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Speed turning-change intervals configuration of a three-phase motor for industrial processes

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Abstract:
It is well-known that in industrial processes, the utilization of three-phase motors is fundamental for the correct operation of many control systems. Many times, different intervals of speeds in the clock and/or clockwise direction are needed for processes such as mixing or blending. Usually, motor speed variators are used, but they are expensive, and sometimes they require special training, which represents an inconvenience. This work presents a cheap and versatile option to configure the turning change intervals for the speed of a three-phase motor using a programmable relay. The ladder diagram and the function block diagram programming options are presented.
Keywords: *Control Systems, Three-phase motor, Speed Variation, Blocks Diagrams Functions, Programmable Logic Controllers*

I. INTRODUCTION

Three-phase motors are a backbone of modern industry because they combine efficiency, reliability, and adaptability in a way that few other drive systems can match. Their importance in industrial processes can be understood through several key points, such as high efficiency and power density, reliability and durability, cost-effectiveness, smooth and continuous operation, versatility in applications, compatibility with industrial power systems and support for automation and process control [1-4].

Three-phase motors deliver more power for a given size compared to single-phase motors, making them ideal for heavy-duty applications, they operate with a smoother torque curve, reducing mechanical stress and increasing the lifespan of both the motor and connected equipment. They also have fewer moving parts and robust construction mean reduced maintenance needs and less downtime and their simple yet rugged design can withstand harsh industrial environments (heat, dust, vibration) without significant performance loss. Three-phase motors have a high efficiency factor, which translates to lower energy costs over time; because they are widely used, spare parts and technical expertise are readily available, reducing repair costs and downtime [5-8].

The constant power transfer in three-phase systems avoids the pulsations common in single-phase motors, leading to quieter and more stable operation. This smooth performance is crucial for precision machinery, conveyors, and process lines. They can power anything from pumps, compressors, and fans to conveyors, mixers, and Computer Numerical Control (CNC) machines, besides, adjustable speed control using variable frequency drives (VFDs) allows fine-tuning for different process requirements [9-12].

Most industrial facilities are wired for three-phase power, so these motors integrate seamlessly without the need for costly electrical adaptations, and three-phase motors work well with modern control systems, enabling precise speed, torque, and position control for automated production lines. On the other hand, configuring speed intervals and the direction of rotation in three-phase motors is critical because it directly affects the performance, safety, efficiency, and flexibility of industrial processes [13-15].

Certain operations, such as conveyor systems or mixers, require different speeds at different stages of production for accuracy and quality. Some machines need periodic reversal (e.g., cranes, hoists, rolling mills) for proper operation. Configuring direction safely ensures smooth transitions. In flexible manufacturing, the ability to reverse direction quickly allows for adjustments without mechanical reconfiguration.

Typically, speed variators are used for controlling the speed of a three-phase motor, nevertheless, they present some disadvantages. Variators add to the upfront investment compared to a direct-on-line (DOL) motor connection. In small applications or where speed control isn't critical, the payback period can be long. They require correct programming and parameter setup, which demands skilled technicians [16-18].

Variators can introduce harmonic distortion into the power supply, which may affect other sensitive equipment. Mitigation may require additional filters, increasing cost. For this reason, cheaper and more versatile options are commonly the best option in small and non-critical applications [19-22].

II. DYNAMIC MODELING

First, let consider the particular case where the three-phase motor is controlled with a programmable relay which commands the activation of four relays, each one with three normally open contacts as shown in Fig. 1. Relays A and B are used to control the direction of the motor rotation, while relays C and D are used to variate the angular speed by changing the speed in one or in other direction (delta or star connection respectively).

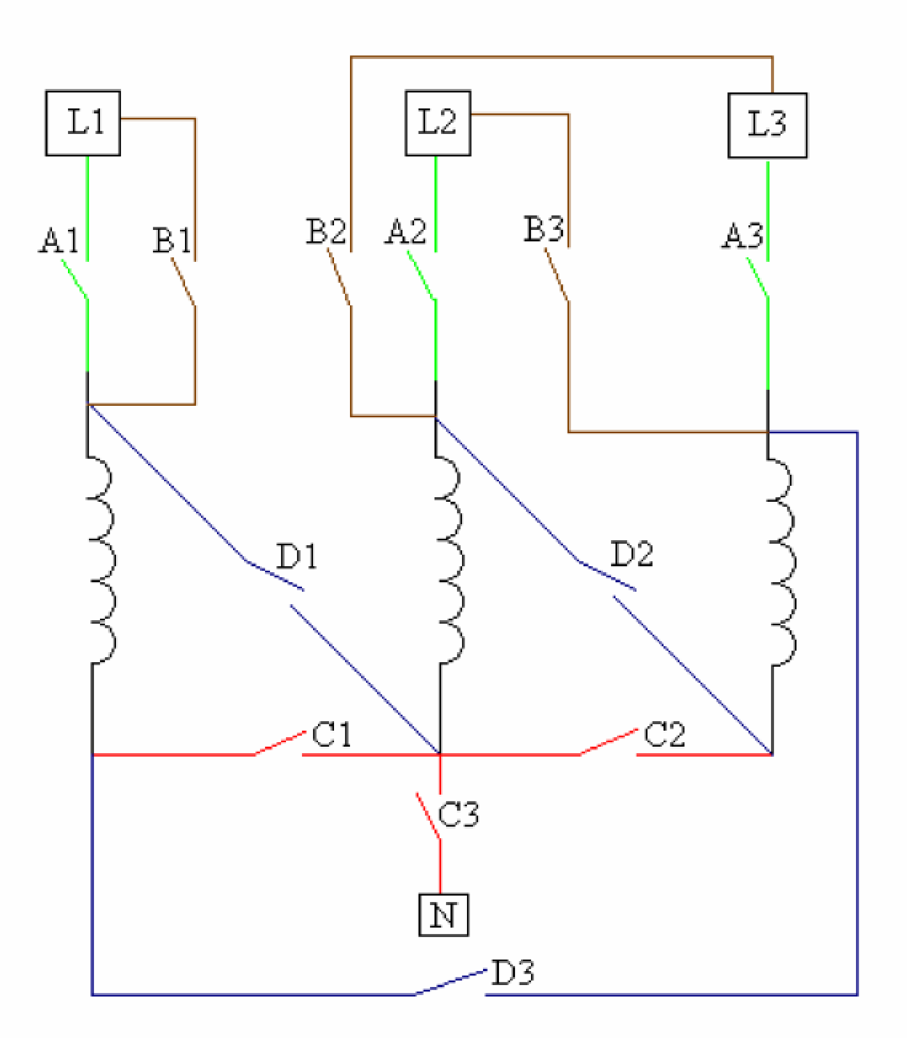

Figure 1. Three-phase motor and relays connections

A Zelio relay model SR3B101 FU was used to control the coils of the relays as shown in Fig. 2 according to the next logical conditions:

- I1 controls the on/off. Enables/disables all the contacts by software.
- Z1 activates the rotation in one direction by disabling coil B and then (after 1s) the activation of coil A.
- Z2 activates the rotation in the other direction by disabling coil A and then (after 1s) activates coil B.
- Z3 Deactivates delta connection disabling coil D and then (after 1s) activates star connection enabling coil C.
- Z4 Deactivates star connection disabling coil C and then (after 1s) activates delta connection enabling coil D.

Additionally, the automatic mode can be activated to consider a sequence according to the pre-configured intervals depending on the necessities of a particular process.

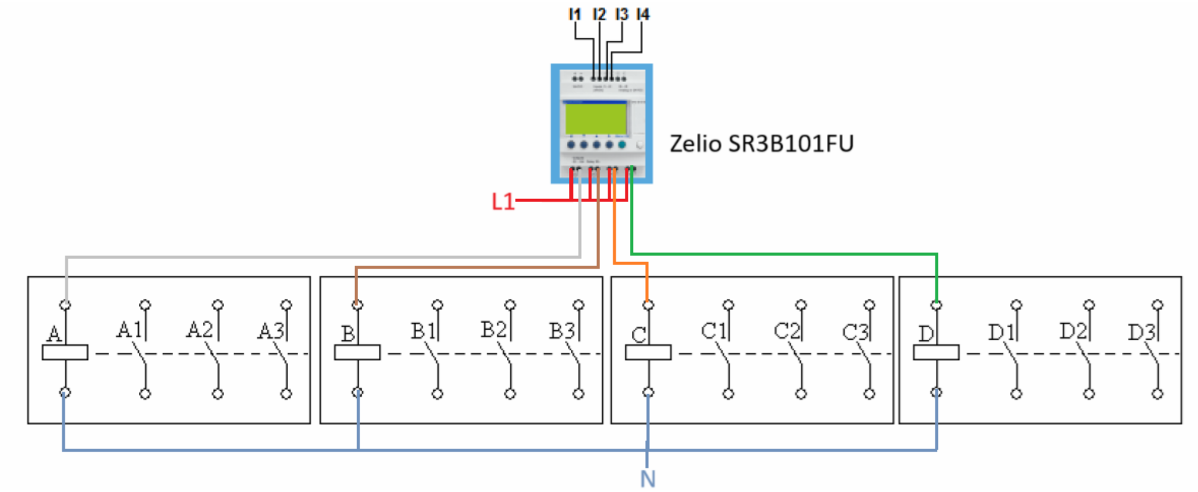

Figure 2. Zelio and relays connections

Fig. 3 shows the three-phase motor, while Fig. 4 shows the relays modules.

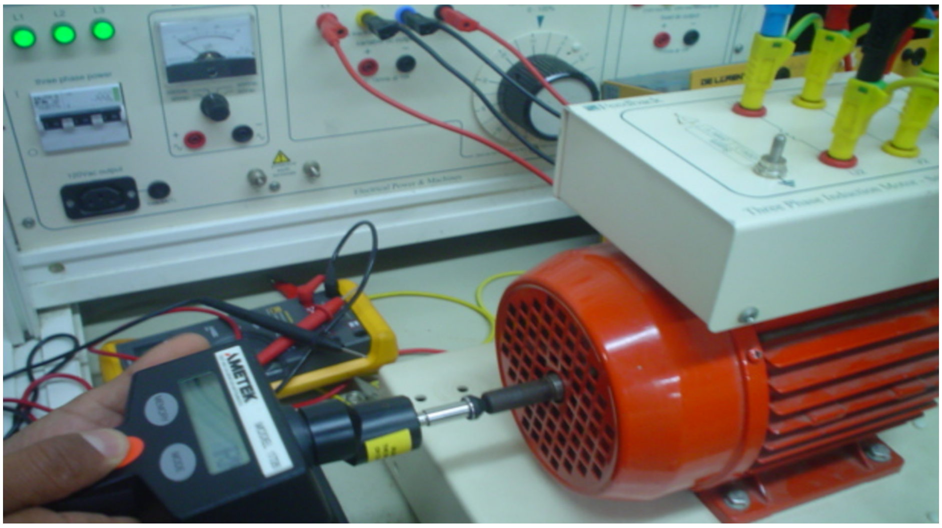

Figure 3. Three-phase motor

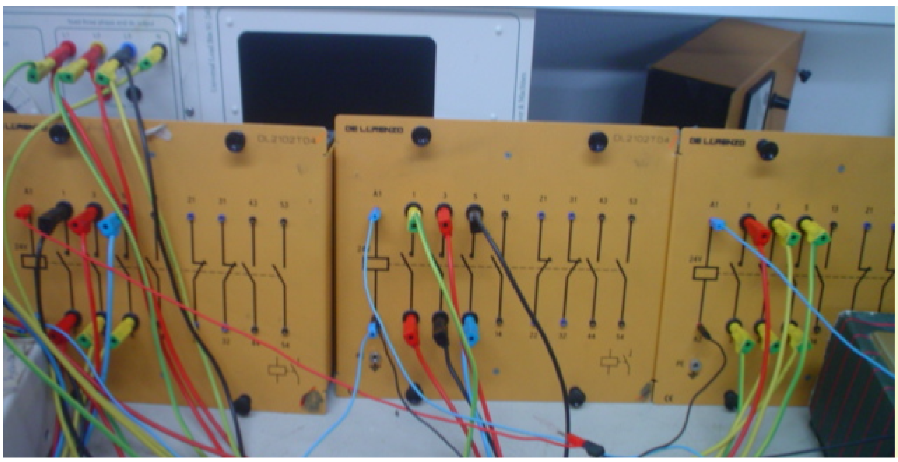

Figure 4. Relays modules

III. PROGRAMMING

Fig. 5 shows the program in ladder diagram. Lines 1-8 indicate the configuration of a one second on-delay timers (Fig. 6). Lines 9-12 are used to control the coils of the relays. The normally closed contacts of the timers are for security reasons.

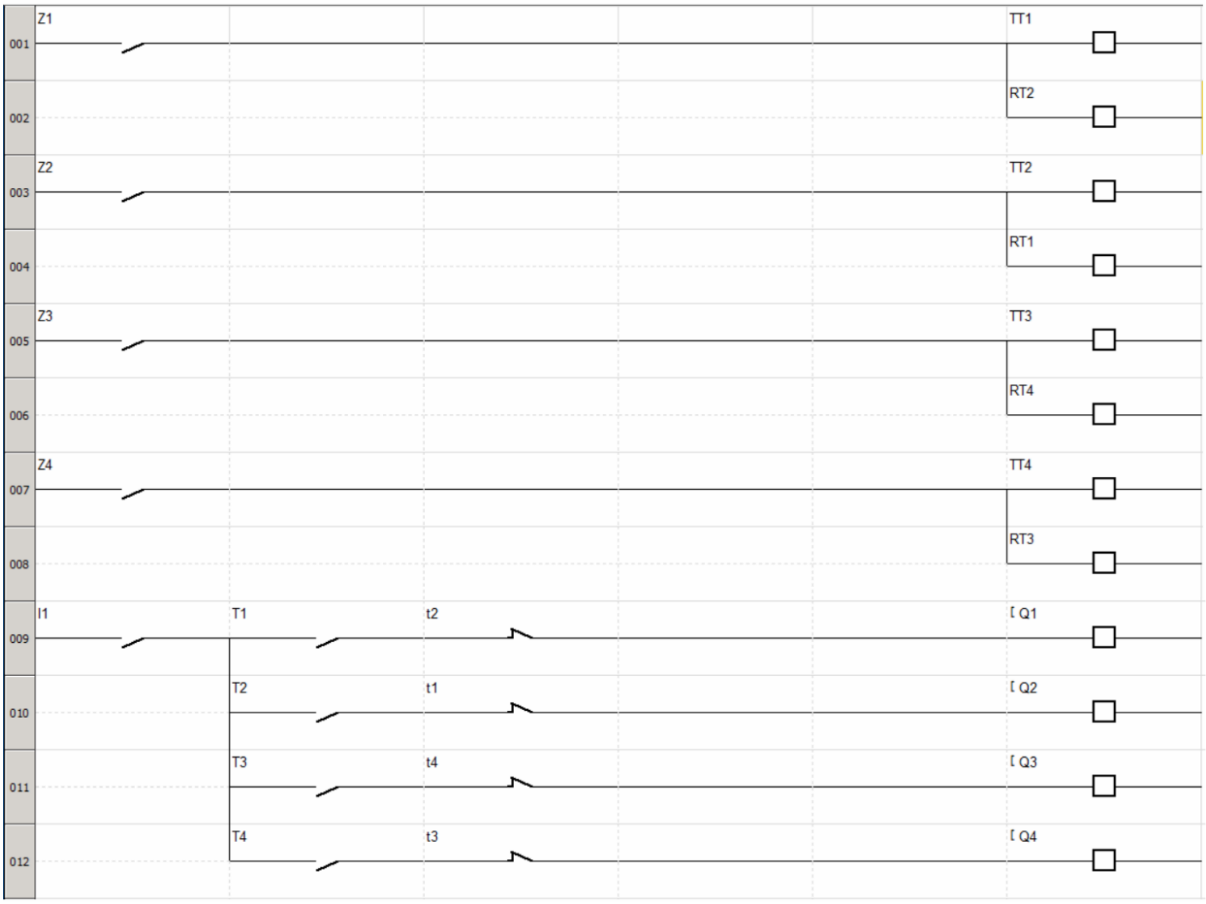

Figure 5. Ladder diagram

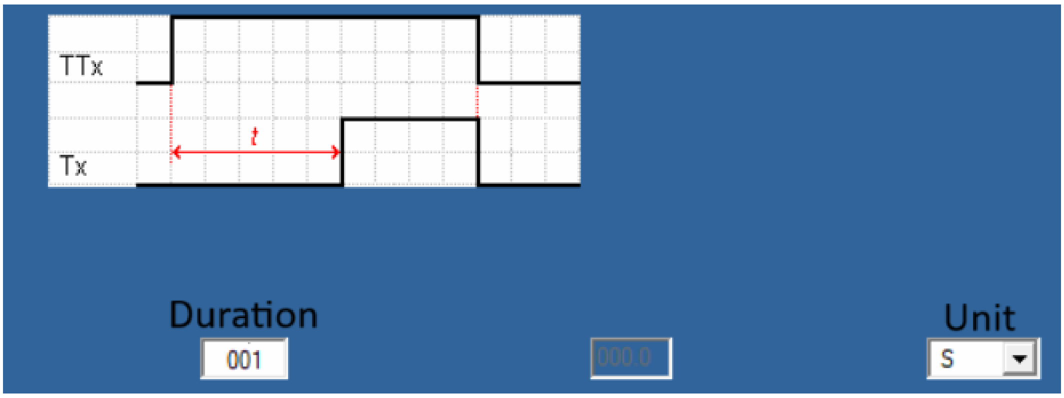

Figure 6. One second on-delay timers

As was said in the introduction, a sequence is commonly needed to fulfill the control system requirements. This can be easily programmed in BDF language by using a sequencer block, as shown in Fig. 7.

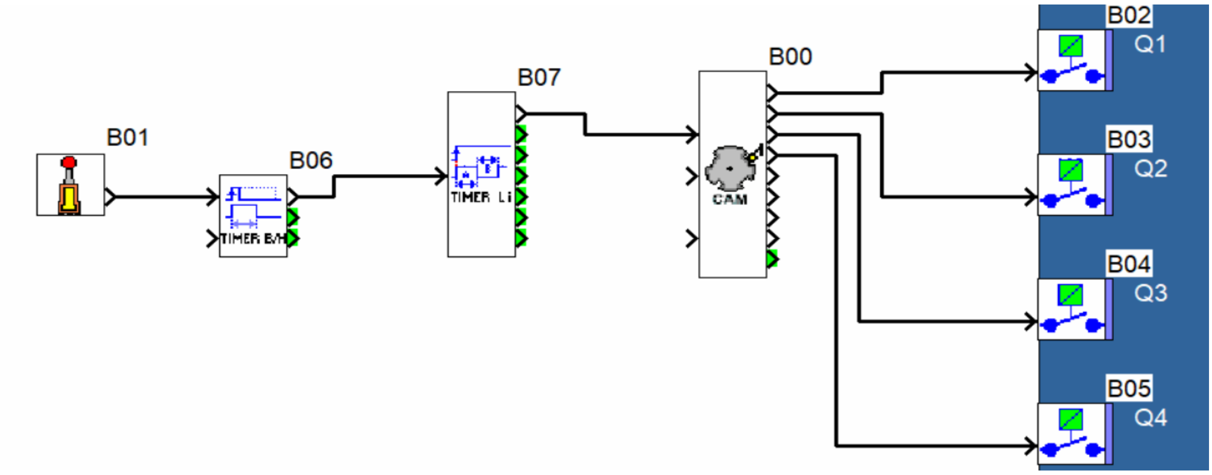

Figure 7. Sequencer block

The block B01 is responsible of the automatic mode, it sends the signal to a single-stable timer (B06), which sends a pulse of time to a free-oscillation timer (B07) of "n" equal intervals of time according to Eq. (1). The sequencer block can be easily configured to send the correspondent outputs according to the control system necessities. For instance, Table 1 shows a particular sequence where the position 1 presents the initial reset position. In the position 2 the shaft of the three-phase motor rotates in one direction and the star connection is activated (low speed). In position 3 the shaft rotation remains in the same direction but the delta connection is activated (fast speed). In position 4 the shaft changes its direction of rotation and the star connection is activated (low speed). Finally, the shaft remains rotating in its last direction and delta connection is activated (high speed).

IV. RESULTS

The implementation showed an appropriate performance. In practice, the direction of rotation was verified and the angular speed changes measured with a tachometer. The safety programming commands to avoid short circuit were also verified. Fig. 8 shows the last part of the sequence simulation, where Q2 and Q4 are activated (position 5 of Table 1).

Table 1. Sequencer configuration

Position	Q1	Q2	Q3	Q4
1	0	0	0	0
2	1	0	1	0
3	1	0	0	1
4	0	1	1	0
5	0	1	0	1

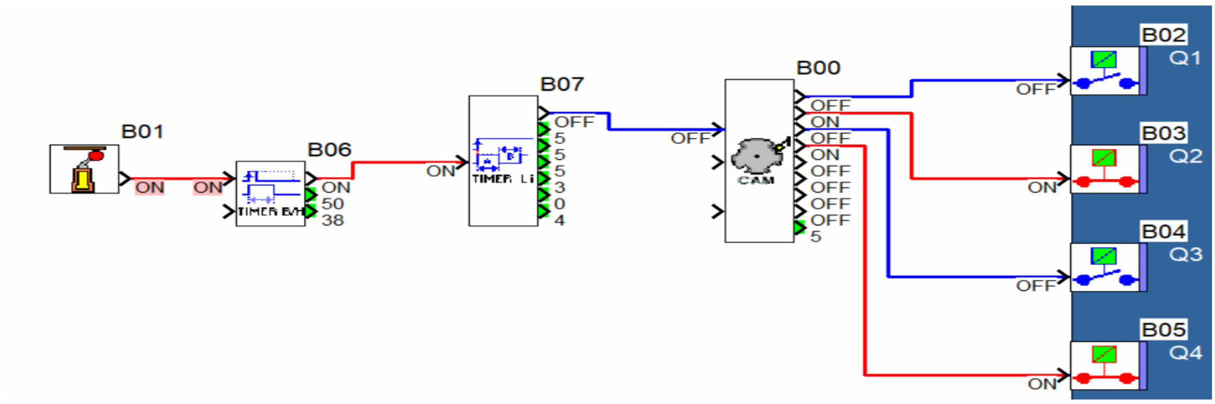

Figure 8. Simulation stage

V. CONCLUSION

This work provides a useful easy and versatile option for programming the speed turning-change sequence of a three-phase motor. The simulation stage as well as the practical implementation showed excellent results. The speed variation was verified using a tachometer while the three-phase motor had a high performance responding accordingly to the programmed intervals. The safety program commands were also verified by physical tests. This research presents advantages especially in cost-sensitive industrial or educational environments. Affordable automation solutions reduce the cost of upgrading existing systems or implementing new ones, making automation accessible for small and medium-sized operations. Simple hardware generally has fewer complex components, meaning repairs and replacements are less expensive. Operators can change speed intervals through simple programming or parameter changes without major rewiring or expensive reconfiguration. The same low-cost system can be adapted for various machines or processes fans, pumps, conveyors by just changing the program or parameters, without buying new control hardware. For engineering students or new technicians, using a low-cost but functional automation platform allows them to experiment with real-world speed control logic without risking high-value equipment. In this sense, this automation system was successfully tested and verified by engineering students in three different superior educational institutions, because of our teamwork.

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