Design of the manipulator control system for charger complex for electric vehicles

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Abstract

The number of electric cars in the world is growing. Many analysts believe that a new era is beginning, in which electric cars mark the end of the oil era. However, despite the popularity of this alternative mode of transport, the age of "black gold" will continue for a long time, the other side is sure. Unlike traditional cars with internal combustion engines, electric cars can be refuelled wherever there is access to an electrical outlet. This facilitates infrastructure development. In addition, ongoing experiments with electric vehicle charging options show the prospects for new ways of charging, such as wireless charging in parking lots or traffic lights.

Electric cars are gradually gaining popularity, but in order to be used nationwide, appropriate infrastructure is needed. The main problem of electric cars is their operational difficulties associated with the duration of travel on a single charge and low infrastructure under them. This is what prevents the full transition to this mode of transport.

At present, different countries have different government programs to encourage both citizens to buy electric cars and entrepreneurs to develop charging station networks.

Automated charging station systems are also gradually evolving. There are already charging station terminals with payment by bank card and other payment systems, but they operate on a self-service basis. To fully automate the charging process, it is not enough to connect the charging station to the electric car without human intervention. Wireless charging solves this problem, but at this stage of development, the power transmitted in this way is not always enough.

The solution to this problem can be the installation of a manipulator arm on the charging station. The manipulator will determine the position of the car and insert the charging station socket into the machine plug, using sensors and machine vision.

1. Introduction

Electric cars are treated as the latest technology in the automotive market. Despite the fact that all developed countries are trying to switch to "green" electric car systems, interest in these vehicles around the world is still low. An important issue for electric vehicles is the availability of adequate charging infrastructure, as waiting at charging stations due to lack of chargers may deny owners of electric vehicles [1, 2].

With each passing month, the number of electric vehicles in Ukraine is growing [3], which brings to the fore the development of charging infrastructure. As of December 1, 2021, there were 32,662 electric vehicles in the country - an increase of 845 units or 2.6 % compared to the previous month. This is a very good pace, which is maintained almost throughout 2021. Increase in four months - 3.2 thousand cars.

According to the marketing agency IRS Group, as of September 2020, there are 8529 in Ukraine points of electric charging stations. The ratio of the number of electric vehicles to the number of points the connection is 4.2. This is a very good indicator, at the level of the best European countries (same index in the Netherlands). At the moment, the big three have formed in Ukraine players of electric charging infrastructure are AutoEnterprise, EcoFactor and TOKA.

A large share of the Ukrainian market of charging stations is occupied by the Kharkiv company AutoEnterprise, which manufactures charging stations, operates its own charging network, and also imports electric cars. AutoEnterprise produces commercial charging stations (including high-speed), as well as complexes that can charge up to 5-6 cars at a time. About a third of the chargers are manufactured for the domestic market, the rest - for foreign companies. AutoEnterprise works within the framework of the white label concept, i.e. chargers manufactured by it are used under the company's brand around the world. In addition, AutoEnterprise itself develops electric vehicles - trolleybuses, tractors and ATVs.

Thus, electric cars can achieve significant energy savings, be part of urban planning, which includes sensors and new communication technologies (e.g. parking, traffic management), and, more importantly, be part of "Electric Mobility" - the main strategy for smart city reduction to reduce emissions from road transport and improving the resilience of cities, which in turn will contribute to the sustainable development of the country as a whole [4, 5].

This development is relevant because the network of infrastructure for electric cars is currently being actively developed and expanded [6]. The need for automation of gas station filling stations increases

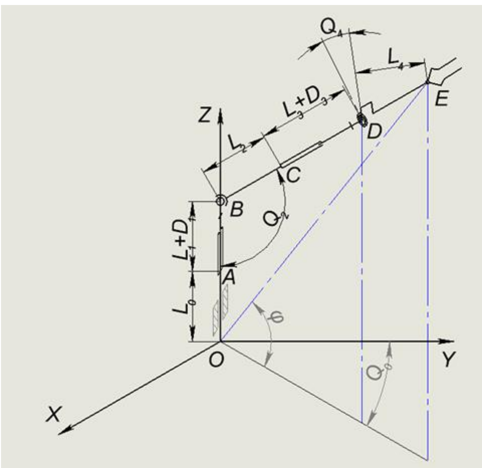

Figure 1: Kinematic diagram of the manipulator

with their number. Automation technologies are becoming more affordable and cheaper [7]. Developments in this area are underway, but not actively enough, as long as they remain within the framework of expensive concepts and only a few companies.

The research is devoted to the design of the manipulator control system for the charging complex of electric vehicles of the company AutoEnterprise.

2. Experimental part

2.1. Development of the kinematic scheme of the manipulator and its control system

For the manipulator it is necessary to provide sufficient kinematic freedom of movement to cover the working area of the charging station, but not to complicate the design [8]. The developed kinematic scheme is shown in Figure 1.

Next, to determine the position of the manipulator in the workspace, the direct and inverse problems of kinematics for this scheme were solved. The result of solving the problems of kinematics is presented in the form of equations:

(1) $X5_x = A5_{0,0} = -\sin(q_0)\cdot\sin(q_4) - \cos(q_0)\cdot\cos(q_4)\cdot\sin(q_2);$

(2) $X5_y = A5_{1,0} = \cos(q_0)\cdot\sin(q_4) - \cos(q_4)\cdot\sin(q_0)\cdot\sin(q_2);$

$X5_z = A5_{2,0} = -\cos(q_2)\cdot\cos(q_4);$

(3) $Y5_x = A5_{0,1} = \cos(q_0)\cdot\sin(q_2)\cdot\sin(q_4) - \cos(q_4)\cdot\sin(q_0);$

(4) $Y5_y = A5_{1,1} = \cos(q_0)\cdot\cos(q_4) + \sin(q_0)\cdot\sin(q_2)\cdot\sin(q_4);$

$Y5_z = A5_{2,1} = \cos(q_2)\cdot\sin(q_4);$

$Z5_x = A5_{0,2} = \cos(q_0)\cdot\cos(q_2);$

$Z5_y = A5_{1,2} = \cos(q_2)\cdot\sin(q_0);$

$Z5_z = A5_{2,2} = -\sin(q_2);$

(5) $P5_x = A5_{0,3} = \cos(q_0)\cdot\cos(q_2)\cdot(d_3 + l_3) + \cos(q_0)\cdot\cos(q_2)\cdot l_2 + \cos(q_0)\cdot\cos(q_2)\cdot l_4;$

(6) $P5_y = A5_{1,3} = \cos(q_2)\cdot\sin(q_0)\cdot(d_3 + l_3) + \cos(q_2)\cdot\sin(q_0)\cdot l_2 + \cos(q_2)\cdot\sin(q_0)\cdot l_4;$

(7) $P5_z = A5_{2,3} = d_1 - \sin(q_2)\cdot(d_3 + l_3) - \sin(q_2)\cdot l_2 - \sin(q_2)\cdot l_4 + l_0 + l_1.$

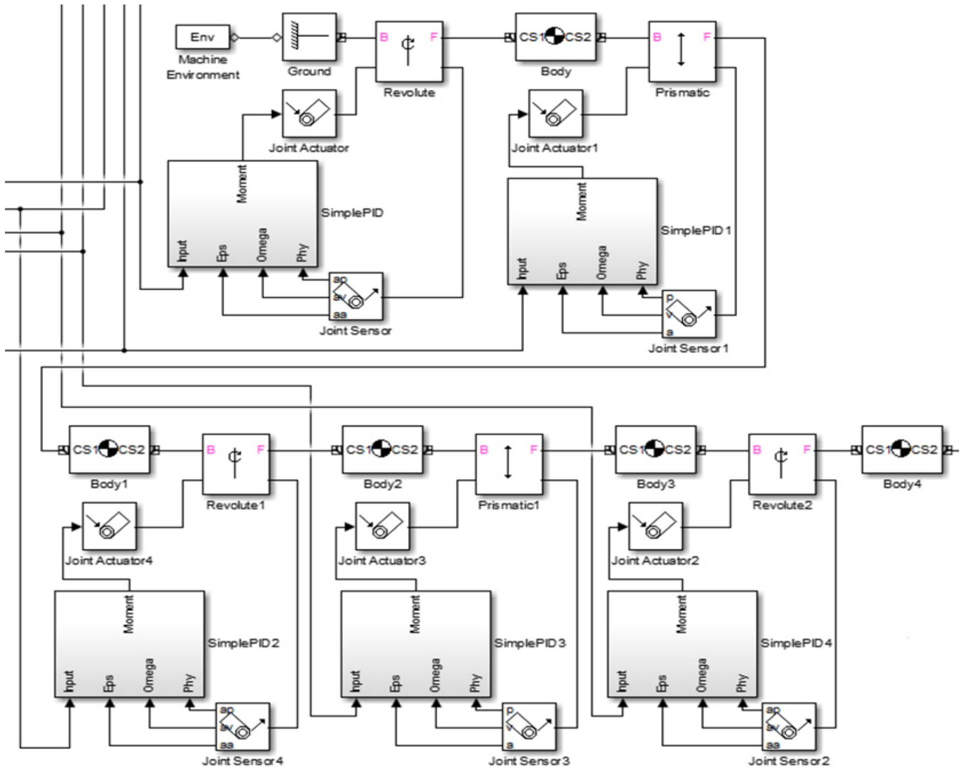

Figure 2: Block diagram of the connection of servomotors and PID controllers with manipulator links and control unit

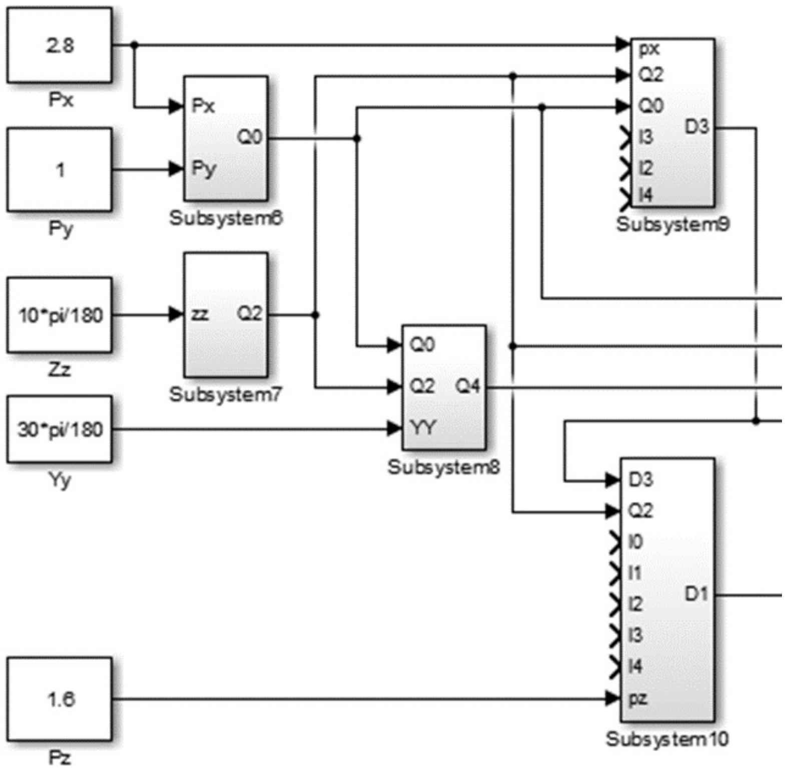

Figure 3: Block diagram of the control unit of the manipulator

The MATLAB application software package simulated a physical model of the manipulator together with servomotors, PID controllers and a control system based on the equations of kinematics problems. The result of the simulation was a block diagram (Figure 2 and 3)

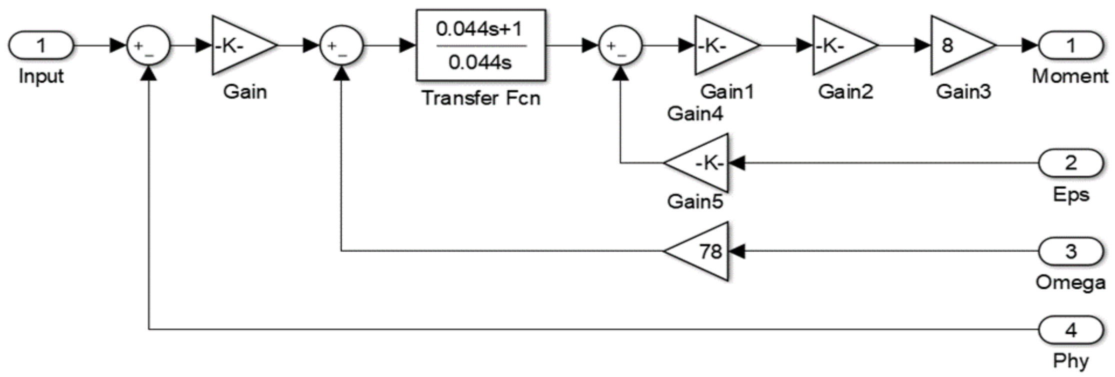

Figure 4: Block diagram of the PID controller

Selection of electronic components and software
For a full-fledged control system of the automated charging station it is necessary to implement systems of machine vision and protection. For machine vision we use Raspberry Pi Zero, Pi camera, cable loop, microSD card, USB power supply, USB-microUSB cable. The machine vision system will ensure that the car's charging connector is located in the working area of the station. Pulse distance sensors (RPT) and the TL725 "MEMS" gyroscope with integrated three-axis accelerometer will provide accurate position tracking and control of charger movement. The integrated CPS servo drive combines everything necessary to control the movement of the motor rotor in different operating modes in one compact housing. A PID controller is used to control the manipulator drives. It forms a control signal, which is the sum of three terms, the first of which is proportional to the difference between the input signal and the feedback signal (mismatch signal), the second - the integral of the mismatch signal, the third - the derivative of the mismatch signal.

The PID controller model is built using the MATLAB software package (Figure 4). Simulation of the PID controller is shown in Figure 5.
As the protection system of the switching device the own design of the protection device at arc breakdown (PDAB) is used (figure 6). The scheme of the control system will be based on the scheme of PDAB with the bipolar mechanism of the automatic switch.

The following sensors were used to determine and control the parameters of the power circuit of the charging complex:

- current sensor (Hall sensor) to measure the current in the circuit due to a change in magnetic field;
- temperature sensor (circuit with thermal converter) for measuring the voltage in the circuit through the temperature of the conductor (Figure 7).

The sensors are connected to a microcontroller that is powered by a switching power supply. The microcontroller uses a thyristor key to disconnect the power circuit. Similarly, electromagnetic and thermal disconnectors disconnect the power circuit when critical values are reached.
For the implementation of this scheme, two Hall sensors huaibei huadian HD-T10IC3, three normalizing amplifiers LM386 Arduino (11171), automatic release ABB S803B-B80 type B, automatic switch BA88-35R 3P 125A 35kA, thyristor 12T and 5 A, Arduino Uno R3 CH340 microcontroller.

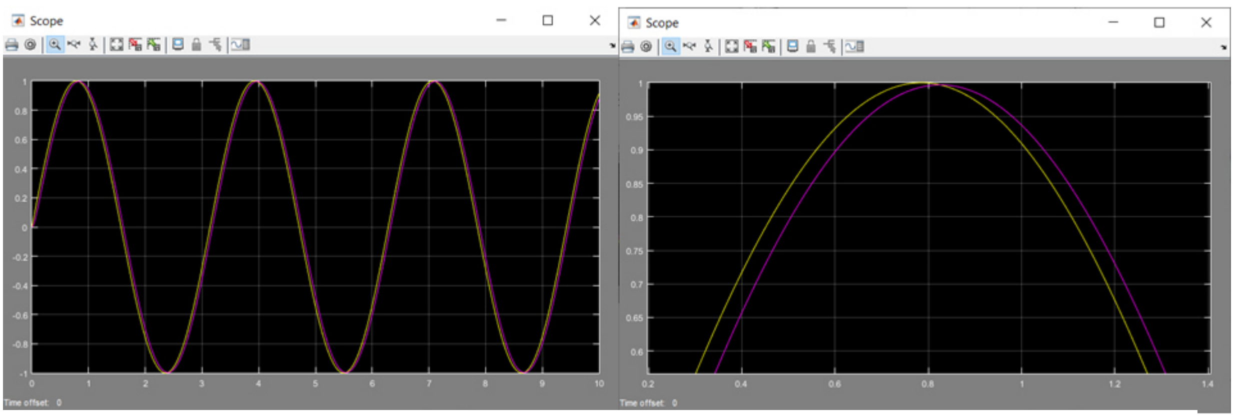

Figure 5: Schedule of the PID controller

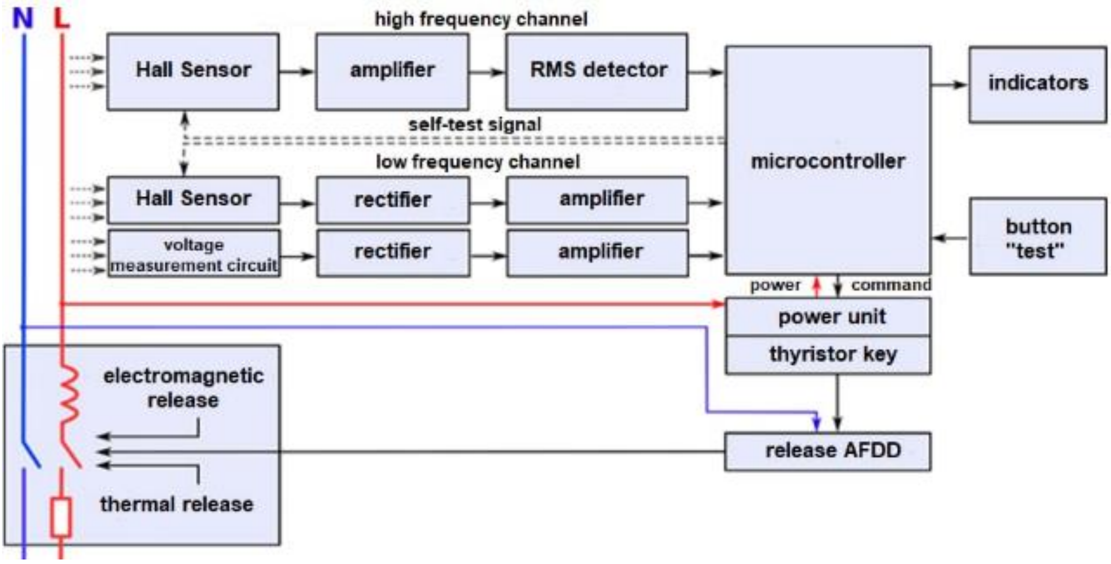

Figure 6: Block diagram of PDAB with bipolar circuit breaker mechanism

2.2. Arrangement and principle of operation

A developed manipulator with built-in sensors, a controller and a protection system for the switching device is connected to the charging station (Figure 8).

The system aims to automate the process of charging an electric car. The designed system is used according to the following principle:
first step: the car approaches the working area of the charging station;
the second step: in the mobile application we initiate the start of charging by making a payment. If everything is done correctly, the machine's vision will determine the position of the charging connector of the electric car, then with the help of sensors and motors, the hand of the manipulator will make the connection. The charging station will lock the connected connector and start charging the electric car. The PDAB protection system monitors the quality of the connection;
third step: After the charging process is completed, the connector will be unlocked and the manipulator will move to the start position.

3. Results and Discussion

The developed system is compatible with the AutoEnterprise Charge Complex-T, and supports different types of standard charging connectors for each standard that supports the charging system. This system allows accurate positioning of the manipulator, considering the characteristics of the charging station.
During the design of the automated charging station, a module of the self-diagnostic system and protective equipment was added, which is a protection device in case of arc breakdown with a bipolar mechanism of the automatic switch. The arc breakdown detection unit monitors the current in the phase conductor with the help of two hall sensors and a voltage meter. This allows you to safely and reliably charge electric cars, which makes the process quick and easy.

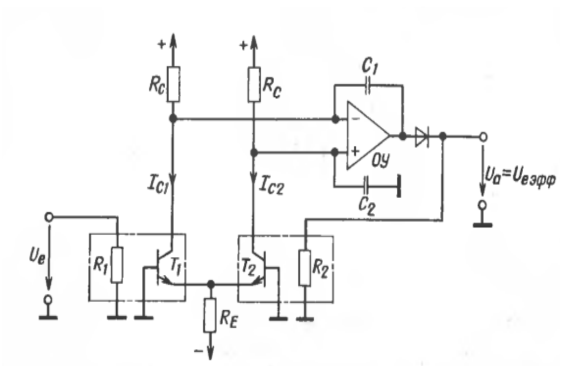

Figure 7: Scheme of measuring the effective voltage in the circuit

Figure 8: Experimental design of an automated charging station

4. Conclusion

The resulting design of the automated charging station is experimental and has many analogues in the world. Similarly, the modularity of the structure allows you to adapt it to other stations, and upgrade it.

The task of reducing charging time is a priority, because this is the secret of increasing the popularity of electric vehicles. In this regard, further research will be aimed at improving the control system of the manipulator for the exchange of information between the car and the charger complex, so that there is a clear connection between them.

5. References

[1] Ján Dižo (2021) Electric and plug-in hybrid vehicles and their infrastructure in a particular European region. Transportation Research Procedia, Volume 55, Pages 629-636, https://doi.org/10.1016/j.trpro.2021.07.029

[2] Kharin, S (2020) Investigation into International Innovative Management of Creating and Producing Electric Cars. IOP Conference Series: Earth and Environmental Science, Volume 628, 8th International Scientific Conference on Sustainability in Energy and Environmental Science 21-22 October 2020, Ivano-Frankivsk, Ukraine. https://doi.org/10.1088/1755-1315/628/1/012005

[3] Honchar, I. A., & Palyan, Z. O. (2018). Statistical Analysis of the Electric Car Market Development in Ukraine: Problems and Solutions. Statistics of Ukraine, 81(2), 13-21. https://doi.org/10.31767/su.2(81)2018.02.02

[4] Kysil S. The issue of transport infrastructure organization for storage of electric vehicles in the urban environment of the largest cities /S. Kysil // Архітектурний вісник КНУБА : наук.-вироб. зб. / Київ. нац. ун-т буд-ва і архіт. ; відп. ред. П. М. Куліков. - Київ : КНУБА, 2017. - Вип. 11-12. - С. 337 - 343. http://repositary.knuba.edu.ua:8080/xmlui/handle/987654321/5118

[5] Wolbertus, R. (2021) Charging infrastructure roll-out strategies for large scale introduction of electric vehicles in urban areas: An agent-based simulation study. Transportation Research Part A: Policy and Practice. Volume 148, June 2021, Pages 262-285. https://doi.org/10.1016/j.tra.2021.04.010

[6] Kapustin, N. (2020) Long-term electric vehicles outlook and their potential impact on electric grid. Energy Policy. Volume 137, February 2020, 111103. https://doi.org/10.1016/j.enpol.2019.111103.

[7] Han Yuan. (2020) Concept Design and Load Capacity Analysis of a Novel Serial-Parallel Robot for the Automatic Charging of Electric Vehicles. Electronics 2020, 9(6), 956 https://doi.org/10.3390/electronics9060956/

[8] Bin Liu.(2021) Vehicle Automatic Charging System Guided Electric by 3D Vision and F / T Sensor, 4th International Conference on Intelligent Autonomous Systems (ICoIAS). 2021. DOI: 10.1109/ICoIAS53694.2021.00025

[9] J. Kenneth Salisbury, John J. Craig. Articulated Hands: Force Control and Kinematic Issues. Volume: 1, page(s): 4-17, 1982. https://doi.org/10.1177%2F027836498200100102