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Glavni urednik
Prof.dr Božo Krstajić

Izdavač
Univerzitet Crne Gore
Elektrotehnički fakultet
Džordža Vašingtona bb., Podgorica
www.etf.ucg.ac.me

Tehnička obrada
Aleksandra Radulović
Centar Informacionog Sistema
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Programski odbor

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Dr Ljubiša Stanković, Elektrotehnički fakultet, Podgorica, MNE
Dr Zdravko Uskoković, Elektrotehnički fakultet, Podgorica, MNE
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Vladan Tabaš, dipl.ing., Čikom, Podgorica

Sekretarijat

Aleksandra Radulović, CIS Univerzitet Crne Gore

SADRŽAJ

NOVI METOD UPRAVLJANJA ASINHRONIH MOTORA SA INTERMITIRANIM REŽIMOM RADA U NAPAJANJU ARTISTIČKIH (MUZIČKIH) FONTANA
A NEW CONTROL METHOD FOR INDUCTION MOTORS IN INTERMITTED WORKING REGIME FOR ARTISTIC (MUSIC-DRIVEN) FOUNTAINS

Goran Klepov, *Imperial Tobacco TKS , Skopje*
Vlatko Cingoski, Roman Golubovski, Saso Gelev, Goce Stefanov*, Faculty of Electrical Engineering - UGD, Stip*

Sadržaj: *Sa svremenim načinom života, sve je veća potražnja turistima za atraktivnim lokacijama za posetu. Zato stalno se grade ili modificiraju postojeće fontane u tzv umetničkim atraktivnim fontanama čiji je rad zasnovan na muzičku podlogu sa potpuno montiranom koreografijom vizuelnih efekata između vode i svetla , tako da što je duže moguće zadržati pažnju posetilaca. Ovaj rad daje novi način i pristup problemu upravljanja električnih pogona kod takvih modernih fontana. Metod pretstavlja tehno-ekonomski kompromis koristeći nezavisnu od muzike koreografiju za svaku pumpnu stanicu pojedinačno bez upotrebe dodatnih skupih servo ventila, da biste dobili potpunu sliku o kompletnom pozorišnom predstavom fontane u ritmu i melodiji muzike sa atraktivnom scenskom i vizuelnom interpretacijom na muzike fontane .*

Abstract: *The modern way of living increases requirement for attractive sites for tourists to visit. Usually artistic fountains are attractive, performing visual and spraying effects synchronized to musical pieces, thus getting tourists attention. This paper proposes a new method and approach to the problem of controlling the electric drive of the pumps. The method is a techno-economic compromise achieving coordinated performance of the individual pump without the use of additional expensive servo valves, for the purpose of their synchronization with the choreography following the music.*

1. INTRODUCTION

The modern way of life, increases demands for attractive tourist sites to visit. Therefore, constantly are built new or modified existing fountains into attractive artistic show, 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, therefore advanced level of control of pumps, between minial and maximal load, in order to achieve different hights, directions and quantity of water columns is needed. This causes the need for modern, energy powerful pumps, hydraulic servo valves, modern control systems and protection from defective conditions.

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 expences 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 of 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 water spray, music and light effects of the fountain.

In this paper, authors are presenting a new method of transformation of the already built fountain with existing infrastructure into artistic musical fountain, without replacing the major existing hydraulic components, with minimal technical activities and under economically affordable expenses. The method was successfully applied to a real object and showed its advantages and disadvantages.

2. THE FORMER SITUATION

The starting point in the development and application of the proposed method were the problems faced by owners of one of the existing musical fountains in the town of Svilengrad, Bulgaria. Namely, the situation met 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 finantial costs for the operation of the fountain, such as: full discharge of water from a fountain, dismantling the motor and pump service performed after installation of defective motor and pump, re-cleaning of the entire installation, and complete cleaning or replacement of the water filter *(halted circulation of water allows for bacteria and fungi to grow in the filter)*. However, the biggest loss is the disappointment of the tourists due to not functional fountain which is the main attraction in the city, leading to additional financial losses of the municipality and the owner of the fountain.

The analysis of the technical features of the equipment on site determined that it is a system composed of six induction motors with rated output of 4 [KW], properly dimensioned pumps, two of which directly powered and four operated through frequency controllers type Moeller DF51, controlled by Microchip PIC18F 258-I/SP, which separates frequencies of the 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].

Table 1: Nominal data for motor and pump.

Rated Power P_n	4 kW (5,5 HP)
Height of water jet H *(max/min)*	24 / 10 m
Amount of water Q *(max/min)*	30 / 70 m^3/h
Nominal Voltage U_n Rated Frequency f	3F ~ 380 - 415 (Δ) V 3F ~ 660 - 720 (Y) V 50Hz
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

From the data provided in the Table 1,one could 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 alternating working features.

Namely, according to the available 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 startings or stoppings, made with thermal insulation class F with max allowed over-temperature of 155^{o}C.

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

1. These pumps will not work permanently, but intermittently according to the needs of the artistic requirements, and

2. These pumps will have frequent starts and/or stops, as well as continuous regulation of the jet hight and amount of water, which means significant and complex requirements for the drive for the pumps, that these motors are not able to perform.

Used motors are designed to work under constant voltage and constant frequency. Considering that the magnetic field of the the motor depends on the relationship between the input voltage and frequency, when this ratio is disturbed, it leads to the appearance of overmagnetisation (saturation) or undermagnetisation of the electric motor [1]. When the motor is in undermagnetized state *(i.e. insufficient excitement),* it generates torque which is too small, thus the motor is no longer able to run normally, it loads larger current during the startup causing significant thermal overload. Additionally, in case of abrupt break, part of its energy is converted into extra heat again resulting into thermal overload and overheating of the windings and the core, leading to defects in both the windings and the rest of the induction motor. 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 supplied voltage and frequency of the induction motors in accordance with the rhythm of the music leads to frequent acceleration and deceleration with constant current overload. Due to the short acceleration times *(the constant frequency variations)* 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 a situationthat they are not able to reach the nominal mode of operation, which is improper for their design.

Required operation mode instead of the actually applied motors provided for operation mode S1, demands application of other types of motors which are at least designed for extended operation with starts and stops and with additional dynamics (S7). Moreover, even better for overcoming the problems resulting from the continuous dynamicly changed loads of the motor as a result of the application requirements, it is desirable to use specially designed motors for operation mode S8 - continuous drive with periodic changes of speed and dynamics, or even mode S9 - where changes have aperiodic properties. These motor types are specially designed for such complex and fast-changing conditions of work, yet significantly more expensive than induction motors implemented in the existing fountain. Additionally, these motors require modern devices to control them *(regulation of supplied voltage, frequency, and obtained torque and speed)* which would put additional financial burden on the project.

3. PROPOSED SOLUTION

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

The following technical requirements were set in front of the research team::

1. Motors need to be prevented from driving the pumps in heavy loads operation mode, i.e. their work to be as close as possible to regime S1 - permanent mode without major speed variations due to start and stop;
2. In order to achieve the necessary 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 with no operation *(pause in the motors operation),* to allow motor to cool down at least closely to the ambiental 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 asynchronous 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 aperiodic variable mode with time breaks, closely corresponding to IEC mode S9.

2. It is necessary to program time diagram of the work 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. Figure 1, is an example of such time diagram.

3. Prior to programming the pump system operation, it is imperative to plan the theatrical choreography of the *"game of the water and light"* of the 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 analog outputs (0÷10VDC) to command four separate variable speed drives that independently control the four pump motors. In this case, for the control system, we are using relatively simple and cheap solution composed of two PLCs LOGO OBA7 each having two analog outputs. These four analog outputs control four frequency controllers of type ABB - ACS150 used for regulation of the operation of the induction motors.

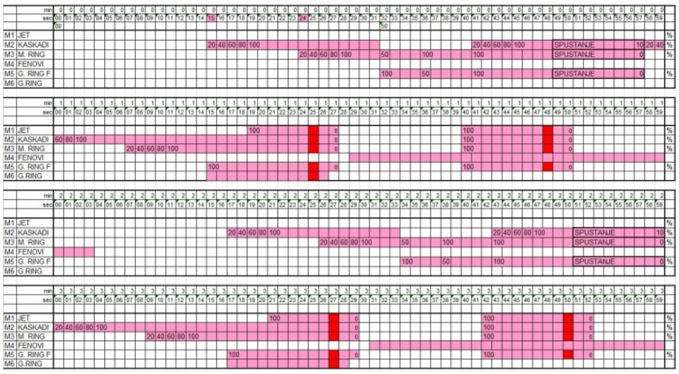

Figure 1: Example of a time diagram of the operation of the system consisted of four motors.

The total cost for management of all four variable speed drives was €448.2, which is much less than the cost of replacement for any of the existing four induction motors with more appropriate ones for the purpose.

The next challenge was to design a 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 PLC to support the needed communication for timely and synchronized start of all four motors. Since it was necessary to command four independent motors, independent code *(functional block)* was written for each of them, controlling its speed acceleration and deceleration specifically and within the proper operation's boundaries. In Figure 2, an example of a functional block for a single induction motor is given. In this case this induction motor drives the pump on the little inner ring of the fountain. In this diagram noticable are separate timings for work and break of the motor as a percentage of the load for any given time interval.

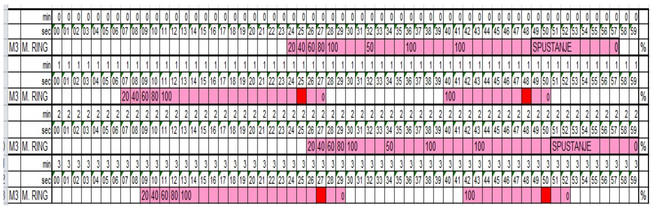

Figure 2: Functional diagram of the operation of the asynchronous motor pump on the little inner ring.

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, which is quite simple and more acceptable for the developers compared to other programming languages like LAD or STL. FDB works with built-in math functions, binary operations, timers, analog multiplexers, real clock, etc. And in our case, allows for customized functions to be built *(**UDF** - User Defined Function)*. These functions are used for definition of each pump's operation separately, and they all get executed simultaneously synchronized to the start of the music. Figure 3, is an example of a user function UDF, made in Logo! Soft Comfort V7.1 to control a single induction motor.

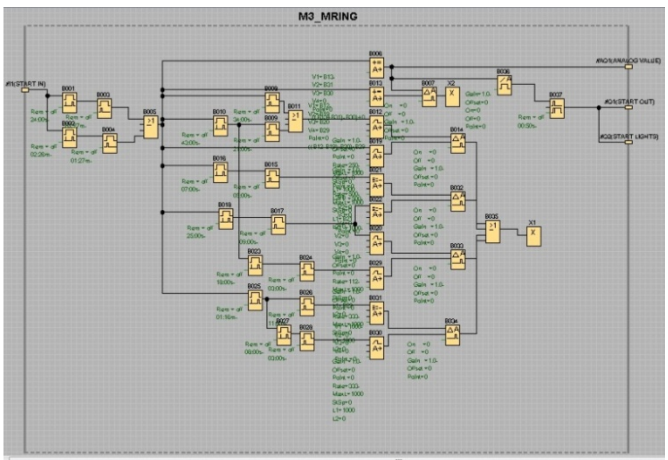

Figure 3: Example of user function (UDF) developed in Logo! Soft Comfort V7.1.

4. CONCLUSION

The proposed method for controlling the system of four induction motors as drive for the pumps is successfully implemented to apply the scenic-visual program on the artistic fountain in the town of Svilengrad in Bulgaria (Figure 4).

Figure 4: Fountain Svilengrad in operation

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 two years. This clearly shows that the proposed method had proven itself as a reliable one, such that allows simple and cheap implementation of upgrade and modernization of existing classical fountains into modern artistic 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 solution 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 UDF)* for all four pumps 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 future use on any memory media (SD card, USB, etc.)

The hardware complexity of the solution is also acceptable, as shown in Figure 5 *(finished electrical cabinet)*.

Figure 5: The electirical cabinet for automation of the fountain.

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