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A NEW PROTOYPE DESIGNING OF CNC MACHINE BY USING ADAPTIVE CONTROL

Mahir DURSUN[1], Esin POLAT TEKTAŞ[2], Semih ÖZDEN[3]

ABSTRACT:

This paper presents adaptive controlled a new 3 axes CNC machine design for education purposes. Firstly in this study, 3 servo motors was simultaneous controlled by using Schineider SoMachine interface in control program and adaptive control. In this system as hardware Schineider brand 1.3 kw, BMH 100mm key IP54 st 16 angular 3 servo motor, 3 motor drivers they are consist of lexium 32, 6A sercos servo motor drivers, multi turn CANopen absolute 3 encoders, GTO touch HMI panel, 12.1 ", communication cables, auxiliary devices such as power supply power supply-5A and Motion Controller Modicon LMC078 is used. The prototype 3-axis CNC machine was installed by mounting the encoders with the control of the system is provided with feedback is possible against errors.

KEYWORDS: Adaptive, controlled CNC, SoMachine, Sercos,

1. INTRODUCTION

CNC machines are widely used in almost all areas of the industry and in the manufacturing industry. However, even though continue to studies to improve of this machines technical qualification and skills there are still some problems need to be solutions. One of the problems is still the desired quality of the correct product cannot be produced at some complex geometrical shape process. The main reason of this problem is the fact that in the production of curved geometric shaped drawings such as spring or conical, the operation and position detection of the microprocessors in the control system of the drive motor in each axis cannot be realized simultaneously. In addition, new education technologies also require new education technicians to understand the problems easily.

It can be seen that researchers have done many studies in the literature to solving production of curved geometric shaped drawings. Also it can be seen that there are such as spring or conical, the operation and position detection about the effect of programming, design, speed and acceleration on the processing quality of CNC machines in similar studies. Some of the studies are summarized below. One of the related studies have been published in 2011 by Zhang L X, Sun R Y, Gao X S, et al. The authors had proposed a multi-period turning method to improve the feedrate at the junctions using the linear acceleration and deceleration mode, which utilizes the maximal acceleration capabilities of the NC machine while satisfying the machining precision [1]. There is a study was published by Jee S and Koren Y in 2004 that describes an adaptive fuzzy logic controller (AFLC) for precision contour machining which adjusts both input and output membership functions simultaneously [2].
It can be seen in the literature that there is a study focused on laser-head with intended electronics control structure controlled by CNC software is developed. The study had been published by Hidayanti N., at al in 2017 [3]. The dynamics in the CNC machining process had been published by L. Pejryd, J Repo and T. Beno in 2012. The authors state that the position encoders are running and the effects on tool wear change the geometry of the cutting edges. This change affects the direction and amplitude of the shear force components. [4] A 3-axis CNC machine design, selection criteria and cost analysis plan were published by

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Büyükşah U.[5]. There is other study that it is presents axis motor control procedure for CNC machine and presented by Kayalık M. in 2009[6]. The importance of motor control had been emphasized at CNC machine presented by Y. Turgut at al. in 2004[7]. A study that it has presented about modern control methods of repetitive neural networks (ARNN) motion control adapted to the CNC machine was published by Faa-Jeng Lin at al, In 2006 [8].

Different from former studies In this study, three different servo motors for 3 axis CNC machine drive were mounted on CNC machine and used in material processing. Moreover differences from previous studies in the literature, when the target coordinate is given, 3 different motors controlling 3 axes with interpolation method are operated at different speeds and accelerations at the same time and more smooth and smooth processing is provided. In this way, the roughness and stair steps are minimized in bow and conical grade corner forming. Although the 3-axis CNC is used for industrial purposes, the 3 axes can easily be converted to the more axes than three thanks to its modular construction.

In the second part of this study, mechanical design and in the third chapter, programming works are given. In the programming part which constitutes the third part of the study; Simultaneous control of 3 servo motors are provided.

2. MECHANICAL DESIGN

In this study, the prototype of 3-axis CNC machine with adaptive control is designed. The diagram of the 3-axis CNC machine connected to the Schneider servo motors is shown in Figure 1.

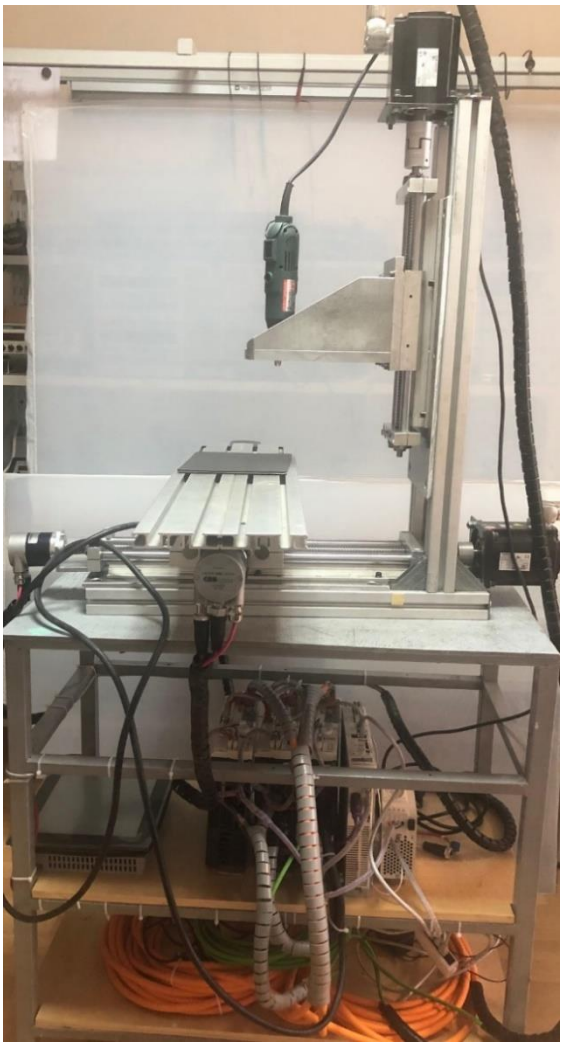


Figure 1. Diagram of 3 axis CNC machine designed

The prototype used 3 screws with 5mm / turn pitches of 100x100x100 mm dimensions. These screws are equipped with three 480V, 1.3 kW, 4000 rpm and 3.4 Nm label values. These motors are driven by 3 Schineider Lexium drives and one LMC78 PLC. Position information is measured on motor shaft ends with CAN Open 360: 32767 bout absolute encoder.

Position information from SERCOS, which is the communication protocol of PLC and motor drive, is measured separately with the information coming from the encoder included in the servo motor in the system and the program. The difference between these two encoders on the same axis is used to detect and correct errors such as torsion, feedback faults that may be caused by screw gap and screws. In this way, a 3-axis CNC prototype can be used directly in real applications if the screw lengths are enlarged.The internal encoder communicating with the SERCOS protocol coupled to the external encoder and servo motor which can communicate via the external CAN BUS protocol is also synchronized. SoMachine program and SERCOS communication protocol and CAN BUS communication protocol were used together. Thus, simultaneous communication with both protocols has been achieved and made safer and more reliable against errors and the error has been reduced in the operation of the CNC. In Figure 2. CNC axes and Control Unit can be seen.

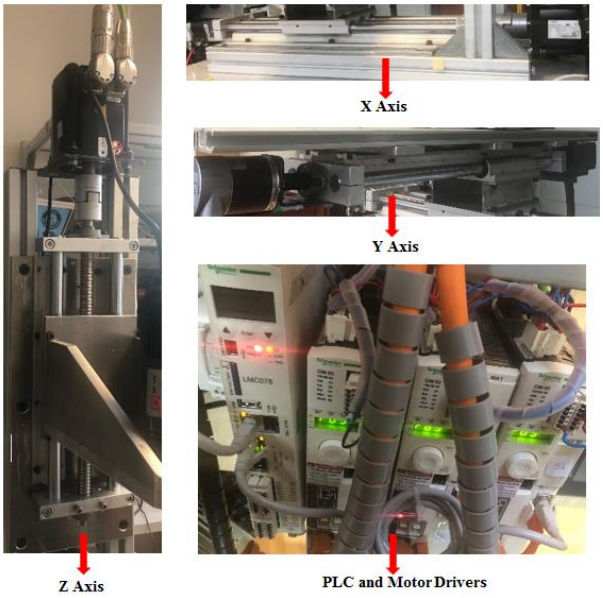


Figure 2. CNC axes and Control Unit

3. SIMULTANEOUS CONTROL OF SERVO MOTORS

Figure 3 shows the process steps of the program prepared in the interface Somachine.The programming part consists of a control program of 3 servo motors. By using Schineder LXM32 motor drive, the friction and inertia parameters of the motor and connected parts were determined experimentally and the control was also optimized. In addition, these parameters are addressed by using SoMove interface program and the parameters are loaded to the drivers and the optimum parameters are used in each servo motor control. After this process, the CNC control program of the PLC was performed.

Addresses made previously in the SoMove program have been entered into the relevant sections in SoMachine program and communication of the drivers with PLC has been ensured. Although the control program was prepared to support the 64 axis, the studies were tested on 3 axes considering that the control in 3 basic axes were sufficient for training. Moreover, even with the adaptive control of a servo motor, infrastructure can be provided for the design of future professional CNC machines. As shown in Figure 4, in the SoMachine program, PLC, Driver, Motor, Display, Encoder selection communication protocols were considered.

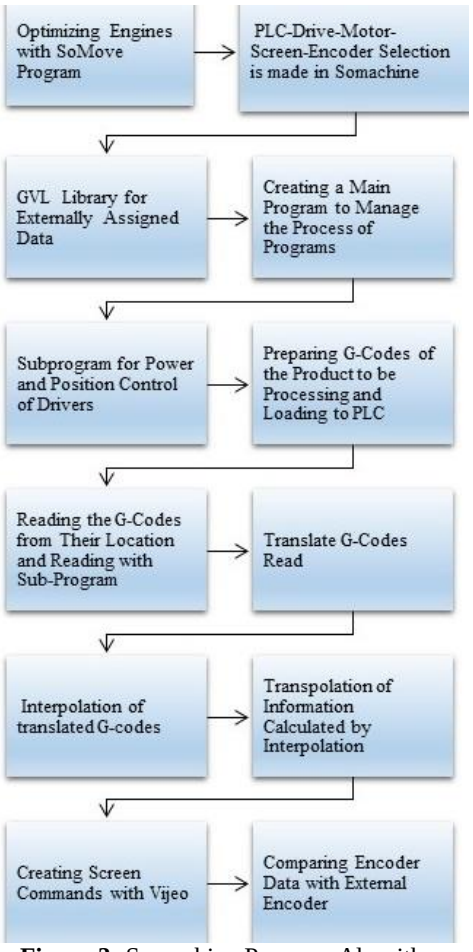


Figure 3: Somachine Program Algorithm

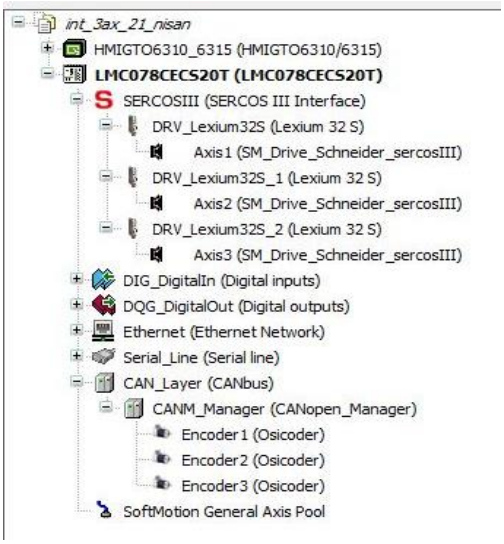


Figure 4. Hardware Installation in the SoMachine Program

In order to manage the external data flow in the program coding stage (position adjustment, power control, G-code loading, interpolarization limit speed and diameter information) commands and assignments written in GVL library are as shown in Figure-5.

```
VAR_GLOBAL
    gvl_power_x AT %MX0.0: BOOL;
    gvl_power_y AT %MX2.0: BOOL;
    gvl_power_z AT %MX4.0: BOOL;

    gvl_stop_x AT %MX1.0:BOOL;
    gvl_stop_y AT %MX3.0:BOOL;
    gvl_stop_z AT %MX5.0:BOOL;

    gvl_repos_x AT %MD120:REAL;
    gvl_repos_y AT %MD140:REAL;
    gvl_repos_z AT %MD160:REAL;

    gvl_enc_x AT %MD200:DWORD;
    gvl_enc_y AT %MD220:REAL;
    gvl_enc_z AT %MD240:REAL;

    gvl_enc_x_dif AT %MD320:DWORD;
    gvl_enc_y_dif AT %MD340:REAL;
    gvl_enc_z_dif AT %MD360:REAL;

    gvl_d_x_out AT %MD130:REAL;
    gvl_d_y_out AT %MD150:REAL;
    gvl_d_z_out AT %MD170:REAL;


    gvl_d_x_in AT %MD260 :REAL;
    gvl_d_y_in AT %MD280 :REAL;
    gvl_d_z_in AT %MD300 :REAL;

    gvl_readnc AT %MX6.0:BOOL;
    gvl_interpol AT %MX7.0:BOOL;

    END_VAR
```

Figure 5. GVL library

For the sorting and management of operations, the main program is created as in Figure-6. Figure 7 shows the servomotor control program interface for the X axis. MC_Power, MC_SetPosition, MC_ReadActual Position, MC_Stop commands are used. MC_Power command is making for controlling the LXM32 driver("on" or "off"). The MC_SetPosition command is designed to assign location information to the axis position. With this command, it changes its actual position to the desired value without causing any movement. It can be used to reference the position of the axis. MC_ReadActual Position reads the actual position of the axis. MC_Stop used for stop.

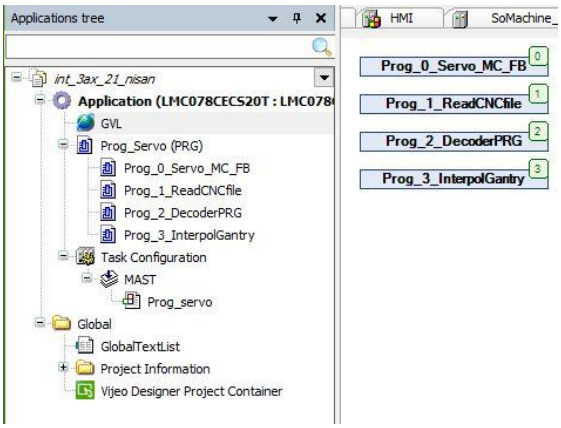


Figure 6. Main Program and Subprogram creation

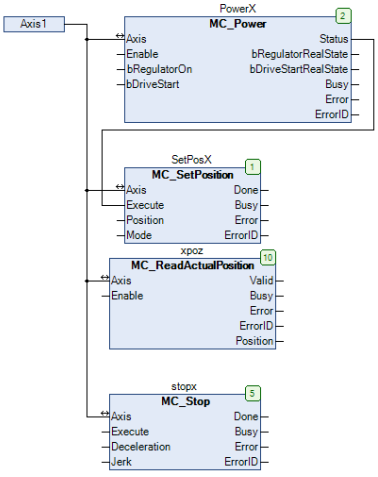


Figure 7. Servomotor control program for X axis

Similar components of a program written in the SoMachine program do not allow copying and pasting when required to be reused. Moreover, even if no error message is received during compilation, the parts copied in the application do not run. This problem is encountered in the application of the program prepared for an axis to other axes in our application. If the problem is solved, it is possible to run 3 axes simultaneously by detecting and correcting the fault in SoMachine program. It was understood that the problem was the copying and pasting of the program written for one axis and the other axes. Thus, in such

programs and in the use of the interface, it was concluded that copy and paste could not be made even if the same program and it was reported to the problem firm. After the problem is solved, the synchronous control program of PLC and servo motors has been completed. With the PLC, servo motor control has been continued and experiments have been confirmed.

Figure 8 shows an example G-code and G-code read command. The adaptive control program generates control signals such as speed, position, torque to the servo motor via G codes. The SMC_ReadNCFile command was used to load the G-Code that we previously created and uploaded to the PLC using the SoMachine interface. SMC_ReadNCFile reads an NC-ASCII file that is passed into the controller and makes it available to SMC_NCDecoder. An NC program can be read and executed while the program is running.

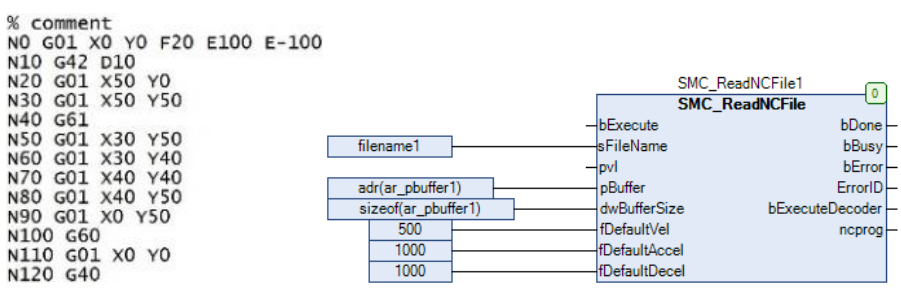


Figure 8.G code read command

The processing of the G-codes read with the commands SMC_NCDecoder, SMC_RoundPath, SMC_ToolCorr, SMC_AvoidLoop, SMC_LimitCircularVelocity, SMC_Check Velocity is shown in Figure.9. SMC_NC Decoder solves program lines and converts a CNC program created in the CNC editor into a SoftMotion GEOINFO.The SMC_RoundPath function rounds the resulting edges in the combination of two objects with circular springs.For rounding in the CNC program, set the start (G52), end (G50) and rounding radius (D <Radius>). With the SMC_ToolCorr command, the compensation of the tool radius or end radius (G41 / G42) is possible by entering the commands and cancellation (G40). The tool radius must be defined by D <angle>. SMC_AvoidLoop; allows skipping when switching between cycles. In the CNC program, the beginning (G61) and end (G60) of the path section for which the correction should be made must be defined. Smc_limitcircularvelocity; This program organization unit controls the transition of two elements. Sets the final speed of the first element so that the acceleration jump does not exceed the dMaxAccJump value. It also limits the road acceleration in the circles to dMaxAcc, reducing the road speed of the circles accordingly. SMC_CheckVelocity; is used to control the path of sharp bends and to reduce the speed to zero.

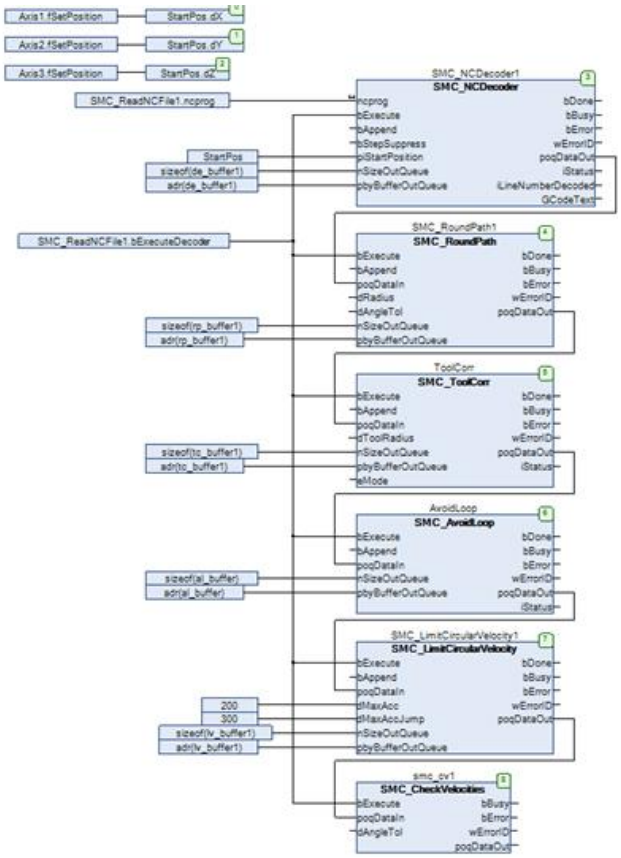


Figure 9. Processing of G-codes

While motor movements were provided with constant speed, interpolarization feature was used with additional software and programming, and the motors were calculated to calculate their speed according to the destination, and to move with variable acceleration and different speeds in coordination with each other. The usage of SMC_Restore Queue, SMC_Interpolator, SMC_TRAFO_Gantry, SMC_TRAFOF_Gantry SMC_ ControlAxisByPos commands for interpolarization is shown in Figure 10.SMC_RestoreQueue The function restores an interpolated response. it is possible to store all the way directions of the processed structure in the order given. SMC_Interpolator An existing continuous path defined by the GEOINFO objects is converted into position points by considering the defined speed profile and time pattern. These position points are then converted to drive axis positions via the IEC program and sent via the Drive Interface. SMC_ControlAxisByPos can be used to write and test target positions on drives. Usually used in the context of CNC and SMC_Interpolator. SMC_TRAFO_ GANTRY3; The conversion module. By performing a backward calculation, the module only adds a shift to the x, y, and z axes and allows the use of three-dimensional portal systems. SMC_TRAFOF_ Gantry3; It uses three-dimensional portal systems without conversion. it is possible to connect each instance of this module to the visualization template.

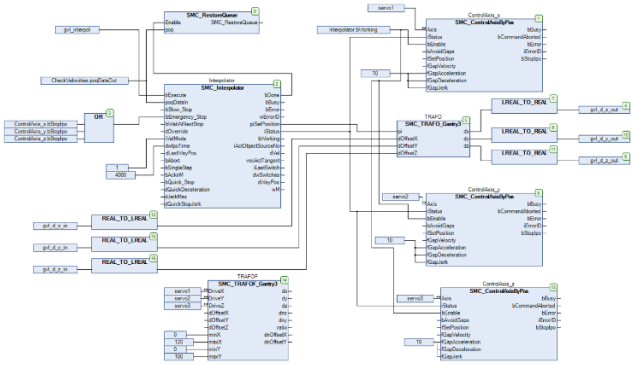


Figure 10. Interpolation Process

The program for adaptive control is provided in figure 11. In the program, the information from the internal and external encoders is compared, and if the difference between 2 mm is exceeded, the motor is stopped. The information from the internal encoder is taken from the position end in the Real_actual_Position function block. Using the old position information in the external encoder and the new position information, the distance is calculated. In this calculation, it was found that the external Encoder produced 8.192 pulses with 1 full turn rotation and 5 mm progression. The number of pulses required for the shaft to move 1 mm is calculated as 5/8192 = 0,0006103515625. Accordingly, the number of pulses in the encoder is multiplied by MUL command with 0.0006103515625 number and the amount of motion in the axis is calculated in mm.

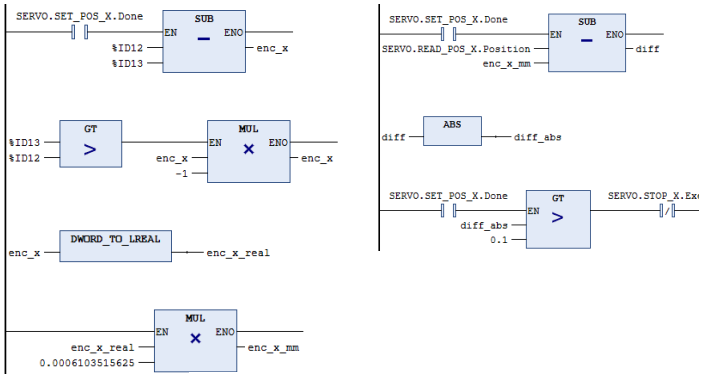


Figure 11. Adaptive Process

The studies have been carried out using the visulation visual design module of the SoMachine interface program. It can be monitored and controlled via web page via computer and internet. Using the GTO touch HMI operator panel, the speed and positions of the program and the motors can be monitored on the screen. Communication between the display and PLC is provided by Ethernet and the Vijeo designer program is used for programming. The prepared panel interface is shown in Figure 12.

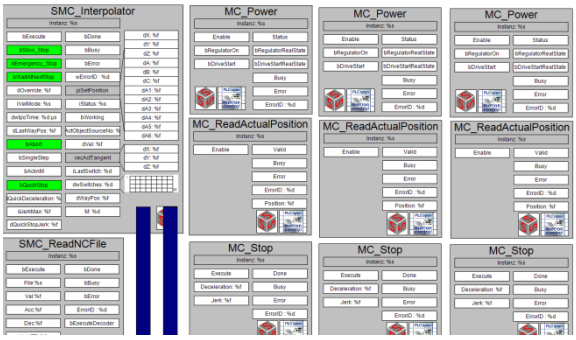


Figure 12. Controlled with visulation

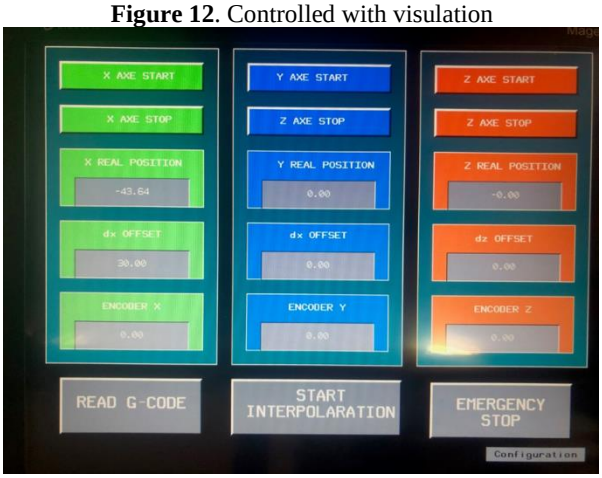


Figure 13. Controlled with HMI Panel

CONCLUSION

In this study, 3 different servo motors for 3 axis CNC machine drive were mounted on CNC machine and used in material processing. In the study, when the target coordinate is given, 3 different motors controlling 3 axes with interpolation method are operated at different speeds and accelerations at the same time, thus ensuring smoother and smooth operation. In this way, the roughness and stair steps are minimized in bow and conical grade corner forming. In application, the encoder on the motor and the external encoder data at the shaft end were compared, and the difference was calculated, and the gears were detected. Thus, in the use of CNC, production errors are taken against the production errors and can be used in real life production. Also, this machine can be used for education purposes at vocational or industrial schools.

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SUPPRESSION OF HARMONICS AT DIFFERENT ATMOSPHERIC CONDITIONS IN A PHOTOVOLTAIC SYSTEM

Mahir DURSUN[1], Turgut DEMİRDÖĞEN[2], Semih ÖZDEN[3]

ABSTRACT

Power obtained from solar panels or solar panel hybrid generation systems under different atmospheric conditions is not stable and determined. On the other hand, non-linear loads also cause reactive power consumption in the grid. In this paper, the design of the behavior of photovoltaic (PV) panels, Maximum Power Point Tracking (MPPT), DC / AC inverter, active filter and PID controllers under different atmospheric conditions and the simulation of the harmonics and inductive reactive power suppression are emphasized.

Keyword: Photovoltaic Systems, Reactive Power Control

1. INTRODUCTION

Environmentally conscious of the importance of renewable energy sources and the use of indigenous resources in Turkey as well as all over the world also increasing with each passing day and its use is widespread. In particular, the number of solar power plants supported by special incentives has increased in the last period and the installed power has reached the value of 5.062.9 MW.

The inverter used in grid-connected PV plants generates inductive reactive power. However, there is a need to control the total reactive power associated with the load side of the inductive reactive loads.

In this study where reactive power control was performed, firstly the general system was modeled and MATLAB / Simulink-SimPowerSystems tool, which was developed especially for the simulation of such systems, was used. The designed PV system has been simulated under variable radiation values and temperature conditions.

The standard linearization methods commonly used in the MATLAB program are not sufficient in the controller design for a non-linear system, such as in photovoltaic hybrid systems under different atmospheric conditions. Because of the developed system, PWM signals are used for the switching of DC / AC inverters and this constitutes a structure which cannot be linearized by MATLAB. Therefore, an alternative method based on simulating system inputs / outputs is used.

It is observed that different strategies are used in studies on reactive power control with PV panels. Reactive Power Injection (RPI) Strategies for Photovoltaic Systems a) constant average active power control, b) constant active current control, c) constant peak current control, and d) thermally optimized control strategy. [1]

From these strategies, a new hybrid control system was developed by combining fixed mean active power control and Q- (V) methods and this was used to reduce unnecessary Q absorption. Under different load conditions, different outputs were generated, the output voltages were measured and the performance of each inverter was compared by controlling the amount of Q [2]

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In addition, the study by Hashemi et al. Also found that reactive power control also helped to decrease Electrical Energy Storage Systems capacity[3].

Chen et al developed a robust predictive deadbeat control (RPDC) and used it to reduce the control delay in the digital signal processor of the inverter in one-phase grid interactive PV plants and to increase the system's robustness due to filter inductance mismatch. [4].

Low voltage ride through (LVRT) is provided, using Droop / PI control to obtain maximum power in normal and fault conditions [5].

In another (LVRT) study, the DC voltage control strategy has been developed and applied to the control of the key signal of the developed technical boost converter. Thus, the DC side voltage of the inverter is kept under control. At the same time, reactive power is provided depending on the intensity of the drop to support the voltage drops occurring in the grid. [6].

In a similar study, the dynamic behavior of the system under abnormal conditions was investigated by developing a new method to increase the ability of the grid to remain at low voltage in photovoltaic systems connected to the 3 phase grid. It is observed that in case of mains failure or if the radiation changes, the reactive power required by the grid can be compensated. [7].

The reference current values of the inverter switches at the PV output have been controlled under LVRT conditions and additionally, the discharge circuit is embedded. Thus, the conditions required for the voltage to remain in the grid at the output side were ensured and the control of active and reactive power was ensured. [8]

In different to the current studies, the reactive power generated in the grid is reduced by adding a control circuit to the reference current in this study.

The entire system developed for reactive power control is simulated with the MATLAB / Simulink-SimPowerSystems tool. The PV and grid system is designed to be connected to the LV side at 400 V to 50 Hz. The cases where the voltage of the photovoltaic system at the mains connection point is higher, equal or lower than the grid are compared in terms of reactive power. It has been seen that The PI control circuit is added to the current loop measured in the PWM generator of the inverter switches and the reactive power is absorbed.

2. SYSTEM DESIGN

In the developed system, SunPower SPR-327NE-WHT-D model is preferred as a solar panel. The total power of 3 series, 5 parallel connected photovoltaic panels is approximately 5 kW. Different irradiance were applied at the same temperature. PWM controlled 3-level IGBT bridge is preferred in the system and active filter is used to suppress the generated harmonics. A 5 kVA 142/400 V transformer is used to connect the inverter to the mains.

The output signal of the inverter was controlled by the Maximum Power Point Monitoring (MPPT) used in the 'Perturb and Obserb' technique. This MPPT system automatically changes the voltage reference signal of the inverter voltage regulator to obtain a DC voltage that will draw maximum power from the PV array. PLL is used for voltage and current measurements and synchronization. The photovoltaic system is connected in parallel with the mains and the active power on the current load and the reactive powers drawn from the mains are read.

2.1. Mathematical model of solar panel

A I-V characteristic of a solar cell is mainly based on the Shockley diode equation. [9] Equation 1 is used for a solar panel.

$$I_{PV} = N_p I_{PH} - N_p I_S = \left(e^{\frac{q(V+I_{PV}R_S)}{aKT}} - 1 \right) - \frac{1}{R_{sh}} \left(\frac{V}{N_S} + \frac{I_{PV}R_S}{N_P} \right) \quad (1)$$

where, R_s is the series resistance in the cell model, R_{sh} is the parallel resistance, I_{PH} is the current produced by the radiation, I_s is the inverse saturation current of the diode, q is the electron charge, a is the diode

ideality factor, T the temperature in Kelvin, N_s is the number of solar cells connected to the series, and N_P is the parallel connected solar panel[10].

All technical specifications of the PV used are given in Table 1. The characteristic curves of I-V and P-V formed under different radiation values of the panel according to these table values are presented in Figure 1.

Table 1 Characteristics of the solar panel

Number of Cells in the Module	N_{cell} = 96
Maximum Power	P_{max} = 327 W
Maximum Power Voltage	V_{mpp} = 54.7 V
Maximum Power Current	I_{mpp} = 5.98 A
Open-circuit Voltage	V_{OC} = 64.9 V
Short-circuit Current	I_{SC} = 6,46 A
Open Circuit Voltage Temperature Coefficient	K_V = -0.2727% / degC
Short Circuit Current Temperature Coefficient	K_V =-0.061734% / degC

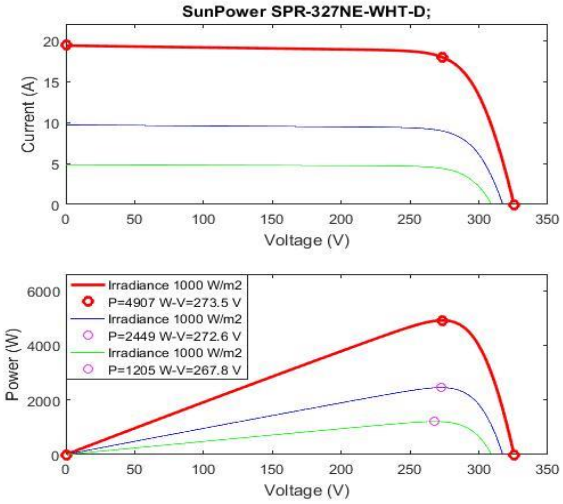


Figure 1. V-I and P-V Curves for SunPower SPR-327NE-WHT-D

2.2. Structure Of The Designed Photovoltaic System

An overview of the simulation of a grid interactive PV power plant is presented in Figure 2. It is presented as general block diagrams of simulation prepared in MATLAB / Simulink environment and the components of the related system are located under each block. The internal structure of the photovoltaic system is given in Figure 3.

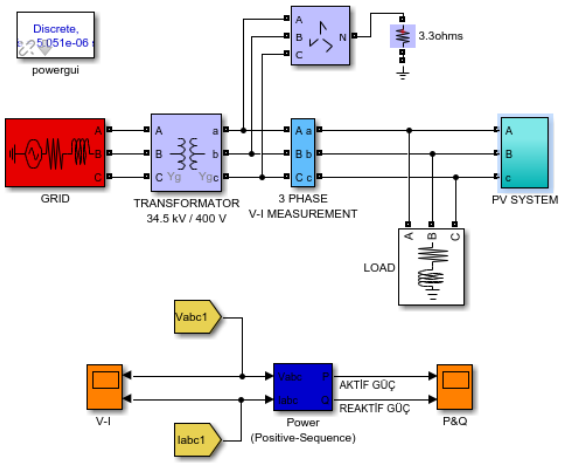


Figure 2- Drawing of the system MATLAB / Simulink-SimPowerSystems

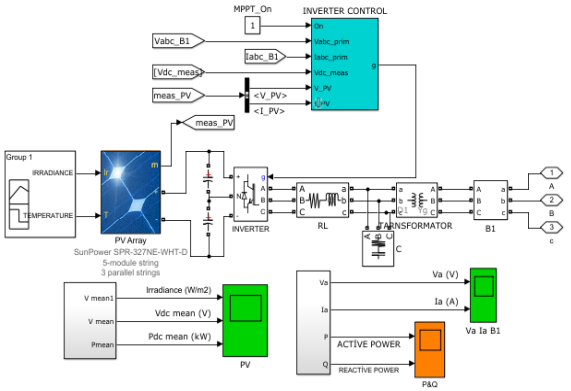


Figure 3- Internal structure of photovoltaic system

It applied the simultaneous reference frame (abc - dq transformation) in which the mains current and the voltage waveform were converted to a rotating reference frame simultaneously with the mains voltage. With this method, the three-phase current and voltage vectors ωt are converted to d (direct) and q (quadrature) vectors. Firstly, the current-voltage vectors converted from three phases to two phases. Then locked to the mains voltages and carried to a (rotating) rotating space with the same ωt velocity. Thus, in the d-q reference plane rotating at synchronous speed, the main component of the load current is converted into the DC signal, while the rotational speeds (frequencies) of the harmonic components shift according to the synchronous speed and direction of rotation. This conversion can be done using Clarke and Park transformations. Equation (2) and equation (3) respectively show the Clarke transformation matrix and the Park transformation matrix, which convert the rotating three-phase vector into the d-q plane.

$$\begin{bmatrix} m_\alpha \\ m_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} * \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \sqrt{\frac{2}{3}} & -\sqrt{\frac{2}{3}} \end{bmatrix} * \begin{bmatrix} m_a \\ m_b \\ m_c \end{bmatrix} \qquad (2)$$

(voltage (V) or current (I) can be replaced by (m)).

$$\begin{bmatrix} m_d \\ m_q \end{bmatrix} = \begin{bmatrix} cos(\omega t) & -sin(\omega t) \\ sin(\omega t) & cos(\omega t) \end{bmatrix} * \begin{bmatrix} m_\alpha \\ m_\beta \end{bmatrix} \qquad (3)$$

The conversion abc-dq0 depends on the dq frame alignment at t = 0. The position of the rotating frame is given by ωt (where ω denotes the rotation speed of the dq frame) Then the maximum P and Q passed through the inverter can be calculated as follows:

$$P = \frac{3}{2}(v_d i_d) \quad (4)$$

$$Q = \frac{3}{2}(-v_d i_q) \quad (5)$$

The control scheme developed for reactive power control is given in Figure 4. In the control circuit, the error value of the PI controller was generated by comparing the current value obtained in the d-q axis with the reference value. This error signal and measured voltage values have been entered the PWM generator.

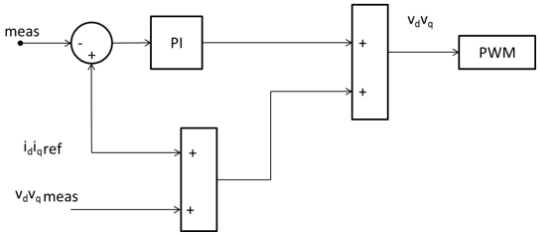


Figure 4 Proposed Control scheme

3. SIMULATION RESULTS

The temperature values of the photovoltaic panel are kept constant, the irradiation values are between 0-0,5 s 1000 W / m^2, between 0,5-1 s 500 W / m^2, between 1-1,5 s 250 W / m^2, between 1,5-2 sec 500 W / m^2, between 2-2,5 s. 1000 W / m^2 is applied. Under these irradiation conditions, the conditions at which the voltage of the photovoltaic system at the mains connection point is higher, equal or lower than the grid are examined and presented in Figure 5. As can be seen from the graph, the output voltage of the photovoltaic panel starts to show inductive effect as it grows more than the grid.

The variation curve of the active and reactive power generated in the case that the developed control system cannot be used is shown in Figure 6. As it is understood from the power change, there is no reactive load in the system and the reactive load drawn from the grid has emerged.

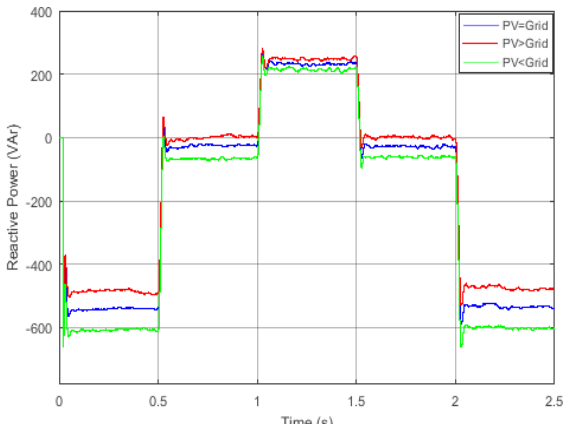


***Figure 5**- Reactive Power Curves from Grid at Different Output Voltages*

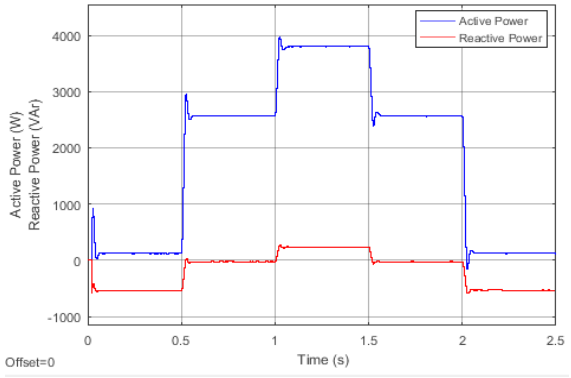


Figure 6 P & Q Curves Before Current Control Is Applied

The variation curve of the active and reactive power generated during the application of the control system developed is shown in Figure 7. As can be understood from the curve, the reactive power was controlled by applying the PI control circuit to the measured current.

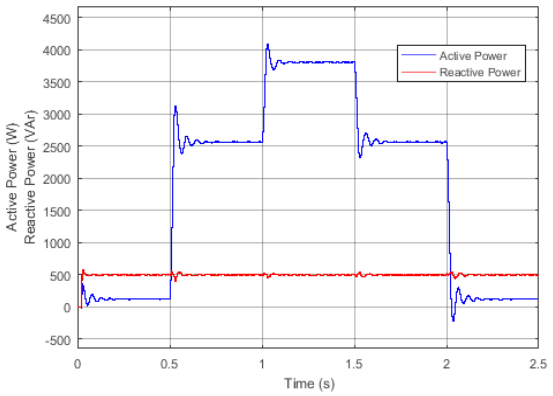


Figure 7: P & Q Curves After Applying Current Control

In Figure 8, the changes in the controlled and uncontrolled state of the reactive power are given in order to clarify the difference formed by the addition of the control system. As can be seen from the curves, it was seen that the used of designed control system the reactive power were significantly reduced.

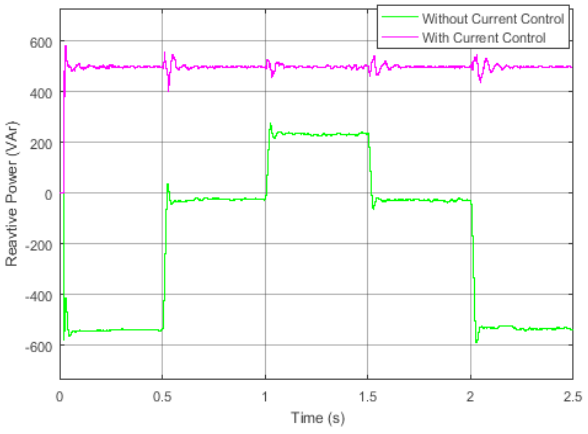


Figure 8- Reactive Power Change After Current Control

3. CONCLUSIONS

Reactive power control simulation was performed in grid-connected photovoltaic power generation systems. In the simulation, the inductive reactive power produced by the load is compensated by the photovoltaic energy source. It is observed that control of the reactive power to be injected into the grid can be adjusted by the duty cycle of the inverter switches. Thus, the reactive power required by the grid and load were provided by solar panels. This reduces the cost of compensation and reduces all the negative effects of the inductive reactive.

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