Analele Universităţii din Craiova, seria Agricultură – Montanologie – Cadastru (Annals of the University of Craiova - Agriculture, Montanology, Cadastre Series) Vol. 51/2/2021

TYPES OF ELECTRIC MOTOR CONTROLLERS THAT CAN BE USED ON AGRICULTURAL ELECTRIC TRACTORS

PHD. STUD. ENG. CRISTEA M.(1), PHD. STUD. ENG. VLADUTOIU L.(1), PHD. STUD. ENG. GRIGORE A.I.(1), STUD. CRISTEA D.R. (2)

1) INMA Bucharest
2) University POLITEHNICA of Bucharest

Keywords: BLDC motor, ecological tractor, agriculture, fuel economy

ABSTRACT

The development of electric propulsion systems has become a necessity for existing pollution regulations. This article presents a series of electric motor controllers that can be used on small or medium sized tractors. These controllers are easy to mount on tractors, do not require special mounting or positioning conditions, can be used with different types of electric motors and have a number of optional functions that can be activated depending on the chosen configuration. Controllers are intelligent enough to deal with the power or torque provided to the engine or change the way the engine works, switching it from engine to generator.

INTRODUCTION

Currently, combating environmental pollution is one of the problems that all states in the world are facing. Reducing the level of toxic gases in the atmosphere led some branches of the automotive industry to adopt constructive solutions that have led to the replacement of internal combustion engines, either they have become more efficient and less polluting or have been replaced by electric motors. The replacement of internal combustion engines with electric ones has led to the development of solutions that help increase battery life, by optimizing the power transmitted to the engine depending on the working mode but also by recovering energy by regeneration using the propulsion engine of the vehicle. (V.Sindhuja, G.Ranjitham, 2015)

An important element in the electric propulsion system is the motor controller. It is the one that is basically in control of the power management that is transmitted to the motor and it is the one that can change the function of the motor to power generator. In order to increase the energy recovery or use efficiency, transfer and distribution strategies can be made, which can contain, in addition to the main battery, an ultracapacitor. (W. Zhao, G. Wu, C. Wang, L. Yuc, Y. Li, 2019)

The controller optimizes power consumption by real-time torque control to achieve maximum efficiency, dynamics and a wide range of vehicle speeds. (Elsherbiny H., Elsherbiny H., Ahmed M.K., Elwany M.A.)

In order to function correctly but also to perform all the control and monitoring functions, the controller needs information about the motor that can be preset in memory but also data that is collected during operation by means of sensors. Thus the controller knows exactly when to increase or decrease the power consumption, knows the speed of the motor and thus can effectively control the torque. (Jimenez-Gonzalez J, Gonzalez-Montañez F, Jimenez-Mondragon VM, Liceaga-Castro JU, Escarela-Perez R, Olivares-Galvan JC)

In order to optimize the power distribution of the motor as economically as possible, the manufacturers have researched and developed a series of control techniques. They can be divided into techniques that are based on rules or techniques that are based on optimizing consumption. (6)

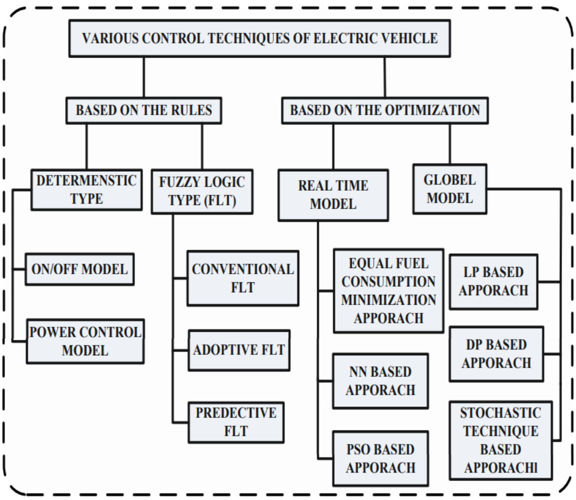

Fig. 1 Various control techniques of electric vehicle (6)

The estimation of the remaining energy is important in the case of electric vehicles but the estimation method is not yet accurate enough. There are studies that use simulations using specialized programs to model the energy consumption of an electric vehicle, in this simulation are included as many factors as possible which can influence energy consumption, in a negative or positive way. (7)

There are situations when an increased traction force is required so you can use the solution with a propulsion motor connected to a 4WD transmission that can be engaged as needed or permanently. Another solution is to use two motors connected to the front axle and another motor to the rear axle, traction control can also be automatic or manual or the four-motors solution (the number of motors depends on the number of axles on the vehicle) mounted on wheels directly can be approached and in this case the traction can be automatic or manual.

There are models of coupling two motors on a chassis that have the possibility of coupling and decoupling as needed, such a scheme being shown in Figure 2. Motor control can be performed by one or two controllers intended for this purpose.

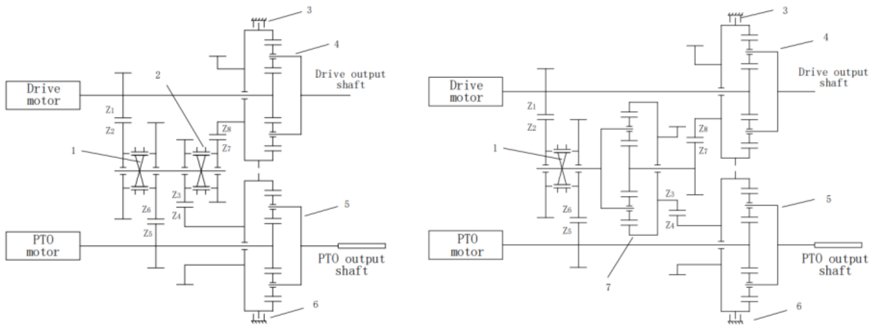

Fig. 2 Diagram for connecting two electric motors to a tractor, one for propulsion and one for power take-off (PTO), 1 and 2 are synchronous, drive mechanism 4, planetary mechanism 5 (8)

Although the motor controller does not have control over the battery, it is able, through the integrated functions, to contribute positively to the extended use of the batteries that power the vehicle.

To extend the working range of an agricultural electric vehicle there are mathematical models that show that when we use gearboxes adapted to electric motors the power conversion achieves high yields. In the modelling of these gearboxes, an important factor is occupied by the controller itself, because by means of its functions the power distribution to the motor is achieved so that the energy consumption is optimal. (9)

In general, due to current battery manufacturing technologies, tractors powered by electric motors are small and medium in size. The motors used to make such vehicles start from about 3kW and can reach up to 50kW and in rare cases this power can be exceeded. A small tractor, e-Tractor, was developed at the University of the Philippines Los Baños, which demonstrated the potential of such vehicles even if they are powered by low-power electric motors. (10)

MATERIAL AND METHOD

Material and method. During the tests, a series of electric motor controllers produced by Curtis Instruments, Sevcon and Kelly Controls were used. The models used were:

1. Curtis AC Motor Controller Model 1239E (11)
2. Sevcon Gen4 (12)
3. Kelly KAC-8080I (13)
4. Kelly KLS (13)

Curtis 1239e controller, is intended for electric and hybrid vehicles that use a system rated voltage of 60–144 V for high power circuits and a 12 V system with the common minus in the vehicle chassis for low power circuits. It is used in conjunction with permanent magnet synchronous motors.

Fig. 3 Curtis 1239e controller before being mounted on the vehicle

Sevcon Gen4 controller. These controllers are intended for road and off-road electric vehicles and have the smallest size in the industry compared to the power supplied.

They have a high efficiency, and thus there is the possibility to integrate these controllers in very narrow spaces without sacrificing performance. The design made by Sevcon is optimized for a low installation cost, without sacrificing the superior reliability needed in the most demanding applications.

Fig. 4 Sevcon Gen4 controller on the test bench

Fig. 5 Kelly KAC controller on the test bench

The range of Kelly KLS programmable controllers are intended for electric motorcycles, light vehicles but also the control of industrial motors. Compared to traditional trapezoidal waveform control technology, this technique is based on sine-wave drive technology and results in low operating noise but also efficiency in powering brushless DC motors. It uses high power MOSFETs to achieve efficiencies of up to 99%. A powerful microprocessor gives controllers precise operation.

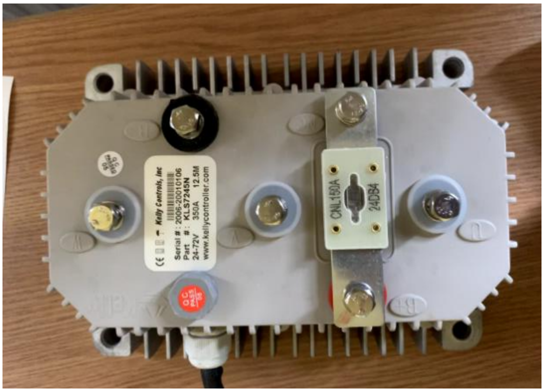

Fig. 6 Kelly KLS controller on the test bench

The table below shows the main specifications of the three controllers studied.

Table 1

Technical specifications of controllers

Model	Curtis 1239e	Sevcon Gen4 72/80V	Kelly KAC 96601 8080I	Kelly KLS 7275
Max Current (A)	500	350	600	350
Rated Power (kW)	65	13.5	23	10
Input Voltage (V)	120-170	50.4-96	24-96	24-72
Adjustable Max Output Voltage (V)	144	116	120	90
Weight (Kg)	5.45	2.7		
Motor types	AC permanent magnet synchronous motor	AC permanent magnet synchronous motor	AC induction motor with dual channel A/B Encoder	AC induction motor with three hall sensors
CAN support	Yes,	Yes, 1Mbps	Yes, 250Kbps	Yes, 250Kbps
Motor sensors	Quadrature encoder (ACIM motors),	AB encoder, sin-cos analogue position	Thermistor KTY84-130/150, Dual	Thermistor KTY84-130/150 or KTY83-

	sin/cos sensor (SPM motors), temperature sensor KTY83–122, KTY84–130, KTY84–150, PT1000		Channel A/B encoder	122, Hall position
Serial port	4-pin Molex	NO	4 pin connector to RS232	4 pin connector to RS232
PC software	1314 PC Programming Station	Drive Wizard - PC based configuration tool	KAC-8080I Config. Program (free)	Kelly KLS 7275 Config. Program (free)
Regen brake function	YES	YES	YES	YES
Bluetooth function	NO	NO	YES	YES
Frequency of Operation	10KHz	16KHz or 24 KHz	10KHz	10KHz or 20kHz
Operating Temperature Range	–40°C to 95°C	-30℃ to 90℃	-40℃ to 90℃	-40℃ to 100℃
Full Power Operating Temperature Range	–40°C to 50°C	0℃ to 80℃	0℃ to 70℃	0℃ to 70℃

The tests were performed on a test bench but also with equipment mounted on different chassis of agricultural vehicles.

In the first test, three types of batteries were used.

The batteries used were 96V and 144V, depending on the motor used. The 96V batteries were of two types, those consisting of LIFEPO4 cells with a capacity of 70Ah, 3.2V; although these cells have the same characteristics, they are different in terms of size. The 144V battery is of the PMI1-40S3P-1069 type. It came from the manufacturer mounted on an aluminium chassis and the BMS had already been mounted inside.

The batteries and equipment were mounted on the bench, the connection diagram was the one that the manufacturer indicated as the default.

After mounting was completed, the batteries were charged to 90% capacity and the system was turned on.

Bench mounting began with the batteries, but they were not connected to the system. The first step was to connect the motor to the controller. This is relatively easy because both the motor and the controller are noted in the same way and practically they cannot be confused. The next step was to connect the accelerator pedal, the CAN bus, the main voltage connector, the direction buttons, the ignition key, the DC/DC converter and the battery. All are connected to the controller via the 35-pin AMPSEAL jack according to the manual.

How to connect the controller to the battery and motor is shown in the table below:

Table 2

High Current Connection Test

Terminal	Function
B+	Positive battery to controller
B-	Negative battery to controller
U	Motor phase U
V	Motor phase V
W	Motor phase W

When all the connections have been made the system is powered by the battery from the main voltage switch, one has to wait a few seconds so that the subsystems are supplied correctly then the ignition key can be put in the start position. Even after the ignition has been switched on, a few seconds are necessary for the motor to be used. In this timeframe the controller loads the operating program.

Once the system has started, the configuration is done using a PC or laptop to which a USB 1314 PC Programming Station adapter and Curtis Integrated Toolkit software or Curtis Model 1313 Handheld Programmer have been connected. The destination, vehicle type and battery model must be taken into account when programming. An average or advanced level of knowledge in the field of electric vehicles is required for programming.

It is recommended that when purchasing such a controller, all the necessary equipment be purchased so that the supplier can carry out the initial configuration of the system.

In the tests performed Curtis Model 1313 was used for programming. It can be ordered with four types of connector to the controller, namely: RJ11, 4-Pin Molex, XLR, DB9. The programmer that was used was equipped with a 4-Pin Molex connector.

After configuration, all factory settings were kept as much as possible, no-load currents were measured (motor off), current at 500 rpm and current at 3000 rpm, acceleration time, but this can be changed from the software and the temperature reached by the controller without additional radiator.

The following equipment was used for the system that is powered by the 144V battery:

1. Motor: Asynchronous three-phase electric motor - type AME
2. Battery: PMI1-40S3P-1069

The Sevcon Gen4 controller was used with a 96V 70Ah battery. The installation procedure was almost identical to the one used for the 144v system. The difference is that the CAN bus was not used on this controller. The scheme recommended by the manufacturer, with a single motor, was used for this controller as well. The connection of the accessories to this controller is made using a 35-pin connector, AMPSEAL. Connecting pins are described in detail in the user manual. The configuration of the controller can be done with a PC or laptop to which IXXAT USB-to-CAN compact V2 - Intelligent CAN interface and DriveWizard program are connected. This program is purchased separately and has a license valid for 12 months, after which it must be renewed. When the PC is connected to the controller and the DriveWizard program is used, the controller automatically switches to programming mode and thus the motor is disconnected and the necessary settings can be made for correct operation. Programming can also be done using Clearview Display. This display also has the function of on-board indicator. The level of knowledge required to make vehicles with such a controller is medium to advanced, so it is recommended to be purchased together with the required motor and to be programmed by the supplier.

This controller has been tested with the following equipment:

1. Motor: Motenergy ME-1115 Brushless DC Permanent Magnet Motor - 96V
2. Battery: Lithium LiFePO4 Prismatic Cell 32X3.2V, 70Ah

RESULTS AND DISCUSSIONS

The first tests performed with the equipment were on a test bench that was composed of all devices to be mounted on vehicles. The settings were made for each controller and the system was started. Each controller was configured with the software created by the manufacturer.

Thus the Curtis controller was configured using the 1313 Handheld Programmer terminal and 1314 PC Programming Station. Motor parameters and settings for digital inputs were entered so that the direction change buttons and economy mode are active, the brake input was not used and the power regeneration part was not activated.

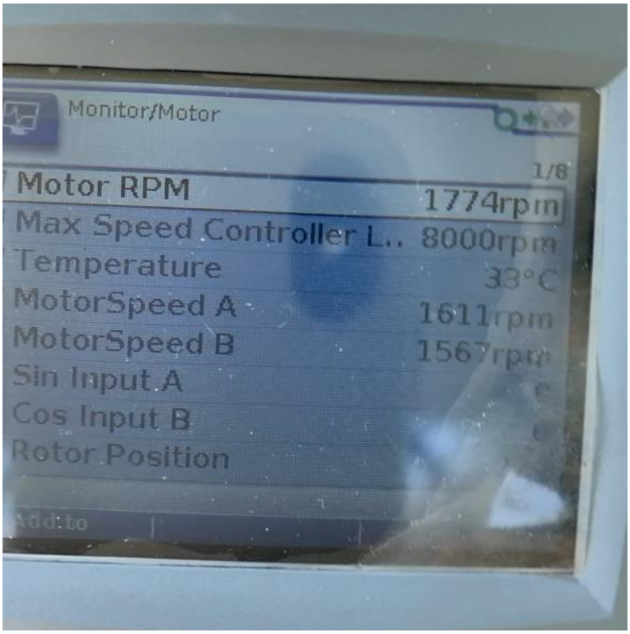

Fig. 7 Settings made with 1313 interface from Curtis

Because the Sevcon Gen4 controller was specially configured by the manufacturer for the ME1115 motor, no changes were made to the motor settings but only to the digital inputs. For configuration can be used the Sevcon Clearview Digital Display terminal or the DVT program, which uses a USB CAN interface to connect the PC and the controller. Unfortunately, the configuration program is not offered free of charge by the manufacturer and has a license valid only for 12 months after which it must be renewed.

The configuration of the motor at Kelly controllers is done automatically, the motor is detected automatically at system start-up, the procedure is simple and it is described in detail in the manual. However, if the motor is not detected, the controller has the possibility to activate the detection protocol whenever necessary. The program used for configuration is offered free of charge by Kelly, it is easy to use and for the communication with the PC a serial adapter (SM-4A to DB9/RS232) is used, which is purchased separately.

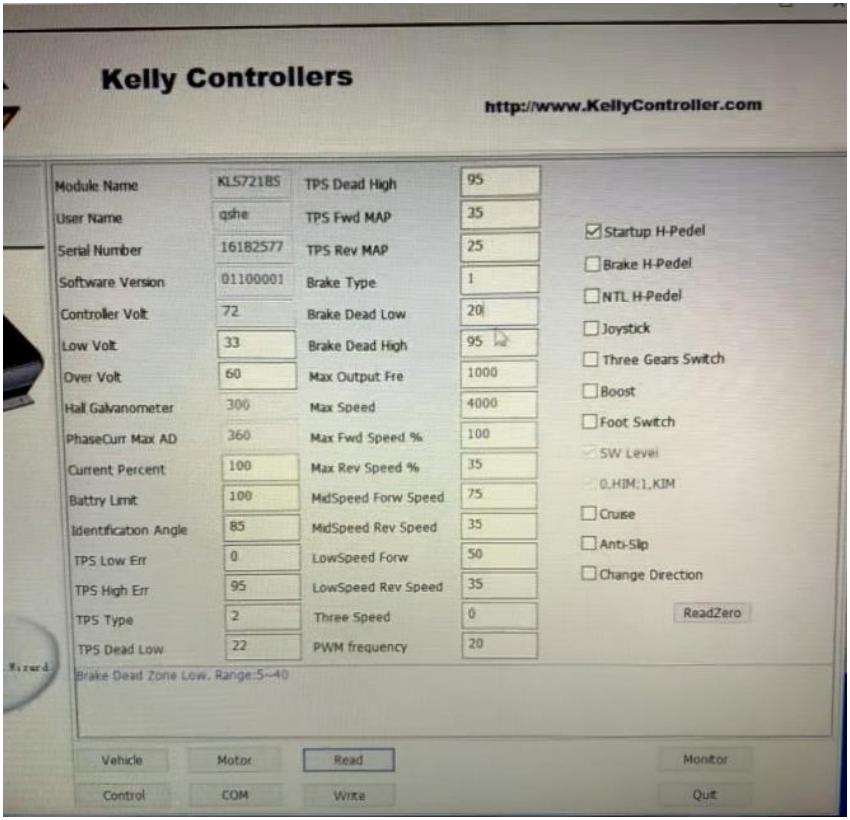

Fig. 8 Kelly Controllers configuration program

Parameters measured in the tests performed on the test bench were:

- Temperature in standby mode
- Temperature at 500 rpm motor speed
- Standby power consumption
- Power consumption at 500 rpm motor speed

The laboratory temperature was measured with a digital thermometer, rotational speed was checked with a digital tachometer and was limited to 500 rpm for work safety reasons. The power consumption was measured with an ammeter connected to the power cable, the plus terminal.

Measurements were performed 30 minutes after the system was powered on.

Fig. 9 Temperature measured in the laboratory

Fig. 10 Motor speed verification

Table 3

Parameters measured in the laboratory test

Controller model / Measured parameter	Curtis 1239e	Sevcon Gen4 72/80V	Kelly KAC 96601 8080I	Kelly KLS 7275
Temperature in standby mode (^{0}C)	20.6	19.8	19.7	19.7
Temperature at 500 rpm motor speed (^{0}C)	30.4	27.6	27.8	26.7
Standby power consumption (A)	1.0	0.8	0.7	0.6
Power consumption at 500 rpm motor speed (A)	1,4	1.2	0.9	0.8

The tests were performed on different chassis in good weather conditions. Tests were performed on straight paved land and towing 1000kg. The tests were performed for 30 minutes and repeated 5 times. The motor speed was limited in this case to 2300 rpm. Consumption is represented by the controller and motor.

The mounting of the controller on the vehicle must be carried out on a flat surface, the fastening being carried out with screws in accordance with those recommended by the manufacturer. That surface must be processed in such a way as to ensure the best possible heat transfer. The power cables from the battery and those that connect to the motor must be multi-wire, as flexible as possible and with a surface area of at least 25 mm^2. The length of the cables must be as short as possible, their route must bypass all possible heat sources or moving parts of the vehicle.

Table 4

Total consumption of controller and motor

Test performed	Curtis 1239e	Sevcon Gen4 72/80V	Kelly KAC 96601 8080I	Kelly KLS 7275
Travel	33 A	35 A	23.6 A	24 A
Towing 1000kg	46 A	49 A	34.2 A	33.9 A
Recorded temperature (^{0}C)	59.4	43.4	41	39.7

Fig. 11 Curtis controller temperature after the towing test

If the controller is mounted on a surface capable of good heat transfer but has no active cooling, when the vehicle is used at an external temperature exceeding 25^{0}C and the power used is over 40% of the maximum motor capacity, the controller may reach high temperatures, above 100^{0}C, and will enter protection state. As a result, the system will not be operational until the temperature drops to normal parameters. Thus, it is recommended to use an active cooling system as those recommended by the manufacturer or even more efficient.

This data was provided by the controllers. The reports were saved using the PC interface, data that was recorded from the controller's internal sensors and was verified with a digital thermometer.

CONCLUSIONS

The pressure to develop new tractor concepts with new roles and tasks will have an impact on field performance. For example, it will be necessary to develop tires, suspensions, engines for high-speed tractors, new types of fuels, etc. For all these directions of evolution, assessments must be made regarding their impact on the field performance of tractors and on the environment.

After all the operations performed, from the installation on the bench to the complete installation of the propulsion system on the chassis, it could be noticed that the installation of such equipment is not accessible to everyone. It requires a relatively rich experience, a number of tools and devices that are intended for these operations.

The choice of an electric propulsion system also depends on the budget allocated for such investments. The solutions presented can cover a fairly wide range of needs. Thus any farmer can choose the solution that is most convenient. The criteria for choosing one system or another must include the costs of purchasing equipment, tools and software but also the technical support that the supplier company can offer and under what conditions.

Currently, the production, integration and use of electric current as fuel, from a financial point of view may seem expensive and inefficient but the long-term calculation shows that, on the contrary, this technology will bring great financial benefits and especially in terms of the impact on the environment.

BIBLIOGRAPHY

1. V.Sindhuja, G.Ranjitham, 2015 - *Regenerative Braking System of Electric Vehicle Driven By BLDC Motor Using Neuro-Fuzzy and PID*, International Journal of Innovative Research in Science, Engineering and Technology (IJIRSET), vol. 3, no. 12, pp. 17847-17854.

2. W. Zhao, G. Wu, C. Wang, L. Yuc, Y. Li, 2019 - *Energy transfer and utilization efficiency of regenerative braking with hybrid energy storage system*, Journal of Power Sources, vol. 427, pp. 174-183.

3. Grigore I., Cristea M., Matache M., Sorică C., Grigore A.I., Vladuțoiu L., Sorică E., Dumitru I., Petre A.A., Cristea R.D., 2020 - *Study on the conversion of a conventional tractor into an electric tractor,* Analele

Universităţii din Craiova, seria Agricultură – Montanologie – Cadastru (Annals of the University of Craiova - Agriculture, Montanology, Cadastre Series)

4. Elsherbiny H., Elsherbiny H., Ahmed M.K., Elwany M.A. 2021 - *Comparative evaluation for torque control strategies of interior permanent magnet synchronous motor for electric vehicles,* Periodica Polytechnica Electrical engineering and computer science, Volume 65, Issue 3, Pag. 280.

5. Jimenez-Gonzalez J, Gonzalez-Montañez F, Jimenez-Mondragon VM, Liceaga-Castro JU, Escarela-Perez R, Olivares-Galvan JC. 2021 - *Parameter Identification of BLDC Motor Using Electromechanical Tests and Recursive Least-Squares Algorithm*: *Experimental Validation*. Actuators. Pag. 143.

6. Punyavathi R., Alagappan P. 2021, - *Study and Investigation of Energy Management Techniques Used in Electric/Hybrid Electric Vehicles* , Journal Européen des Systèmes Automatisés
Vol. 54, No. 4, pp. 599-606

7. Miri I., Fotouhi A., Fotouhi A., Ewin N.b 2021 - *Electric vehicle energy consumption modelling and estimation—A case study*, International Journal of Energy Research, 45(1), pp. 501-520.

8. Li S., Liu M., Xu L. 2021 - *Selection and Analysis of Dual-motor Coupling Device Based on Efficiency Power*, Journal of Physics: Conference Series 1939

9. Deryabin E. I., Zhuravleva L. A. 2020 - *Electric traction drive of an agricultural tractor*, IOP Conf. Series: Earth and Environmental Science 548

10. Amongo R. M. C., Quilloy E. P., Ranches M. A. F., Larona M. V. L., Madlangbayan M. S. 2019 - *Development of an electric hand tractor (e-Tractor) for agricultural operations*, IOP Conf. Series: Earth and Environmental Science 542

11. www.curtisinstruments.com

12. www.borgwarner.com/sevcon

13. kellycontroller.com