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A NOVEL METHOD FOR CONTROL AND OPERATION OF INDUCTION MOTORS IMPLEMENTED IN INTERMITTENT WORKING REGIME FOR MUSICAL FOUNTAINS

Vlatko Cingoski[*], *Roman Golubovski*[**], *Saso Gelev*[*], *Goce Stefanov*[*], *and Goran Klepov*[***]

Keywords: *induction motors, control systems, intermittent operation, artistic fountains.*

Abstract: The modern way of living increases the need for attractive sites for tourists to visit. Usually artistic fountains are attractive performing visual and spraying effects synchronized to musical pieces, and thus getting tourists' attention. This paper proposes one novel method and approach to the problem of controlling and operation of an electric drive of the pumps. The proposed method is a techno-economic compromise achieving coordinated performance of the individual pump without usage of additional expensive servo valves, for the purpose of their synchronization with the choreography based on the desired music theme.

1. INTRODUCTION

The modern way of life increases demands for attractive tourist sites to visit. Therefore, new or modified existing fountains into attractive artistic show are constantly built, based on music background with fully staged performance of visual effects, with water and lights to keep visitor's attention. However, from a technical point of view, the choreography that follows the dynamics of musical rhythm and melody requires instant response, i.e advanced level of control of pumps, between minimal and maximal load, in order to achieve different heights, directions and quantity of water columns. For this reason, modern, energy powerful

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pumps, hydraulic servo valves, modern control systems and protection from defective conditions are needed

The practice shows that this challenge is not always easy and quick to implement. Almost as a rule, renovation or upgrade of existing fountains with relatively old infrastructure *(inadequate pumps and motors)*, becomes a serious challenge which often requires additional costs for servo valves to regulate water spray appropriately according to the imagined project. Direct application of frequency controllers by the rhythm of the music almost always exceeds the dynamic capabilities of already existing motors *(size of torque and motor dynamics, slip, overheating due to excessive current in the windings, etc.)*. This can often lead to damage of the motor or the pump.

As a result, it is necessary according to the technical capabilities of the existing drives, to perform control of their acceleration and deceleration regardless of the musical background, so the viewer will get a visual illusion and perception of dynamic alignment between the water spray, music and light effects of the fountain.

In this paper, the authors present a novel method for the transformation of the already built fountains with existing infrastructure into artistic musical fountains, without replacing the major existing hydraulic components, with minimal technical activities and under economically affordable expenses. The proposed transformation method was successfully applied to a real fountain and the obtained results together with the method's advantages and disadvantages are discussed and presented in this paper.

2. THE FORMER SITUATION OF THE FOUNTAIN

The starting point in the development and application of the proposed method were the several technical problems perceived by owners of one of the existing musical fountains in the town of Svilengrad, Bulgaria. Namely, the situation in question was such that the existing musical fountain had constantly experienced defects and relegation from the normal operation of the motors driving the hydraulic pumps.

Those failures had frequently caused unexpected defects of the motors entailing additional activities, thus unnecessary and unforeseen significant increase of financial costs for the operation of the fountain, such as: full discharge of water from a fountain*(emptying the whole water system)*, dismantling the motor and performing unscheduled pump service, and after installation of defective motor and pump, re-cleaning of the entire installation, and complete cleaning or replacement of the water filters*(halted circulation of water allows for bacteria and fungi to grow in the filter)*. Nevertheles, , the biggest non-commercial loss is the disappointment of the tourists due to nonfuntional fountain which is the main attraction in the city, leading to additional commercial losses of the municipality and the owner of the fountain.

Deeper analysis of the technical features of the used equipment on the site determined that it is a system composed of six induction motors with rated output of 4 KW each, properly dimensioned pumps, two of which directly powered and the remaining four operated through frequency controllers type Moeller DF51, controlled by Microchip PIC18F 258-I/SP, which separates frequencies of the applied audio signal to control the dynamics of the motors driving the pumps. The actual variable speed drives were obviously intensively worn-out due to the visibly enlarged dimensions of electrolytic capacitors of the rectifier. Table 1 provides main data of the motors and pumps [2].

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Rated Current I_n	9,6 / 5,5 A
Rated Speed n	2900 min^{-1}
Rated Power Factor cos ϕ	0,85
Nominal Mode (IEC)	S1, icl. F

According to the data provided in the Table 1, one can conclude that:

1) They are properly dimensioned for the purpose, and
2) They are not appropriate for the actual operation mode of this type of load requiring special working operation conditions very similar to the so-called intermittent operation regime.

Namely, according to the available rated data, the installed induction motors are designed to operate in mode of operation S1, which is actually a permanent operation mode with constant torque load and rare transitional regimes such as starting or stopping, made with thermal insulation class F with maximum allowed overtemperature of 155 °C.

Therefore, one can immediately notice two main problems using these motors for driving the pumps of the artistic fountain:

1) These pumps will not work permanently, but intermittently according to the needs of the musical requirements, and
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Used motors are designed to work under constant voltage and constant frequency. Considering that the magnetic field of the motor depends on the relationship between the input voltage and frequency, when this ratio is disturbed, it leads to the appearance of over magnetization *(i.e. magnetic saturation)* or under magnetization of the electric motor [1]. When the motor is in under magnetized state *(i.e. insufficient excitement)*, it generates torque which is too small or inadequate to perform the requested tasks, thus the motor is no longer able to run normally, it loads larger current during the start up causing significant thermal overload. Additionally, in case of abrupt break, part of its energy is converted into extra heat which again results into thermal overload and overheat of the windings and the core, resulting with potential defects in both the windings and the rest of the induction motor.

In fact, the actual motors are of wrong type for the required operation mode since they are driven by permanent variation of shafts' rotation frequency *(acceleration and* *deceleration)* for the purpose of desired artistic effect, according to which the height and amount of water jets in the fountain should "follow" the music. This constant change of the supplied voltage and frequency to the induction motors in accordance with the rhythm of the music leads to frequent acceleration and deceleration of the rotor shaft with constant current overload. Due to the short acceleration times*(the constant frequency variations)*which depend on the applied music theme and the continuous variation of the stator current for the purpose of rotor speed variations in order to obtain variations in height and the amount of water spray, installed induction motors are forced into an abnormal operational situation. The induction motors are not able to reach the nominal operation mode in accordance with their design. Accordingly, instead of the actually applied induction motors design to operate in the operation mode S1, normal fountain operation demands utilization of different types of induction motors which are at least designed for extended operation with large number of starts and stops and with additional extended operational dynamics i.e. *intermittent periodic duty with electric braking* (S5), or *continuous operation with intermittent load* (S6).

Moreover, to successfully overcome the problems resulting from the continuous dynamically changing loads of the motor as a result of the application requirements (rhythm of the music base), sometimes it is desirable to use specially designed motors for intermittent or continuous drive with periodic changes of speed and dynamics (e.g. S8). These types of induction motors are specially designed for such complex and fast-changing of operational conditions, yet significantly more expensive than ordinary induction motors already implemented in the existing fountain. Additionally, these motors require modern control devices, in particular, regulation of supplied voltage, frequency, and obtained torque and speed, which would put additional financial burden on the project.

3. A NOVEL METHOD FOR CONTROL AND OPERATION

The basic purpose of this research was to find a suitable way and methodology for achieving the required performance of the musical fountain without modification of its existing infrastructure *(mainly existing induction motors, pumps and control system)*, that would on one hand assure safe operation of the system, and on the other hand realize required visual effects that follow the musical rhythm.

The following technical requirements were set for research team:

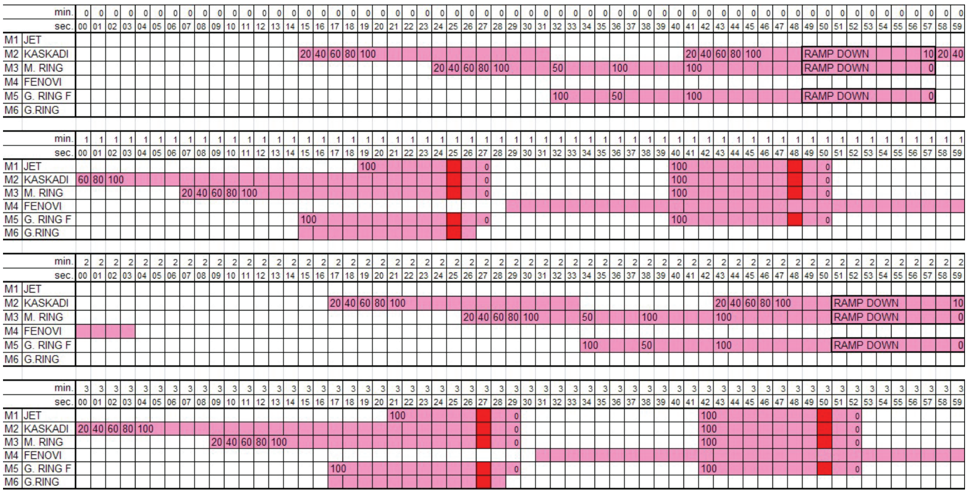
1) Induction motors need to be prevented from driving the pumps in heavy loads operation mode, i.e. their work should be as close as possible to the their designed operation mode S1 - permanent mode without major speed variations due to start and stop;
2) In order to achieve the necessary motor dynamics *(torque, speed)*, it is necessary to implement soft acceleration *(rump up)* and mild slowdown *(rump down)* to prevent overheating of the motors due to improper mode of operation;
3) It is necessary to define a suitable time without operation *(pause in the motors operation)*, to allow a motor to cool down as close as possible to its ambient temperature - each motor should have its runtime, without significant variations in speed and with sufficient time to avoid its overheating.

Given these requirements, the solution was built based on the following main assumptions:

1) Operation mode of the induction motors should be as close as possible to that for which they are intended, or as close to the regime S1, yet still to support limited dynamics in the operation. Therefore, the chosen mode of operation is a periodic variable mode with breaks, closely corresponding to IEC mode S6.
2) It is necessary before starting with the operation to program a special so-called operational time diagram for each induction motor separately in accordance with the dynamics, rhythm and melody of each song that needs to be visually simulated by the artistic fountain. In Fig. 1, an example of such operational time diagram is shown.
3) Prior programming the operation of the pump system, it is imperative to plan the theatrical choreography of the "game of the water and light" of the fountain, i.e. to predict each pump's operation at any point of time during the song *(capacity of operation, pauses, etc.)*.

This choreography requires four analogue outputs (0÷10VDC) to command four separate variable speed drives that independently control the four pump motors. In this case, for the control system, the authors used relatively simple and cheap solution composed of two LOGO OBA7 PLC, each having two analogue outputs. These four analogue outputs control four frequency controllers of type ABB - ACS150 used for regulation of the operation of the induction motors. The total cost for management of all four variable speed drives was €448.2, which was much less than the cost of simple replacement of any of the existing four induction motors with new more appropriate ones for the same purpose.

The next challenge was to design suitable software that would support the proposed hardware solution. For this purpose, our team used the software compatible with the proposed hardware Logo! Soft Comfort V7.1 [3], which enables network connection between the PLCs to support the needed communication for timely and synchronized start of all four motors. Since it was necessary to command four independent motors simultaneously, independent code *(functional block)* was written for each of the four motors separately, controlling its speed, and specifically its acceleration and deceleration within the proper operational boundaries. In Fig. 2, an example of a functional block for a single induction motor is presented. In this case, this induction motor drives the pump on the little inner ring of the fountain. In this diagram, separate timings for work and operational breaks of the motor for any given time intervals, as a percentage of the full load, are given.



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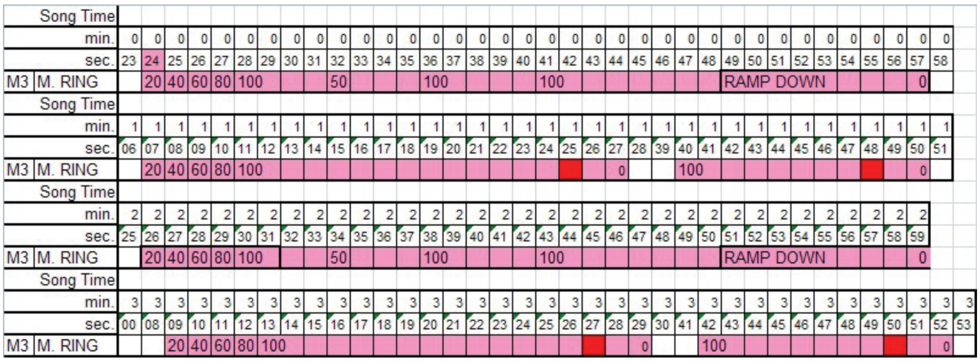

Fig. 2. Functional diagram of the operation of the induction motor driving water pump on the little inner ring.

Although, at first sight this looks like a complicated procedure, using the advantages provided by the used software package Logo! Soft Comfort V7.1, the process of coding is rather simplified, thanks to the use of a specific programming language FDB. The FDB programming language is quite simple and largely appreciated among software developers compared to other programming languages like LAD or STL. FDB works with built-in math functions, binary operations, timers, analogue multiplexers, real clock, etc. In our case, using FDB allows us to build specific customized functions or the so-called UDFs *(User Defined Functions)*. These functions could be used to precisely define each pump's operation separately, and they all get executed simultaneously synchronized with the start of the music. In Fig. 3, an example of a user function UDF, made in Logo! Soft Comfort V7.1 to control a single induction motor is given.

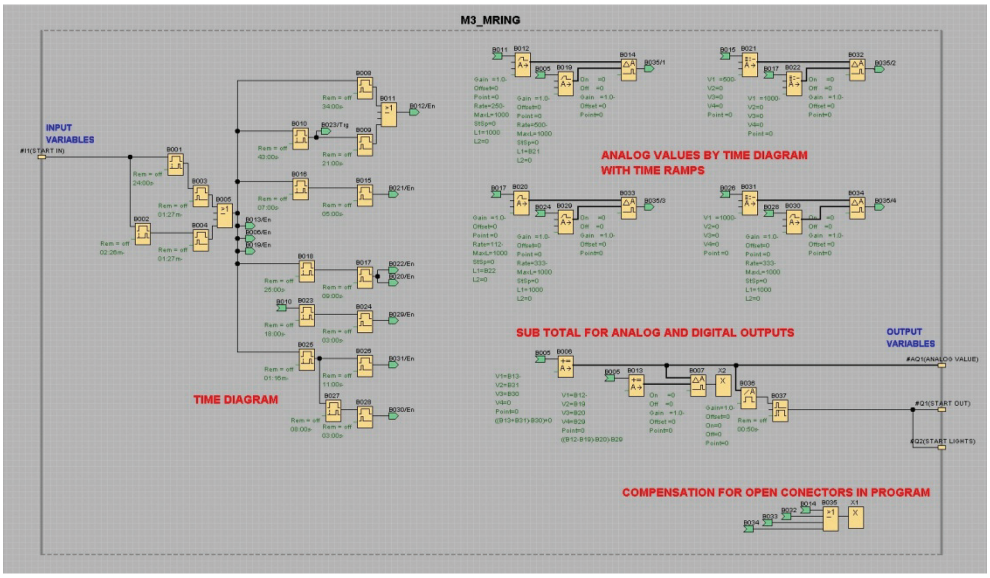

Fig. 3.Example of user function (UDF) developed in Logo! Soft Comfort V7.1.

4. IMPLEMENTATION OF THE METHOD AND OBTAINED RESULTS

The proposed novel method for controlling the system of four induction motors as electric drives for the pumps was successfully implemented to apply the scenic and visual program on the artistic fountain in the town of Svilengrad in Bulgaria (Fig. 4).

Since the implementation of the new control system of this fountain on 28.08.2012, there have been no reports of significant defects or problems for more than three years. This clearly shows that the proposed method had proven itself as a reliable one, such that allows simple and cheap implementation of upgrading and modernization of the existing classical fountains and transform them into modern musical type fountains in which the system of running water and light effects can be harmonized with pre-set background music.

The only disadvantage of the proposed novel methodology is the fact that each new song requires development of entirely new choreography *(scenic and visual)*. This means that it is necessary to develop new user functions *(new UDFs)* from scratch for each pump separately for the different music background. This disadvantage could be easily resolved with saving of all developed UDF functions for each melody and keep them for any further use on any memory media (SD card, USB, etc.). The hardware complexity of the solution is very low and is acceptable for operation and maintenance as can be easily seen from Fig. 5 which represents a front panel of the electrical cabinet used for operation of the system.

Fig. 4. Fountain in the city of Svilengrad, Bulgariain operation.

Fig. 5.The front view of the electrical cabinet for automation of the fountain.

5. CONCLUSIONS

A novel method for control and operation of induction motor drive system utilized for modern musical water fountains is presented. The main contribution of this novel driving method is its successful implementation of operation and control of the induction motors designed for continuous working regimes (S1) in rather complex intermittent working regimes, such as S5, S6 or even S8, which usually requires specially designed and usually more expensive types of induction motors and electric drive systems.

The key idea presented in this paper is implementation of rather simple and cheap solution composed of only two LOGO OBA7 PLC controllers, each having two analogue outputs that control four frequency controllers of type ABB - ACS150 used for regulation of the induction motor operation. To program the PLC controllers, the authors used compatible software with the proposed hardware i.e. Logo! Soft Comfort V7.1, which provided perfect network connection between the PLCs for timely communication and synchronized start/stop of all motors. The proposed novel method was successfully implemented on the real object, the artistic water fountain in the Bulgarian city of Svilengrad.

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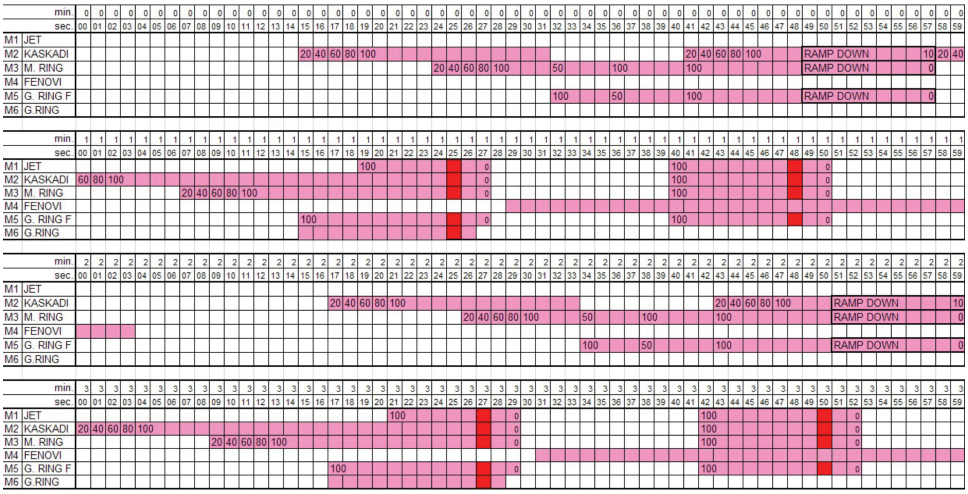

Fig. 1. Example of operational time diagram for a system consisted of four motors.

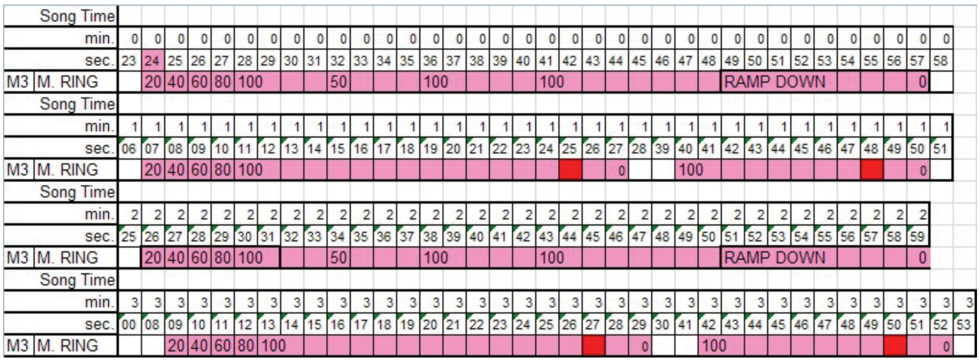

Fig. 2. Functional diagram of the operation of the induction motor driving water pump on the little inner ring.

Although, at first sight this looks like a complicated procedure, using the advantages provided by the used software package Logo! Soft Comfort V7.1, the process of coding is rather simplified, thanks to the use of a specific programming language FDB. The FDB programming language is quite simple and largely appreciated among software developers compared to other programming languages like LAD or STL. FDB works with built-in math functions, binary operations, timers, analogue multiplexers, real clock, etc. In our case, using FDB allows us to build specific customized functions or the so-called UDFs *(User Defined Functions)*. These functions could be used to precisely define each pump's operation separately, and they all get executed simultaneously synchronized with the start of the music. In Fig. 3, an example of a user function UDF, made in Logo! Soft Comfort V7.1 to control a single induction motor is given.

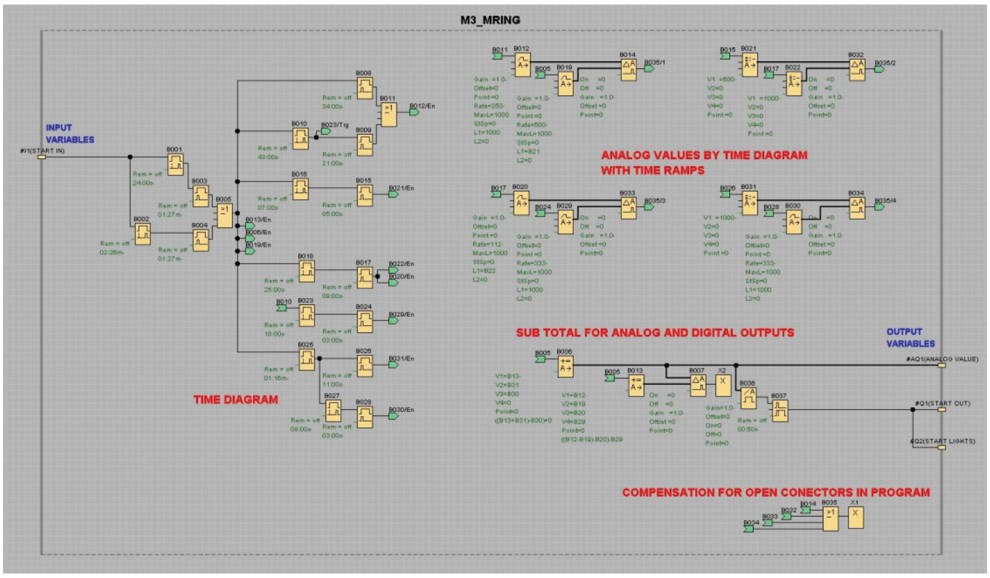

Fig. 3.Example of user function (UDF) developed in Logo! Soft Comfort V7.1.

4. IMPLEMENTATION OF THE METHOD AND OBTAINED RESULTS

The proposed novel method for controlling the system of four induction motors as electric drives for the pumps was successfully implemented to apply the scenic and visual program on the artistic fountain in the town of Svilengrad in Bulgaria (Fig. 4).

Since the implementation of the new control system of this fountain on 28.08.2012, there have been no reports of significant defects or problems for more than three years. This clearly shows that the proposed method had proven itself as a reliable one, such that allows simple and cheap implementation of upgrading and modernization of the existing classical fountains and transform them into modern musical type fountains in which the system of running water and light effects can be harmonized with pre-set background music.

The only disadvantage of the proposed novel methodology is the fact that each new song requires development of entirely new choreography *(scenic and visual)*. This means that it is necessary to develop new user functions *(new UDFs)* from scratch for each pump separately for the different music background. This disadvantage could be easily resolved with saving of all developed UDF functions for each melody and keep them for any further use on any memory media (SD card, USB, etc.). The hardware complexity of the solution is very low and is acceptable for operation and maintenance as can be easily seen from Fig. 5 which represents a front panel of the electrical cabinet used for operation of the system.

Fig. 4. Fountain in the city of Svilengrad, Bulgariain operation.

Fig. 5.The front view of the electrical cabinet for automation of the fountain.

5. CONCLUSIONS

A novel method for control and operation of induction motor drive system utilized for modern musical water fountains is presented. The main contribution of this novel driving method is its successful implementation of operation and control of the induction motors designed for continuous working regimes (S1) in rather complex intermittent working regimes, such as S5, S6 or even S8, which usually requires specially designed and usually more expensive types of induction motors and electric drive systems.

The key idea presented in this paper is implementation of rather simple and cheap solution composed of only two LOGO OBA7 PLC controllers, each having two analogue outputs that control four frequency controllers of type ABB - ACS150 used for regulation of the induction motor operation. To program the PLC controllers, the authors used compatible software with the proposed hardware i.e. Logo! Soft Comfort V7.1, which provided perfect network connection between the PLCs for timely communication and synchronized start/stop of all motors. The proposed novel method was successfully implemented on the real object, the artistic water fountain in the Bulgarian city of Svilengrad.

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