumptions.

There are two general methods to control an air compressor: 1) The Load/Unload controller with fixed speed. 2) electro-motor speed control systems. It is found that VSDs (variable speed drive) are used to match the required loads in order to save electrical motor energy in compressed-air systems [1]. In addition, in many huge industries more than one compressor is used. In such systems the algorithm takes into account the dynamics of the air pressure, as well as timing constraints on the minimum period between two subsequent activations of each compressor [2]. The comparison with a PI regulated control shows the potential of model predictive control scheme (MPC) both from a pressure stabilization standpoint and, slightly, also from an energy saving standpoint [3]. The constant pressure controlling progress of air compressor, limited by the production load and the changing of compression material flow, is a representative time-varying system. [4].

2. Previous Works

Study on air compressors shows that three control methods are used to drive the electro-motor described as follows.

2-1- Driving a Compressor without Inverter

In old and standard control systems, once the compressor needs to increase the pressure, the mechanical valve closes and motor loading will have an impulse which can lead to an electrical shock and due to this repeated load and unload, depreciation and pressure vibrations are propelled. At this mode there is no energy saving because of the fix speed of the motor.

2-2- Driving a Compressor with an Inverter and Constant Speed

The second method is constant speed drive. In this method an inverter is used to change motor speed. This approach is more reliable than the previous one since the motor speed starts from low speed and gradually increases speed frequency and there is no impulse on the electro-motor loading. The supply frequency is regulated by a feedback PID controller [5]. Furthermore, mechanical depreciations and periodical maintenances are reduced. Motor speed diminish on unload mode can cause considerable energy saving, considering the fluids Affinity Laws, as it is shown in fig.1. As indicated before, sequential compressor loading causes depreciation in the long term.

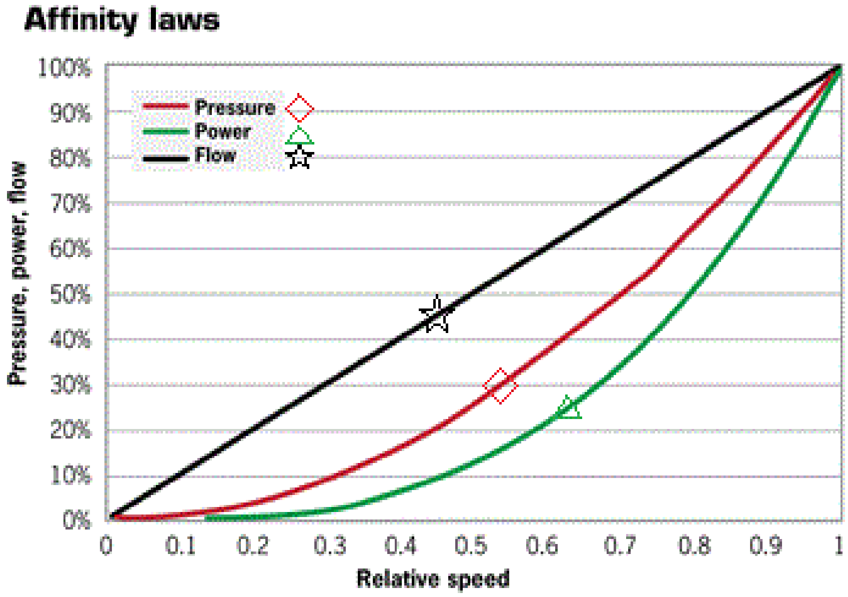

Fig.1. The fluids Affinity Laws diagram

2-3- Variable Speed Drive Control

Different control algorithms such as PID, fuzzy logic and Artificial Neural Network (ANN) were experimented [6]. The basic design of this method includes a PID controller which attempts to determine motor speed based on compressor output pressure and the flow rate requirement. This is where an inverter is used to control motor speeds. Thus energy consumption decreases. Usually, a collector is used to stable pressure in air compressors. The control system’s goal is to stable output pressure, so the pressure is the objective function. This means that PID factors allow us to stable pressure by changing electro-motor speed. The advantages are the same as previous methods since it is using an inverter. In VSD control, mechanical unloaded, electrical valve, and collector in some cases, could be eliminated which reduces installation cost.

The problem here is that the PI controller factors couldn’t be remodeled. In case of system behavior changing or when the working conditions are changed, it would be impractical to find suitable PID coefficients for such a nonlinear system. Another factor of concern is electro-motor speed vibrations. In VSD control system the stable output pressure is ensured, but electro-motor speed will be unsteady (about 200 to 400 RPM) which damages rotating sections of compressor.

3. Optimized VSD Controller

The solution that we have proposed is to adjust PI factors automatically based on system behavior. Here the key is to drive electro-motor with nominal speed while the compressor pressure and adjusted pressure are extremely different and decrease the motor speed while the compressor pressure is close to adjusted value.

Screw compressor modeling combines the analysis of thermodynamic and fluid flow processes. Both are dependent on the screw compressor geometry and combining them in a mathematical model is a complex process. [7]. Thus, the proposed method is based on actual experiences and practical tests.

3-1- P Coefficient Adjustment

In order to adjust P factor, it is needed to compare compressor output pressure with adjusted pressure which is defined as error. The amount of error controls the P factor. While the error is more than 0.3, the P factor is constant and was measured from the VSD control of an air compressor as 300.

$$P(n) = 300\ (Set\ by\ Operator), if \quad |Error(n)| > 0.3 \tag{1}$$

To obtain reasonable system gain, in the moment the error value is less than 3, the P factor will decrease as follows:

$$P(n) = 110.3\ x\ \exp(|Error(n)|), if \quad |Error(n)| <= 0.3 \tag{2}$$

In this system, the pressure amounts are normalized. The result is depicted in fig.2. And it shows the small overshoot of system [8].

3-2- I coefficient adjustment

While a compressor is operating, the motor speed it is being sampled by control system to obtain a period cycle. Also the maximum and minimum amounts of a period cycle were compared. The motor speed vibrations are high if the maximum and minimum amounts of motor speed are more than 100 RPM. It can be seen in fig.3 that when the amplitude is more than 100 RPM, the I coefficient is increased as follows:

$$I(n) = 100[0.05\ x\ [max(Pres(n)) - min(Pres(n))]]; \quad (3)$$

$$if\ cycle\ available\ \&\ I(n) < 50$$

$$\mathrm{I(n)} = 50; \quad (4)$$

$$\text{if cycle available}\ \&\ \mathrm{I(n)} \geq 50$$

The control system will fix the I factor while the amplitude is low. This value is measured from VSD controller.

$$I(n) = 3.3(default\ value);\ no\ cycle; \quad (5)$$

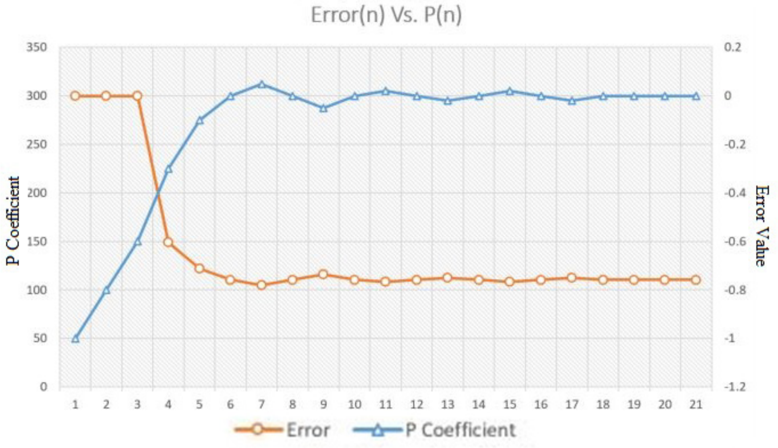

Fig.2. “P” coefficient changes in proportion of error changes

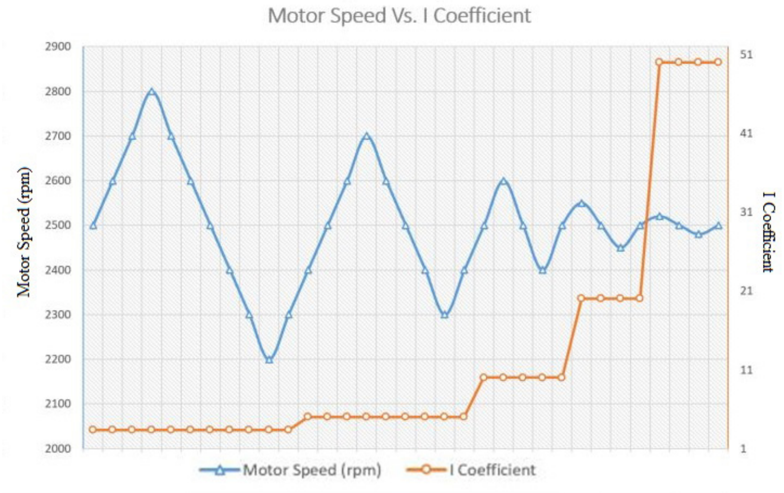

Fig.3. Effects of variation of “I” coefficient magnitude on motor speed vibrations

4. Modular controller board

The proposed controller board presents practical features for subsequent uses and also it is particularly designed for industrial applications.

All the parameters (except motor speed) are measured by this hardware. At the input level; there are 2 inputs to connect to pressure sensors and 2 inputs for RTD temperature sensors, and for the speed monitoring the Combivis 5 software is used.

To simplify hardware renovation and maintenance job, the essential components such as pressure and temperature sensors inputs, the current command output, and the Modbus network are implemented on various modules. In addition, the screen and control knobs are designed separately due to easier installation. Controller board is shown in fig.4, the overall architecture and the modular parts are presented in (a) and (b), respectively.

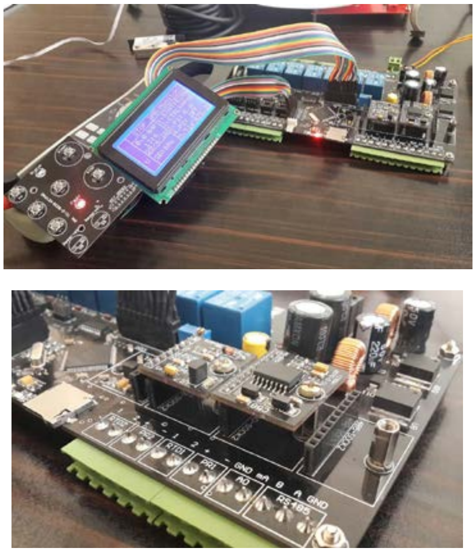

Fig.4. (Upper) Controller board. (Down) Modular parts of controller board

5. Practical Test Results

The designed controller board is tested on GA111 compressor of Atlas Copco Company which is shown in fig.5. Following diagrams are obtained from discrete data produced by Combivis 5 software which is able to connect to the mentioned compressor inverter. The responses of proposed optimized VSD in comparison to VSD are shown in fig.6 and fig.7. As it is shown in fig.6, after about 2 seconds the output pressure tracks the set-point adjusted by operator with an extremely low overshoot and acceptable oscillation (1% of full-scale value). The result shows that pressure stability is improved 40%. Fig.7 shows the electro-motor speed vibrations improvement of optimized VSD control compared with VSD control.

Fig.5. GA111 compressor of Atlas Copco Company

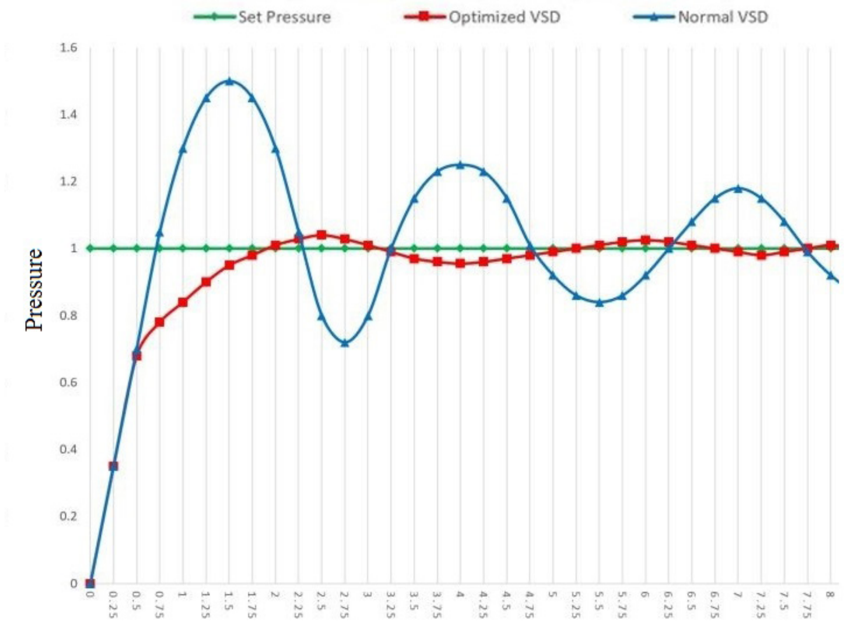

Fig.6. Comparison of output pressure of VSD and optimized VSD

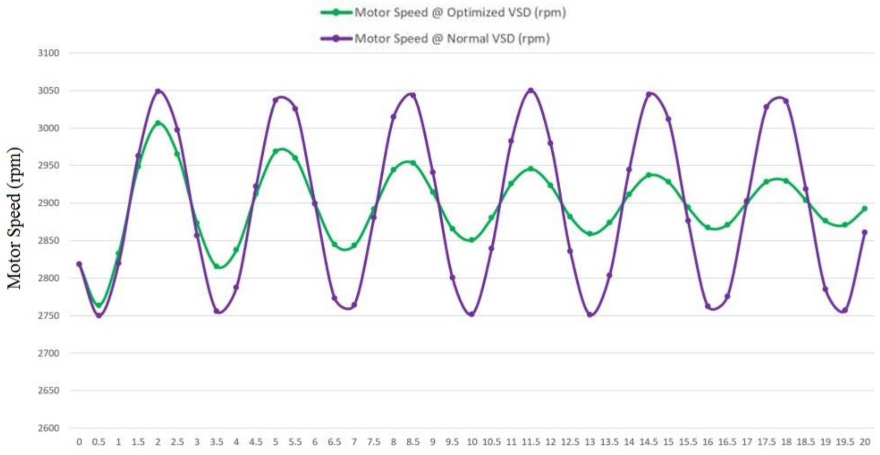

Fig.7. Comparison of speed of VSD and optimized VSD electro-motor

6. Conclusions

In this paper, a new method of screw air compressor control has been described. The complexity of an air compressor modeling made us to present this algorithm through actual experiences and practical tests. This project includes software and hardware designing for VSD controller optimizing purpose. The prototype electrical board was built and has been tested on a GA111 compressor. It has been proved that PI factors adjustment improves the pressure and motor speed vibrations stability. Reasonably good success has been achieved such as energy saving, system stability and depreciation reduction. Analysis of optimized VSD control effects is given through this practical test.

This article and further works could be helpful for this high consumption system to favor system stability and electrical power saving. Further works would be dedicated to torque stability using a closed loop system. Also it is used to test this method on a high range compressor (e.g. 250 kW).

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