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Araştırma Makalesi/Research Article

Performance Evaluation of Microprocessor Control in Multi Motor Asynchronous Electric Drive Using Petri Nets

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Abstract- **The paper describes the development of the electric diagram and description of the microprocessor control process for the multi-motor asynchronous electric drive with the use of bidirectional shift registers and resistor banks, the operation algorithm, the Petri net and the matrix method for the Petri net analysis. It offers to use contemporary mathematical apparatus the Petri nets in modeling, analyzing, synthesizing and describing logical operations taking place within a microprocessor control device of an electromechanical system, which allows increasing the level of automation in an industrial process, operational reliability, ensuring coordinated rotation of electric motors and better performance and cost efficiency.**

Keywords- **Microprocessor control, asynchronous motor, petri nets.**

I. INTRODUCTION

The majority of technological processes in modern industry are performed with the use of mechanical energy. It is most expedient to generate such energy with an electric drive. Multi-motor electric drive is the most appropriate choice for general industrial machines - bridge cranes (trolley traveling mechanism), transporter lines, and rolling mills - in metallurgy and machine tool industry taking into account the production requirements and operation modes. It requires application of more complex control methods for electromechanical systems, since two and more motors must work in coordination for the same load. It means the use of new power and control hardware components that would allow implementing these technological operation cycles [1-2].

Continuous development of technology places challenging demands to the electric drive in terms of motion accuracy both in static and dynamic, speed performance and reliability. All of these requirements can be met by using special fast-response microprocessors (MP) as the basis of the control system for the multi-motor asynchronous electric drive. It gives broad options for creation of technically advanced controlled drives. It is even more relevant considering that the cost of electric drive control systems needs to be reduced in view of intensive development of electronics and semiconductor technology [3].

II. MICROPROCESSOR CONTROL OF MULTI-MOTOR ASYNCHRONOUS ELECTRIC DRIVE USING BIDIRECTIONAL SHIFT REGISTERS AND RESISTOR BANKS

Figure 1 shows the electric circuit diagram of microprocessor control for multi-motor asynchronous electric drive using bidirectional shift registers and resistor banks. It has been developed to ensure coordinated rotation of the drives of the bridge crane trolley‘s traveling mechanism and maintain their specified ratio. The automated control system operates in the following way. Signals I11, I12, U21, U22 containing information about the drive operation M1, M2 from the secondary coils TA1, TA2, TC1, TC2, are converted in compliance with the required range with the help of rectifier bridges, condensers and resistors.

Current values which first to the input port and then to the analog to digital encoder (ADE) flow to the MP control system. ADE converts the incoming data into digital codes and sends them to the central processor (CP) via an internal bus. CP calculates the incoming data according to the present program and initiates an appropriate operation, if necessary. The operation code is sent via the internal bus to the pulse-width modulator (PWM). In the PWM, the incoming binary coordinate is transformed into the on-off time ratio coordinate for rectifier activation. Then, resistances of specified values are connected for a certain time interval in the rotor circuit based on the data received and processed by the CP [4].

The operation algorithm of the automated control system of the multi-motor asynchronous drive has been developed on the basis of the above circuit diagram in figure 2. To be operable, the microprocessor control device based on the algorithm and the circuit diagram requires development of mathematical models for the automated control of the multi-motor asynchronous drive, which will serve as the basis for programming.

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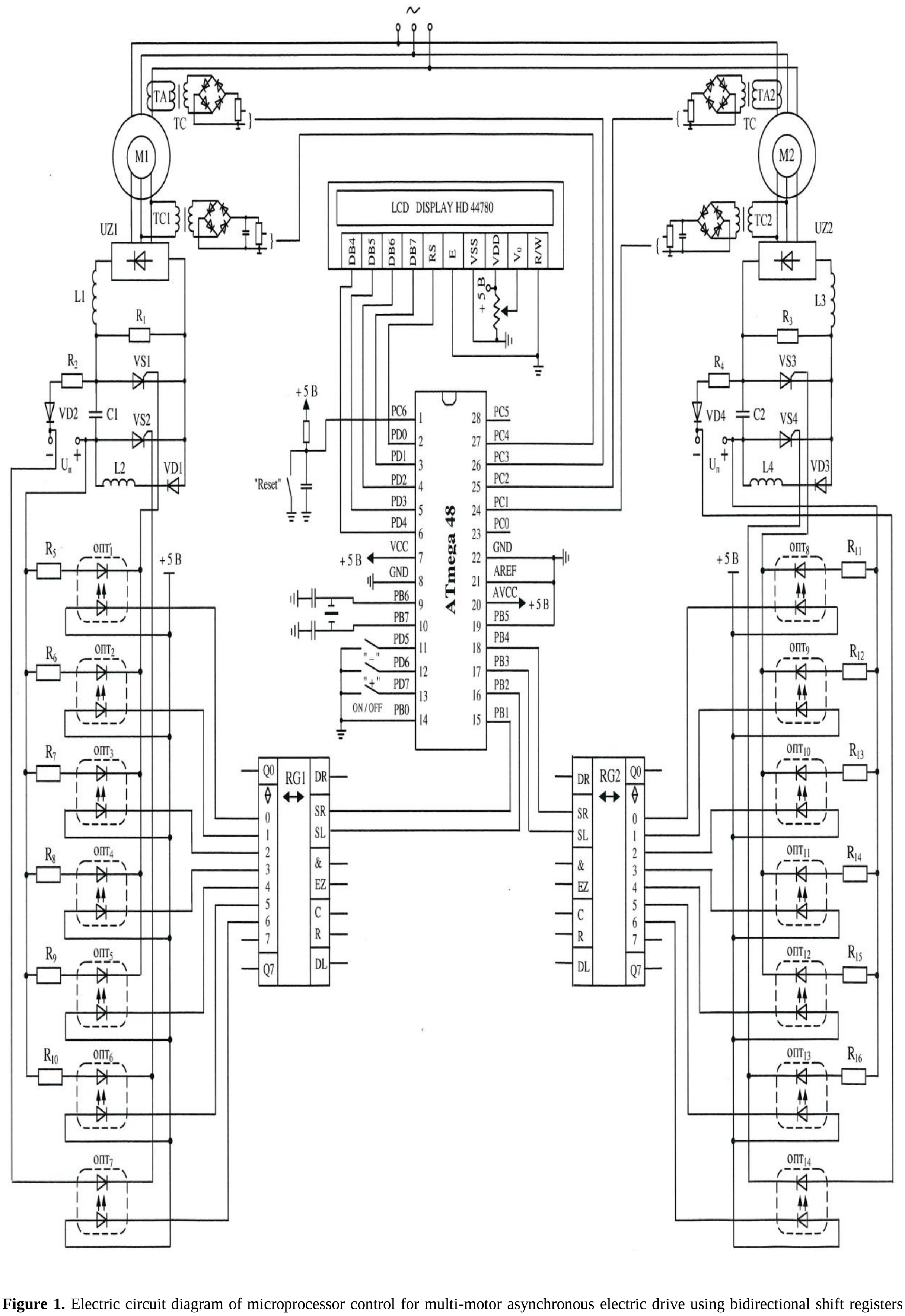

Figure 1. Electric circuit diagram of microprocessor control for multi-motor asynchronous electric drive using bidirectional shift registers and resistor banks

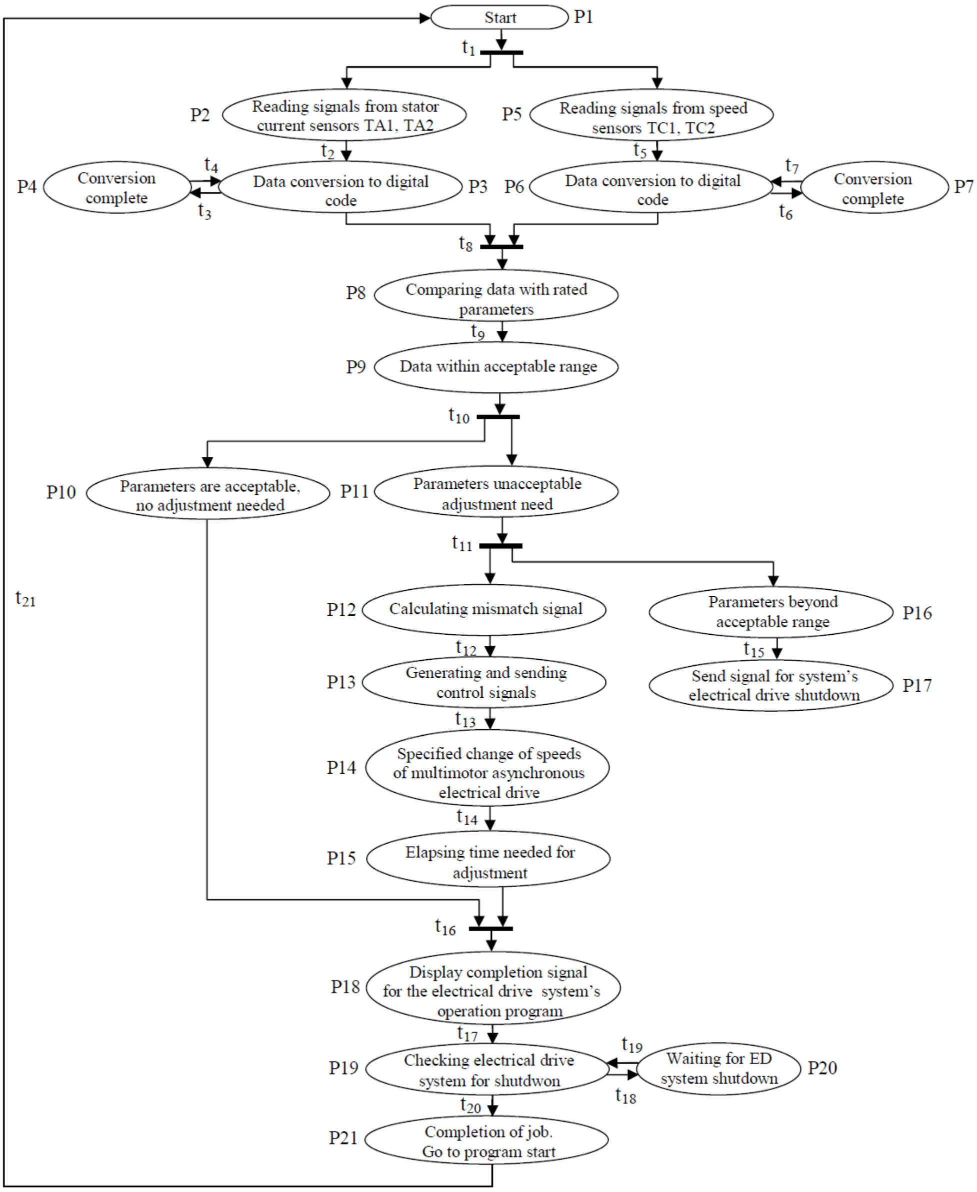

Figure 2. Operation algorithm of automated control system of multi-motor asynchronous drive

III. USING PETRI NET FOR THE DEVELOPMENT OF THE MATHEMATICAL MODEL OF THE AUTOMATED CONTROL DEVICE FOR THE MULTI-MOTOR ELECTRIC DRIVE

In this section, the simulation of the indirect microprocessor vector controlled drive is presented. These applications include pumps and fans, paper and textile mills, subway and locomotive propulsions, electric and hybrid vehicles, machine tools and robotics, home appliances, heat pumps and air conditioners, rolling mills, wind generation systems etc. The energy saving aspect of variable frequency drives is getting a lot of attention now days. The control and estimation of AC drives in general are considerable more complex than DC drives, and this complexity increases substantially if high performance are demanded. The main reason of this complexity is need of variable frequency, harmonically optimum convertor power suppliers, and the complex dynamics of AC machines, machines parameter variations and difficulties of processing feedback signals in the presence of harmonics.

The Petri net is one of the contemporary mathematical tools for modelling, analysis, synthesis and design of discrete systems with parallel processes. The formal Petri net theory addresses the development of basic means, methods and notions related to Petri nets application. Modelling in Petri nets is performed at the event level determining what actions are carried out in the system, what actions are carried out in the system, what states have preceded the actions and what states the system will take after the actions are performed. The execution of an event model in Petri nets describes the system behaviour [5-6]. Based on the operation algorithm in figure 2, a Petri net has been developed for the automated control system of the multi-motor asynchronous drive as shown in figure 3. At modelling in Petri nets, places denote certain system states, while transitions denote actions taking place in the system. The system may generate certain actions being in a certain state; and, vice versa, execution of a certain action shifts the system from one state to another. The current system state is defined by the Petri net marking, i.e. the location of marks in the net places. Execution of actions in the system is defined as transition actuations in Petri nets. Actuation of transitions generates new marking, thus, generating new location of marks in the net.

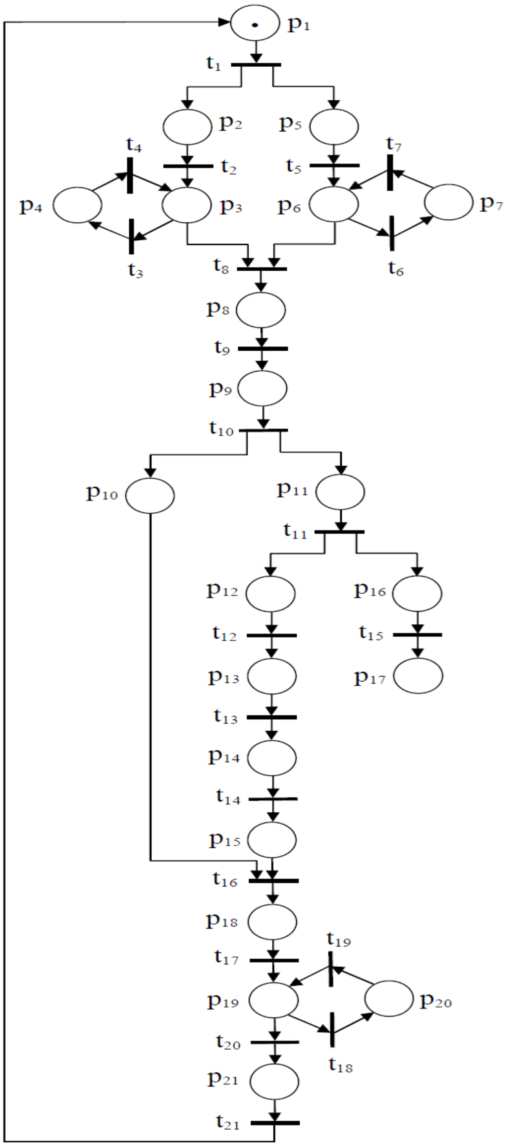

Figure 3. Petri net for automated control system of multi-motor asynchronous drive

The Petri net is a directed graph;

$$C = (T, P, F, Mo), \quad (1)$$

where $T = \{t_1, t_2, t_3, \ldots, t_n\}$, $n > 0$ is a finite number of transitions;
$P = \{p_1, p_2, p_3, \ldots, p_m\}$, $m > 0$ is a finite set of places;
$F = P \times T \cup P \times T \rightarrow (0, 1)$ is a function of incidence showing the presence of arcs connecting places to transitions and vice versa;
$Mo = P \rightarrow \{1, 2, 3, :\}$ is initial marking [7].

The Petri net shown in figure 3 has a complex structure due to the existing parallel processes. In such cases, decomposition of the Petri net is expedient, since the parallelism conditions increase in the number of system states in geometric progression accompanied by the increase of positions of each branch. Decomposition ensures decrease the number and complexity of synthesized logical sequences and more efficient realization of the sequences in distributed systems. When using decomposition, each branch is treated as a separate subnet. Decomposition results in a set of subnets and a net coordinating the starting of the subnets. The Petri net decomposition in the automated control system of the multi-motor asynchronous drive will result in functional subnets of the initial Petri net as shown in figure 4. After the hierarchical Petri net and its subnets have been shaped, the resulting subnets, the number of states and lockups shall be analyzed.

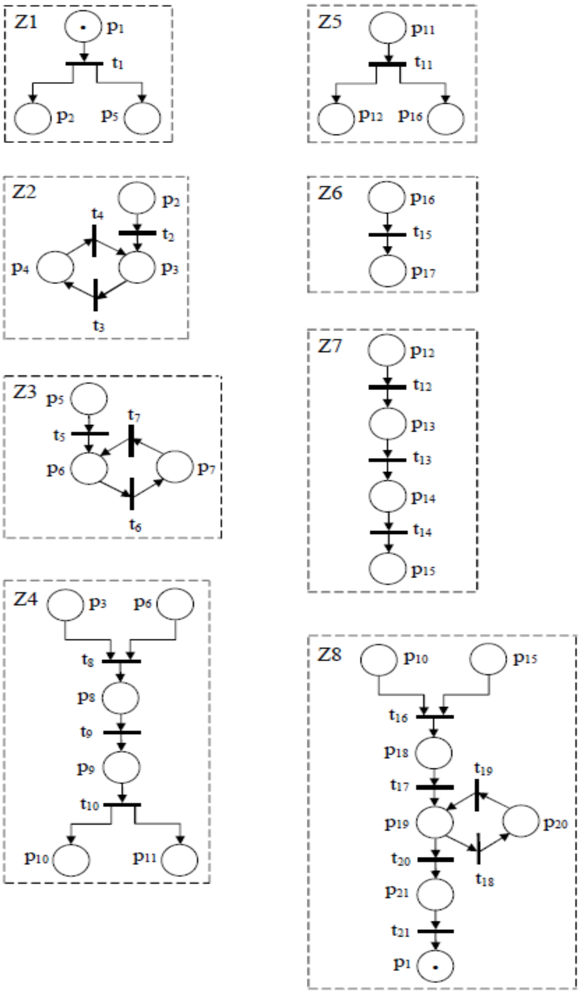

Figure 4. Functional subnets of initial Petri net of automated control system of multi-motor asynchronous electric drive

IV. ANALYSIS OF PETRI NET OF AUTOMATED CONTROL DEVICE OF MULTI-MOTOR ASYNCHRONOUS DRIVE

Modeling system with Petri nets is primarily conditioned by the need to thoroughly examine their behavior. Such examination requires analysis methods for the Petri nets as such. This approach implies reduction of the actual system examination to the analysis of certain properties of the modeling Petri net. Basic properties of Petri nets [8];

Safety: A Petri net place is safe if the number of its markings is never more than 1. A Petri net is safe if all its places are safe;

Limitedness: A Petri net is called *k*-limited unless more than *k* marks are accumulated at any place in any state;

Saving: A Petri net is saving if it is saving in relation to a certain positive nonzero weighting vector;

Activity: A transition is active unless it is a lockup. If the transition is active, the Petri net can always be transformed from its current marking to the marking, where the startup of transition becomes permitted;

Reachability: Cover property of markings.

There are two basic method groups of Petri net analysis. The first one is matrix methods, and the second one method is based on derivation of coverability tree and plotting of reachability graph. The first method group is based on matrix representation of markings and sequences of transition startups. Defining two matrices D^- and D^+ representing input and output functions is alternative to defining a Petri net as (T, P, F, M_o). Each matrix has *m* rows (two per transition) and *n* columns (one per place). D^- defines transition inputs; D^+ outputs [9]. The matrix form to define a Petri net (T, P, D^-, D^+) allows giving definitions in terms of vectors and matrices. Let us define a single vector *e[j]* of dimension *m* containing zeros in all places but the one corresponding to the transition being started at the moment. Apparently, the transition is permitted if;

$$\mu \geq e\,[j]\,.\,D^- \tag{2}$$

The result of the startup of the *j* transition can be described as follows;

$$\mu' = \mu + e\,[j]\,.\,D \tag{3}$$

where $D = (D^+ - D^-)$ is the incidence matrix. Let us perform the matrix analysis of the subnets Z1÷ Z8. The subnet Z1, as shown in figure 4, has 3 states (p_1, p_2, p_5) and 1 transition (t_1). Let us plot the matrix of inputs, the matrix of outputs and the incidence matrix for the subnets Z1÷ Z8.

$$Z1 \quad \rightarrow \quad D^- = \begin{pmatrix} 0 & 1 & 1 \end{pmatrix}; \quad D^+ = \begin{pmatrix} 1 & 0 & 0 \end{pmatrix}; \quad D = (1 \quad -1 \quad -1);$$

$$Z2 \quad \rightarrow \quad D^- = \begin{pmatrix} 0 & 1 & 0 \\ 0 & 0 & 1 \\ 0 & 1 & 0 \end{pmatrix}; \quad D^+ = \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix}; \quad D = \begin{pmatrix} 1 & -1 & 0 \\ 0 & 1 & -1 \\ 0 & -1 & 1 \end{pmatrix};$$

$$Z3 \quad \rightarrow \quad D^- = \begin{pmatrix} 0 & 1 & 0 \\ 0 & 0 & 1 \\ 0 & 1 & 0 \end{pmatrix}; \quad D^+ = \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix}; \quad D = \begin{pmatrix} 1 & -1 & 0 \\ 0 & 1 & -1 \\ 0 & -1 & 1 \end{pmatrix};$$

$$Z4 \quad \rightarrow \quad D^- = \begin{pmatrix} 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \end{pmatrix}; \quad D^+ = \begin{pmatrix} 1 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \end{pmatrix}; \quad D = \begin{pmatrix} 1 & 1 & -1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \end{pmatrix};$$

$$Z5 \quad \rightarrow \quad D^- = \begin{pmatrix} 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}; \quad D^+ = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 1 & 0 & 0 \end{pmatrix}; \quad D = \begin{pmatrix} 1 & -1 & 0 & 0 \\ 0 & 1 & -1 & 0 \\ 0 & 1 & 0 & -1 \end{pmatrix};$$

$$Z6 \quad \rightarrow \quad D^- = \begin{pmatrix} 0 & 1 \end{pmatrix}; \quad D^+ = \begin{pmatrix} 1 & 0 \end{pmatrix}; \quad D = (1 \quad -1);$$

$$Z7 \quad \rightarrow \quad D^- = \begin{pmatrix} 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}; \quad D^+ = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \end{pmatrix}; \quad D = \begin{pmatrix} 1 & -1 & 0 & 0 \\ 0 & 1 & -1 & 0 \\ 0 & 0 & 1 & -1 \end{pmatrix};$$

$$Z8 \quad \rightarrow \quad D^- = \begin{pmatrix} 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 \end{pmatrix}; \quad D^+ = \begin{pmatrix} 1 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 \end{pmatrix}; \quad D = \begin{pmatrix} 1 & 1 & -1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & -1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & -1 & 0 & 0 \\ 0 & 0 & 0 & -1 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & -1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & -1 \end{pmatrix};$$

The matrix analysis method ensures vivid demonstration of the application of mathematical apparatus in describing internal logical operations of the microprocessor control device of the multi-motor asynchronous drive.

V. CONCLUSIONS

Electrical drives have become an important part of the modern industry. High dynamic performance of an electric motor is a fundamental prerequisite in motion control applications, also known as servo drives. In various applications where speed and position control is of great significance, the drives are controlled via a power electronic converter, an interface between the input power and the motor. Power consumption of the drive and the harmonics that it injects in the supply plays an important role in the overall performance of the drive. Recent developments in the field of microprocessors and power electronics have enabled faster and faster movements with an electric motor. The paper shows the application of Petri nets in developing the operation algorithm and mathematical models of automated control of the multi-motor electric drive. It allows increasing the level of automation and reliability, ensuring coordinated rotation of electric motors and accuracy in adjusting technological parameters with optimum energy consumption and maximum performance of the electric drive.

The goal of this research is to summarize the existing models and to develop novel petri net models, in order to obtain a unified approach on modeling of the multi-motor asynchronous electric drive for vector control purposes. The other positive features of a using petri net model are summarized as:

1. Improved reliability, i.e. if one multi-motor asynchronous electric drive fails, the asynchronous motor continues to run (though at reduced rating) thus continuity of operation is maintained, this is because the two neutrals are kept open.
2. As losses are reduced, efficiency is improved as there are no circulating currents because of harmonic reduction owing to 30 degrees phase shift.
3. By using 30 degrees phase displacement, for the same air gap flux, the asynchronous motor dc bus voltage is reduced by approximately a half (Because of 30 degrees displacement).
4. Also control is economical as sensor less vector control is implemented.

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