Indirect Identification of the Disturbances by Programmable Logic Controller Simatic S7-200

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***Abstract* – The programmable logic controller (PLC) Simatic S7-200 offers maximum automation at minimum cost. It can be used for simple controls as well as for complex automation tasks. It finds application in many branches of industry, power engineering and transport. These advantages cause to teaching the students how to use and program this PLC.**

***Keywords* – indirect identification, - PLC, education quality.**

I. Introduction

The development of the energy and transport equipment entered to a new stage during the past years. Contemporary electrical transport vehicles are designed on the base of power drives controlled on high efficient devices and microprocessor safety and control systems. The new technologies used in electrical equipment make headway at accelerated rates. Regenerative converters (based on IGBT technology) and energy-saving motors are introduced into many modern trams, trolleybuses and locomotives.

On the other hand, in many branches of industry the positioning systems realize very often motions determining production quality and efficiency. The contemporary positioning systems require efficient solutions of the problem of the indirect identification of the disturbances in case of fast running processes.

Therefore, the efficiency of the traction drives and the accuracy of the positioning systems are directly connected to the possibility of control devices of recognition the peculiarities of the dominant disturbances.

II. Applicability of the PLC Simatic S7-200 to the Motion Drives Automation and to the Power Engineering

The SIMATIC Modular Controllers have been optimized for control tasks and specially designed for ruggedness and long-term availability [1]. They can be flexibly expanded at any time using plug-in I/O modules, function modules, and communications modules. The modular controllers can also be used as fault-tolerant or fail-safe systems.

The S7-200 series of programmable logic controllers can control a wide variety of devices to support automation needs. These PLCs are compact and highly powerful (e.g. in relation to its real-time response), they are fast, feature great communications capabilities and they are based on very user-friendly software and hardware. The SIMATIC S7-200 family is suitable for applications where programmable controllers would not have been economically viable in the past.

Siemens provides different S7-200 models with graduated range of CPUs with many basic PLC functions; with a diversity of features and capabilities that help to create effective solutions for varied applications [2].

S7-200 has been already introduced in the transport. It is used in the object level in SCADA system (Supervisory Control And Data Acquisition system), which controls the electrical equipment in the traction substations and Electricity transmission network. PLCs are used in many contemporary electrical transport vehicles (locomotives, under ground wagons etc).

S7-200 can be used in automation configurations based on Automation and Drives standard products for easy, fast and cost-saving implementation of automation tasks for small-scale automation. It is particularly suitable for industrial applications requiring the positioning of objects [5]. The compatible with S7-200 product combination in conjunction with the software library enables a cost-effective positioning solution in the following applications: cutters, for example, for pipes; conveyors; feeders; lifting stages; rotary tables; hoisting devices.

III. Laboratory Simulator for Control on Electrical Drives with a PLC S7-200

The fast industrial progress set up higher requirements of education quality. The power engineering and the transport are attractive areas for Bulgarian and foreign investment for progress, modernization and expert education. The training under the bachelor and master programmes Power Engineering and Electrical Equipment in The Todor Kableshkov University of Transport prepares highly qualified experts in the fields of the Electrical Equipment of the transport, industry and power engineering. The Todor Kableshkov University of Transport's lecturers realize the necessity of training of skilled workers for electrical transport and power engineering needs. There is a modern laboratory simulator built on contemporary devices (Fig.1). It includes an energy-saving induction motor (AD), controlled by a frequency converter Sinamics G120. A synchronous generator (SG) and resistors realize the load of the motor. There is a positioning system, too. A PLC Simatic S7-200 supplements the simulator and can be used for control and optimization both of the inverter drive and the positioning system. An HTL encoder reports the traveled distance of the positioning axis to

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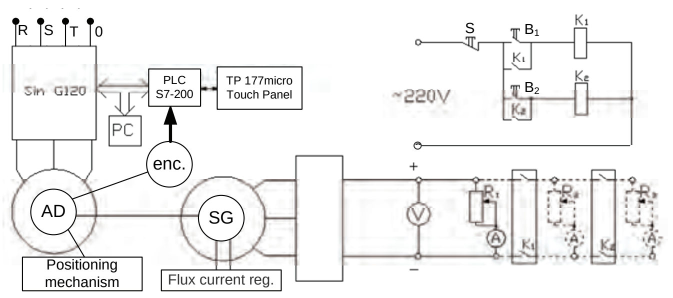

Fig. 1. Laboratory simulator

the S7-200 in the form of pulses. This encoder can also be used for closed loop motion control on the drive. TP 177micro Touch panel, connected to the PLC, gives the possibility of visualization and control of the drive system, as well as of entering the initialization and parameterization data and work conditions. A WINDOWS-based computer system is used for configuring and data archiving. The necessary configuration software is installed on this computer: Step 7 MicroWin for programming the PLC Simatic S7-200, WinCC Flexible Micro for configuring the Touch panel and STARTER for setting-up the frequency converter Sinamics G120.

The SINAMICS G120 frequency converters family is designed to provide precise and cost-effective speed and torque control of AC motors [3]. They are modular frequency inverters for standard drives. SINAMICS G120 is ideally suited as a universal drive in various industrial applications, e.g. in the automotive, textile, printing and chemical industries, for higher-level applications, in conveyor systems. Each SINAMICS G120 comprises two operative units – the Power Module and Control Unit. The Power Module is controlled by a microprocessor in the Control Unit. State-of-the-art IGBT technology with pulse-width modulation is used to achieve the highest degree of reliability and flexible motor operation. Comprehensive protection functions provide a high degree of protection for the Power Module and the motor. The Control Unit controls and monitors the Power Module and the connected motor using several different control types that can be selected. It supports communication with a local or central control and monitoring devices.

The simulator offers various possibilities of implementation into practice many laboratory exercises, for example:

- Examination of a synchronous generator at a constant speed and variable load;
- Examination of an open loop motion control in case of inconstant load torque. A sensorless Vector control (SLVC) without speed feedback or a V/f characteristic control can be examined. The V/f characteristic can be linear, flux current control (FCC), square-law characteristic (f^2 characteristic) or programmable characteristic, which takes into consideration the torque characteristic of the driven load [4];
- Examination of a closed loop speed control in case of inconstant load torque. There are several versions. In one case the closed-loop speed control with the evaluation of the encoder signal using a PID controller and V/f characteristic control can be examined. In other case the closed-loop vector control with speed encoder can be examined (this is the preferred solution in the most applications).
- Examination of a positioning system in case of inconstant load torque. The speed influence over the positioning accuracy can be examined;
- Optimization of the travel profile by the PLC Simatic S7-200. The encoder measures the traveled distance of the positioning axis and the motion speed can be calculated to achieve the wanted accuracy at highest efficiency.

The travel profile is essentially defined by the technological application and an energetic optimization. Depending on the requirements of the particular application various optimization methods can be used. Determining factors are the time within which the positioning operation has to be completed, the acceleration and deceleration whose upper limits are determined by the motor performance, the application's mechanical system and the actual process and the power demand of the application.

In all examinations the load torque can be changed by various techniques:

It can be changed lightly altering the resistance of the load resistors or the generator flux current;

It can be changed with a jerk switching the circuit closers K_1 and K_2 by pushing buttons B_1 and B_2.

IV. Indirect Identification of the Disturbances

The disturbances influence materially on the accuracy in the positioning systems. The dominant disturbance in the hoisting devices is the moment of inertia closely connected with the load mass. In the industry, the worse work conditions (like the moisture, dustiness, vibrations etc.) result in the load torque variation and decrease of the positioning accuracy.

In the electrical transport, the main disturbances are the supply pressure fluctuations, climatic conditions, load mass, road profile and track condition. They result in the vehicles speed variation.

The identification of the disturbances will optimize the efficiency and accuracy in the positioning systems as well as the passenger comfort and the energy consumption in the electrical transport. The direct identification will be very difficult depending on the various natures of the disturbances. The indirect identification takes into consideration the change of controlled parameters as a result of a disturbance. Sensors mounted on the system and connected to the PLC can easily measure these parameters. The S7-200 can be connected to the specific for positioning systems sensors (linear and rotary pulse encoders, voltage and current sensors), as well as with the speed, voltage and current sensors and energy consumption meters used in the power drive systems. After the calculating of the controlled parameters (for example, consumed active power, motor speed and current, power factor etc.) the disturbances influence can be eliminated and optimal drive behaviour can be achieved. Programmed PID controller can be used to obtaining a fast response of a disturbance appearance. In steady state operation, a PID controller regulates the value of the output so as to drive the error (e) to zero. A measure of the error is given by the difference between the setpoint (SP) (the desired operating point) and the process variable (PV) (the actual operating point). The principle of PID control is based upon the following equation that expresses the output, M(t), as a function of a proportional term, an integral term, and a differential term:

$$M(t) = K_c.e + K_c.\int_0^t e.dt + M_{in.} + K_c.\frac{\partial e}{\partial t} \quad (1)$$

where:
$M(t)$ is the loop output as a function of time;
K_C is the loop gain;
e is the loop error (the difference between setpoint and process variable);
$M_{in.}$ is the initial value of the loop output.

In order to implement this control function in a digital description, the continuous function must be quantized into periodic samples of the error value with subsequent calculation of the output. The corresponding equation that is the basis for the digital algorithm solution is:

$$M_n = K_c * e_n + K_I * \sum_{x=1}^{n} e_x + M_{in} + K_D * (e_n - e_{n-1}) \quad (2)$$

where:
M_n is the calculated value of the loop output at sample time n;
e_n is the value of the loop error at sample time n;
e_{n-1} is the previous value of the loop error (at sample time n-1)
e_x is the value of the loop error at sample time x;
K_I is the proportional constant of the integral term;
K_D is the proportional constant of the differential term.

The integral term is shown to be a function of all the error terms from the first sample to the current sample. The differential term is a function of the current sample and the previous sample, while the proportional term is only a function of the current sample. In a digital processor, it is not practical to store all samples of the error term, nor is it necessary. Since the processor must calculate the output value each time the error is sampled beginning with the first sample, it is only necessary to store the previous value of the error and the previous value of the integral term. As a result of the repetitive nature of the digital algorithm solution, a simplification in the Eq. (2), which must be solved at any sample time, can be made. The simplified equation is:

$$M_n = K_c * e_n + K_I * e_n + MX + K_D * (e_n - e_{n-1}) \quad (3)$$

where:
MX is the value of the integral term at sample time n-1 (also called the integral sum or the bias):

$$MX = K_I * \sum_{1}^{n-1} e_x + M_{in.} \quad (4)$$

The S7-200 uses a modified form of the Eq. (3) when calculates the loop output value. This modified equation is:

$$M_n = MP_n + MI_n + MD_n \quad (5)$$

where:
MP_n, MI_n *and* MD_n are the values of the proportional, integral and differential terms of the loop output at sample time n [2].

The proportional term MP is the product of the gain (K_C), which controls the sensitivity of the output calculation, and the error (e), which is the difference between the setpoint (SP) and the process variable (PV) at a given sample time. The equation for the proportional term as solved by the S7-200 is:

$$MP_n = K_c * (SP_n - PV_n) \quad (6)$$

where:
SP_n is the value of the setpoint at sample time n;
PV_n is the value of the process variable at sample time n.

The integral term MI is proportional to the sum of the error over time. The equation for the integral term as solved by the S7-200 is:

$$MI_n = K_c * \frac{T_s}{T_I} * (SP_n - PV_n) + MX \quad (7)$$

where:
T_S is the loop sample time;
T_I is the integration period of the loop (also called the integral time or reset).

The integral sum or bias (*MX*) is the running sum of all previous values of the integral term. After each calculation of MI_n, the bias is updated with the value of MI_n, which might be adjusted or clamped. The initial value of the bias is typically set to the output value ($M_{in.}$) just prior to the first loop output calculation. Several constants are also part of the integral term, the gain (K_C), the sample time (T_S), which is the cycle time at which the PID loop recalculates the output value, and the integral time or reset (T_I), which is a time used to control the influence of the integral term in the output calculation.

The differential term MD is proportional to the change in the error. The S7-200 uses the following equation for the differential term:

$$MD_n = K_c * \frac{T_D}{T_S}\left[(SP_n - PV_n) - (SP_{n-1} - PV_{n-1})\right] \quad (8)$$

where:
T_D is the differentiation period of the loop (also called the derivative time or rate);
SP_{n-1} is the value of the setpoint at sample time n-1;
PV_{n-1} is the value of the process variable at sample time n-1.

To avoid step changes or bumps in the output due to derivative action on setpoint changes, the Eq. (8) is modified to assume that the setpoint is a constant (SP_n = SP_{n-1}). This results in the calculation of the change in the process variable instead of the change in the error as shown:

$$MD_n = K_c * \frac{T_D}{T_S}(PV_{n-1} - PV_n) \quad (9)$$

The process variable rather than the error must be saved for use in the next calculation of the differential term. At the time of the first sample, the value of PV_{n-1} is initialized to be equal to PV_n.

In many control systems, it might be necessary to employ only one or two methods of loop control. Setting the value of the constant parameters makes the selection of the type of loop control desired. If the integral action is not required, then a value of infinity “INF” should be specified for the integral time T_I. Even with no integral action, the value of the integral term might not be zero, due to the initial value of the integral sum MX. If the derivative action is not required, then a value of 0.0 should be specified for the derivative time T_D. If the proportional action is not necessary (I or ID control is required), then a value of 0.0 should be specified for the gain K_C. Since the loop gain is a factor in the equations for calculating the integral and differential terms, setting a value of 0.0 for the loop gain will result in a value of 1.0 being used for the loop gain in the calculation of the integral and differential terms.

Eight PID instructions can be used in a program, which controls S7-200. Each loop has four constant parameters, two input variables (the setpoint and the process variable) and output value, which is generated by the PID calculation. The setpoint is generally a fixed value. The process variable is a value that is related to loop output and therefore measures the effect that the loop output has on the controlled system. A loop table stores nine parameters used for controlling and monitoring the loop operation and includes the current and previous value of the process variable PV_n and PV_{n-1}, the setpoint SP, output M_n, gain K_C, sample time T_S, integral time T_I, derivative time T_D, and the integral sum MX (bias). The output value field in the loop table is updated at the completion of each PID calculation.

Therefore, it is possible to realize a multidimensional system that includes up to eight closed-loop control processes. Such is the case, for example, that positioning and speed regulators are used and a current (toque) governor is in a state of subordination of the speed controller. In this case, the setpoint of the low range and the setpoint of the high range should correspond to the process variable low range and high range.

In the laboratory simulator, the load torque is depending on the output power and the speed of the synchronous generator. The output power is the product of the output current and voltage of the generator. Therefore, the load torque might be calculated and measuring the current, voltage and the speed of the generator, might identify disturbances appearance.

The S7-200 must calculate the load torque. The outputs of voltage and current sensors mounted on the output circuit of the synchronous generator have to be connected to the analog inputs of the S7-200 [6]. By multiplication of these two signals the output power of the synchronous generator must be calculated. The rotary encoder mounted in the induction motor might be used for speed measuring. The load torque can be calculated dividing the output power and the generator speed:

$$M_c = \frac{30 * K_U * U * K_I * I}{\pi * n} \quad (10)$$

where: M_c is the load torque;
U and I are measured voltage and current values;
K_U and K_I are the sensors constants;
n is the measured value of the speed.

The Eq. (10) might be used for a process variable in a PID controller. In this way, the drive system behaviour will be optimized.

When the positioning system is examined, the rotary encoder must be used for the measuring of the traveled distance. If a linear encoder will be mounted on the positioning mechanism, it could be used for precise position measuring. The friction error and the clearance in the gear will be eliminated. A high accuracy can be achieved, because the standard resolution of the traveled distance amounts to 0.01mm. Three output signals are available to be connected to the PLC’s digital inputs: the channels A and B are 90° phase shifted and the index pulse is a periodic pulse, which is released each 5 mm’s. A high-speed counter might be used for calculating the traveled distance and the absolute position of the mechanism. These values can be used for the travel profile optimization.

V. Conclusion

In this paper the examinations of the power drive and positioning systems are given. The laboratory simulator gives possibilities of student’s practical training in many terms of reference, for example:

- Training the programming skills for setting-up the controllers, inverters and touch screens – a knowledge of the relevant software products is necessary;
- Synthesis of algorithms for optimal control on the positioning and drive systems, using PID controllers and selecting the values of their parameters (gain K_C, sample time T_S, integral time T_I, derivative time T_D);
- Using the vector control on the power drive systems - the Sinamics G120 has a current measurement function, which permits the output current to be precisely determined, referred to the motor voltage. This measurement guarantees the output current to be sub-divided into a load component and a flux component. Using this subdivision, the motor flux can be controlled and can be appropriately adapted and optimized inline with the prevailing conditions;
- Estimation of the positioning error at the random load torque disturbances as well as at the various speed;
- Evaluation of the PLC’s possibilities for its using in the positioning and power drive systems for the efficiency optimization.

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