THE USE OF ELECTRIC MOTORS FOR THE PROPULSION OF AGRICULTURAL VEHICLES

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This paper presents research on tractor performance parameters to predict tractor performance before operating in the field. The components that make up the electric propulsion control system, the mounting method on the tractor, and a series of experiments that were carried out with the electric motor mounted on the tractor chassis are detailed. The main objective was the integration of an electric motor on an agricultural tractor chassis.

Keywords: Electric tractor, controller, BLDC motor, Li-ion, BMS, Agriculture.

1. Introduction

By using electricity as the main power source, electric tractors eliminate the need for diesel or gasoline, reducing the consumption of non-renewable resources [1]. This shift to electric tractors contributes to a more sustainable and environmentally friendly agricultural sector, as it helps reduce greenhouse gas emissions and decrease dependence on fossil fuels [2]. By transitioning to electric tractors, farmers can play a crucial role in reducing their carbon footprint and promoting a cleaner energy future [3].

Electric tractors offer lower operating costs and increased efficiency compared to traditional diesel tractors. Although electric tractors may have a higher initial purchase cost, they have lower long-term operating and maintenance expenses [4]. Electric tractors require less maintenance, have fewer moving parts, and are more reliable, leading to reduced downtime and increased productivity [5]. In addition, improved control systems on electric tractors increase operating efficiency by reducing battery power consumption and extending continuous operation time [6]. These cost savings and increased efficiency make electric tractors an attractive option for farmers looking to optimize their operations [7].

Adoption of electric tractors also aligns with efforts to reduce air and groundwater pollution [8]. By reducing greenhouse gas emissions, electric tractors help combat global warming and create a more sustainable agricultural sector [9].

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Initiatives such as electric tractor demonstrations and market development programs further support the transition to electric tractors and pollution reduction [10]. Overall, the environmental benefits of electric tractors make them a compelling choice for farmers who want to minimize their environmental impact [3].

2. Essential components of electric tractors

One of the essential components of electric tractors is the battery, which plays a crucial role in powering the vehicle. Compared to traditional diesel engines, batteries have a lower energy density, which means that electric tractors with the same rated power will require more volume and weigh more than their internal combustion engine counterparts [11]. However, advances in battery technology have led to the development of more efficient and powerful batteries specifically designed for electric tractors.

For example, the application of AMBY-supported flywheel batteries has been explored as a new type of power battery for electric tractors, capable of absorbing wasted energy and improving overall efficiency [12]. In addition, research has been conducted on the use of solar-assisted plug-in hybrid electric tractors, which use various battery technologies to improve their performance [13].

Controllers are another essential component of electric tractors, responsible for regulating the tractor's performance. The main function of the electric controller is to collect the driver's operating signals and various sensor signals to control the rotor speed and ensure optimal performance [14]. In addition, controllers can be designed to implement control strategies that distribute the current, maximizing the benefits of power sources [15].

The implementation of slip control solutions in electric tractors has also been explored, aiming to improve traction and stability by automatically adjusting the power supply to the wheels [16]. The integration of advanced control systems into electric tractors enables precise and efficient operation, improving overall performance and productivity [17][18].

Charging systems and infrastructure are vital considerations for electric tractors. Conductive charging, which requires the tractor to be physically connected to a charging station, or battery swapping systems, where depleted batteries are replaced with fully charged ones, are two common charging methods for electric tractors [19]. The availability of charging infrastructure is crucial for the widespread adoption of electric tractors on farms [20].

The development of efficient and affordable charging infrastructure, along with advances in charging technology, will contribute to the successful integration of electric tractors into agricultural operations [21]. In addition, ensuring that electric tractors are fully charged before use is essential to maximize their performance and efficiency [22].

Electric vehicles mainly use two types of motors: direct current (DC) electric motors and alternating current (AC) electric motors.

Direct current (DC) electric motors are the oldest and simplest types of motors used in electric vehicles. They work by feeding a constant electric current into the motor windings, which creates a stable magnetic field.

Alternating current (AC) electric motors are more often used in modern electric vehicles, including electric cars. AC motors offer higher efficiency and more power than DC motors, and are better suited for higher-power applications. These can be either induction (asynchronous) AC motors or synchronous AC motors. Synchronous AC motors offer more precise speed control and potentially greater efficiency, but they require a more complex control system.

It is important to note that these are only the two main types of motors used in electric vehicles.

3. Economic and environmental impact of electric tractors

The adoption of electric tractors in agriculture can result in significant cost savings and long-term financial benefits. While electric tractors may have a higher initial cost compared to their diesel counterparts, they are much cheaper to operate and maintain [23]. According to a case study conducted in 2021 by Future Farming, which compares a diesel-powered vineyard tractor from John Deere, with an electric tractor, MK-V, built by Monarch, used for mowing operations with a total operating time of 1000 hours per year, it was demonstrated that electric tractors can provide fuel savings of up to $2,655.71 per year, along with a reduction of 109.83 kg of CO2e emissions. [24]. These cost savings, along with the potential for government incentives and subsidies, make electric tractors an economically viable option for farmers in the long term. In addition, reduced dependence on fossil fuels can protect farmers from fuel price fluctuations, further enhancing their financial stability.

Electric tractors play a crucial role in reducing greenhouse gas emissions and air pollution associated with traditional diesel tractors. Diesel tractors are a significant source of carbon dioxide (CO_2) emissions and other harmful pollutants. By switching to electric tractors, farmers can help reduce greenhouse gas emissions and improve air quality in their communities [2]. Government programs provide financial support to farmers to purchase cleaner and more durable equipment, including electric tractors [25]. Widespread adoption of electric tractors can have a substantial impact on reducing carbon emissions and mitigating climate change [26]. For example, Frito-Lay Modesto's transformation resulted in a 91% reduction in greenhouse gas emissions from their fleet [27]. By choosing electric tractors, farmers can actively contribute to a healthier and more sustainable environment.

Electric tractors are part of a wider movement towards sustainable farming practices. [28]. Electric tractors offer a solution by creating a more sustainable future in agriculture [29]. By reducing their reliance on fossil fuels, farmers can minimize their carbon footprint and promote renewable energy solutions [30]. Sustainable agricultural practices, including the use of electric tractors, promote environmental stewardship and ensure the long-term viability of farmland [31]. The adoption of electric tractors not only benefits farmers financially, but also contributes to the overall health of the ecosystem and communities they serve.

4. Case Study: Mounting the Electric Drive System to the Chassis

This case study describes how to mount an electric propulsion system on an agricultural chassis.

The simplest case is when the chassis exists and there is already a thermal engine mounted on it. The existence of the thermal engine is helpful because, in this way, we can choose the future engine that will equip the chassis. The simplest criterion for deciding on the electric motor is that it has a power close to, if not equal to, that of the thermal engine. Another characteristic is the torque, which must be very close in value to that generated by the thermal engine.

One of the reasons why the two motors must have roughly the same characteristics is that with the existing heat engine, there are a number of auxiliary systems that are attached to the engine and have operating characteristics designed for them. For example, the power steering pump or the hydraulic pump intended for machines that are towed have maximum speeds that cannot be exceeded. Also, if the existing gearbox on the tractor is used, it is designed for certain maximum torque values.

The chassis chosen for the experiments was that of a vegetable tractor, equipped from the factory with a gasoline-powered thermal engine with a maximum developed power of 14 kW (Fig.1).

Fig. 1. Vegetable chassis with battery mounted

The chassis has been slightly modified to accommodate the battery, but a new motor mount has also been designed, allowing it to be mounted or removed easily.

The engine was coupled to the gearbox by means of an elastic coupling specially designed and made to fit the engine and gearbox.

After mounting the motor and battery, all the necessary control and monitoring devices for the propulsion system were installed. Among these, we mention the charger, the connection box (Fig. 2), the 12 V battery, and the accelerator pedal.

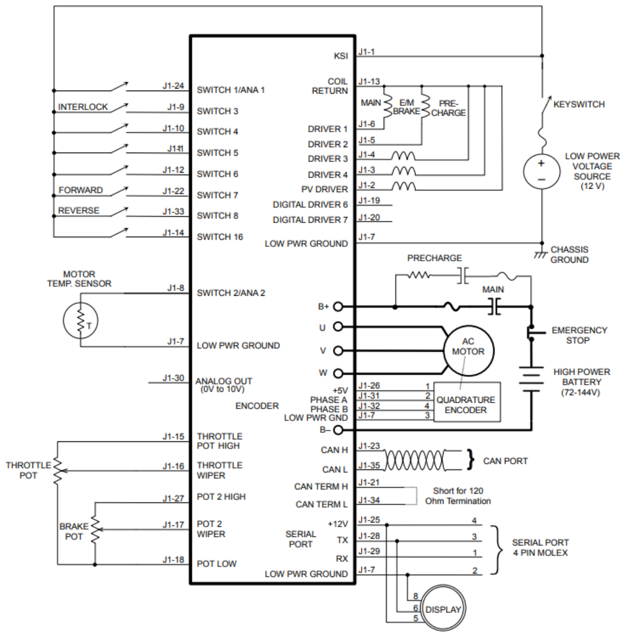


Fig. 2. Electrical wiring diagram provided by Curtis Instruments [32]

To make the connections between the devices that made up the propulsion system, the schemes provided by the manufacturers on the Internet were used at no additional cost.

After mounting all the devices and making the connections, the system was started, and the experiment went to the next stage: configuring the controller for the mounted motor and configuring communication on the CAN bus between the controller, BMS, and charger. Configuration was done using dedicated interfaces and software created by each individual manufacturer.

Solutions from Curtis Instruments and BMS manufacturer Orion were used for the configuration. The Model 1313 handheld programmer was used for the motor controller, and the USB CAN interface was from Orion.

The program used was the CANdapter Utility Suite for configuring the BMS, which can be downloaded for free from www.ewertenergy.com.

Cheaper solutions can be used to configure the system. These are made using Arduino or Raspberry Pi development boards, to which CAN interfaces are attached. When such solutions are used, a higher degree of knowledge and above average experience in using these boards is required.

After all the electronic devices were configured and checked to ensure that they had the correct parameters, the tractor was subjected to a series of tests.

5. Experiments made with the tractor

The experiments with the electric drive tractor were particularly focused on the analysis of the data provided by the control devices in the drive system in various real-world situations and the operation mode of the loading devices.

Test conditions: maximum rotor speed 2300 rpm, maximum torque (from the motor characteristics chart) approximately 200 Nm, flat asphalt or stubble ground, ambient temperature 24-27 ºC, humidity 40-60 %, wind speed 1-1.2 m/s, maximum travel speed 15 km/h (Fig.3). Note that such an electric vegetable tractor chassis does not have a hydraulic pump installed and as a result cannot be used with machinery that requires power hydraulic power from the tractor.

Figures 4 to 7 show a small part of the data that is saved by the propulsion system and is used only as an example of the use of the technical solutions that are available to the user for controlling the devices that make up the electric propulsion.

Fig. 3. The electric tractor on the test track within INMA Bucharest

The tests were carried out at INMA Bucharest on a track specially set up for off-road testing of agricultural vehicles.

Operating parameters were recorded by SD memory cards, which are fitted to the BMS and motor controller.

The files generated by BMS are of the form "name_file.odl" which has saved the date and time. These files can be viewed by the Orion BMS 2 Software Utility program (Fig.4), which has the possibility to convert these files into the "file_name.csv" format. These converted files can be used with the program created by Microsoft, Excel.

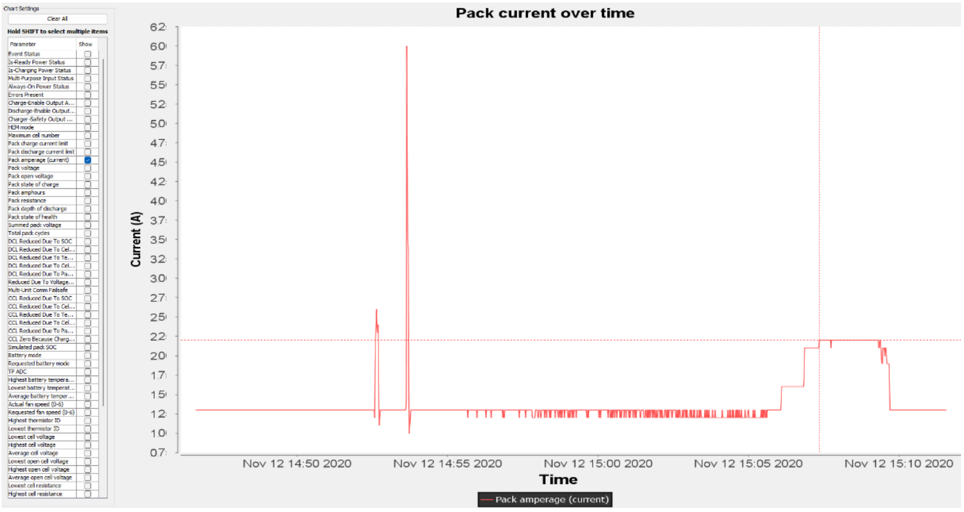


Fig. 4. Example of displaying an "odl" file directly with the program created by Orion

Entering the "CSV" file into Microsoft Excel results in a table like the one in figure 5. It is possible that because of using the regional packages of the Office suite, for example, Romanian or English, values in Excel are "n" times higher than in reality. The data must be verified before processing.

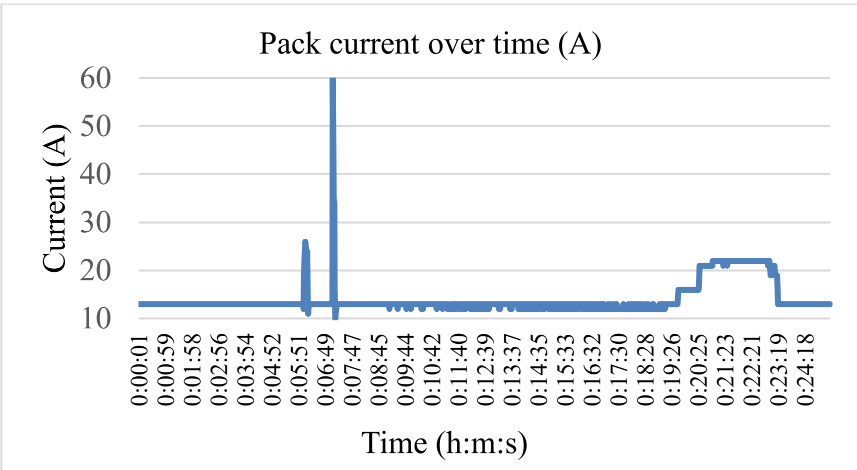
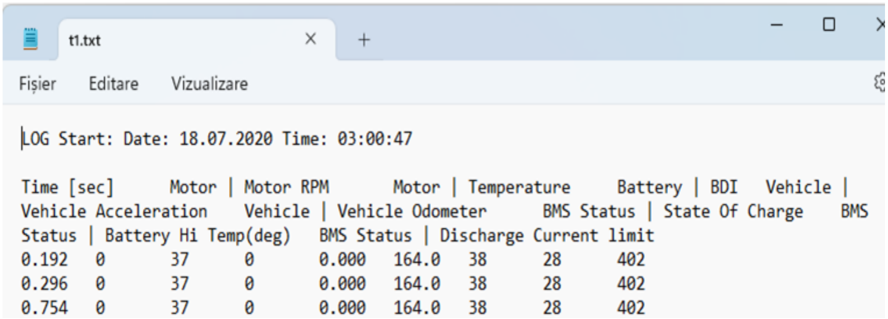


Fig. 5. Example of a "csv" file shown in Microsoft Excel program

The interface with the motor controller saves parameters during operation in the form of "file_name.xls" but practically after the files have been copied to a computer, they can be renamed without problems to "file_name.txt" and thus can be read with any text editor (Fig.6).


t1.txt
Fişier Editare Vizualizare

LOG Start: Date: 18.07.2020 Time: 03:00:47

Time [sec]	Motor | Motor RPM	Motor | Temperature	Battery | BDI	Vehicle | Vehicle Acceleration	Vehicle | Vehicle Odometer	BMS Status | State Of Charge	BMS Status | Battery Hi Temp(deg)	BMS Status | Discharge Current limit
0.192	0	37	0	0.000	164.0	38	28	402
0.296	0	37	0	0.000	164.0	38	28	402
0.754	0	37	0	0.000	164.0	38	28	402

Fig. 6. Example file generated by the 1313 interface from Curtis

After the text file is inserted into an XLS file, we can process the data and find out, for example, the variation of the voltage on the motor, the variation of the current through the motor coil, or the variation of the generated torque.

Devices in the propulsion system perform parameter saving every second. When the travel time is higher, it is possible that the high number of lines in the table is too large to work with Excel; therefore, there are solutions that can do the work with these files more easily. One can use Python 3.8.10 with pandas and datetime libraries to read "CSV" files, and the output for the same file is shown in figure 7.

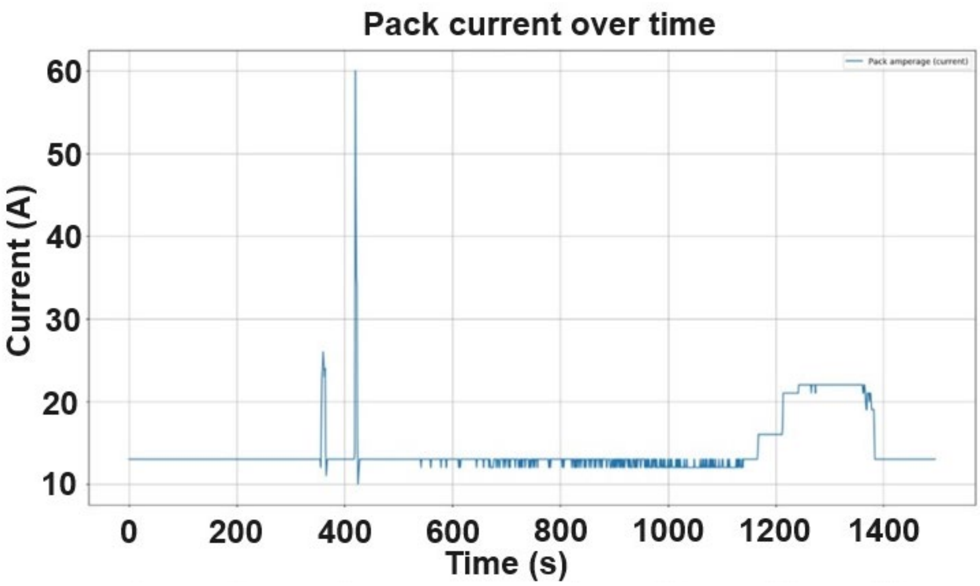


Fig. 7. Example of data processing using the high-level programming language Python

The most important parameters that are recorded are: battery voltage, battery current, number of cells, cell temperature, cell operating status, rotor speed, motor temperature, current through the rotor coil, and voltage at the motor terminals.

When all these variables are known, the transmission characteristics and wheel radii can be calculated, and the required parameters are of research interest.

To calculate the moment reaching the wheel from the motor, the following relation is used [33]:

$$T_\omega = i_g i_0 \eta_t T_p \quad (1)$$

Knowing the relationship of traction force:

$$F_t = \frac{T_\omega}{r_d} \quad (2)$$

If we substitute relation (2) into (1) we have the traction force:

$$F_t = \frac{T_p i_g i_0 \eta_t}{r_d} \quad (3)$$

To find out the travel speed:

$$V = \frac{\pi N_\omega r_d}{30} \quad (4)$$

or:

$$V = \frac{\pi N_p r_d}{30 i_g i_0} \quad (5)$$

Where: T_ω is the torque reaching the wheel [Nm];
i_g is the gear ratio to the rear differential;
i_0 is the gear ratio of the rear differential;
T_p is the torque from the motor [Nm];
η_t is the transmission efficiency [%];
F_t is the traction force [N];
V is the travel speed [m/s];
r_d is the radius of the deformed wheel [m];
N_p is the motor rpm [rpm];
N_ω is the wheel rpm [rpm];

When all the known data is substituted in the above relations the following variables can be calculated: V, F_t, N_ω, T_ω and η_t=95%. The results are presented in the table1

Table 1

Calculation of the wheel rotation speed, travel speed, wheel torque and traction force as a function of engine speed.

N_ω (rpm)	T_ω (Nm)	F_t (N)	i_g	i_0	T_p (Nm)	V (m/s)	r_d (m)	N_p (rpm)
7,57	9097,79	7278,23	5,8	11,38	142,1	0,991	1,25	500
15,15	8982,55	7186,04	5,8	11,38	140,3	1,983	1,25	1000
22,72	8822,49	7057,99	5,8	11,38	137,8	2,974	1,25	1500
30,30	8636,82	6909,45	5,8	11,38	134,9	3,966	1,25	2000

In order to determine the actual energy consumption of the battery, an 800 m route was carried out on a flat asphalted ground with a 2000 kg trailer for 5 minutes. The average speed of the tractor recorded with the help of a GPS was 9 km/h. The results that were recorded by the BMS, the voltage and current variation, are shown in the figure 8.

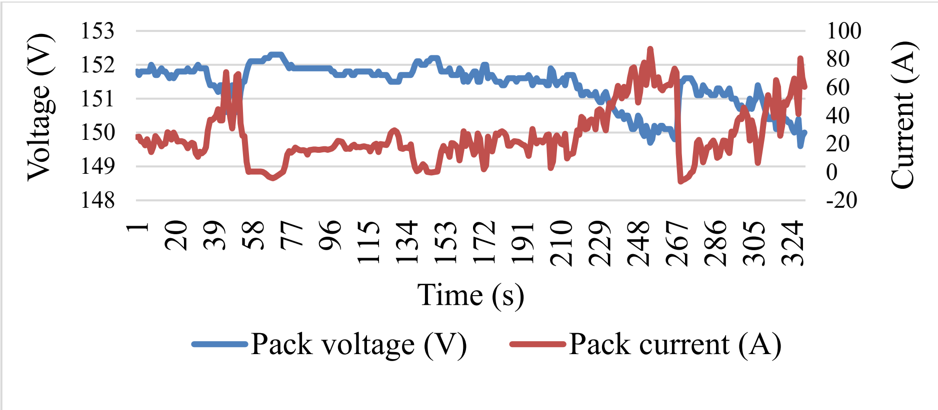


Fig. 8. Variation of voltage and current during the movement of the electric tractor with a load of 2000 kg.

Knowing the values by which the voltage and current that is supplied to the electric motor of the tractor varies, the power that was supplied by the battery during the movement can be determined. Figure 9 shows the graph with the power variation calculated using the data saved in the BMS memory.

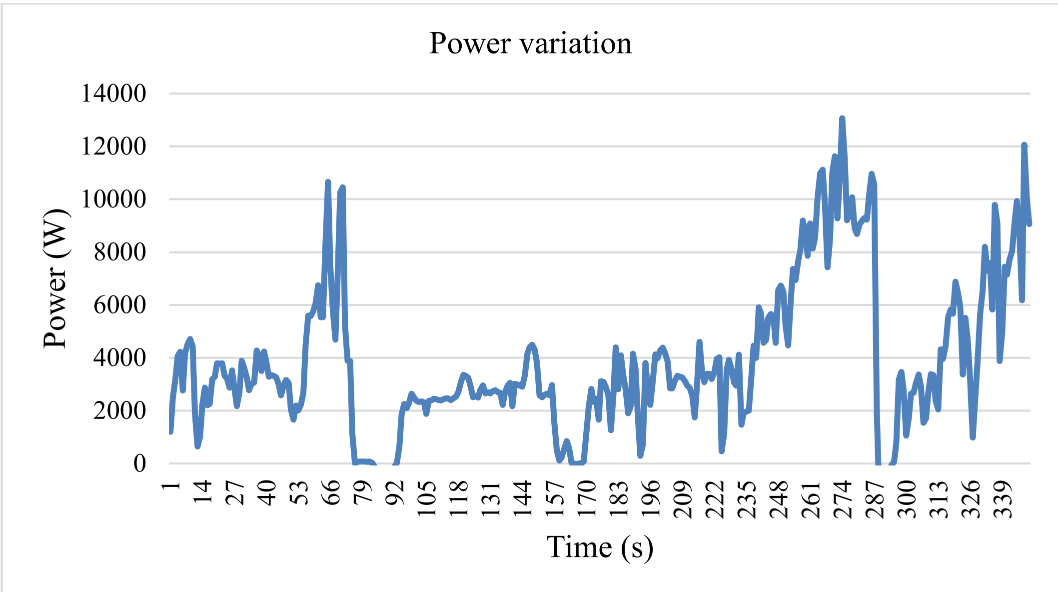


Fig. 9. The variation of the power supplied by the battery while driving for 5 minutes

Thus, with the help of the data recorded by the electric propulsion system, it is possible to optimize the parameters so that the results we want are obtained.

Using the consumption information, greater autonomy can be achieved, or the system can be configured to use more energy when needed.

In the experiments carried out with the chassis of the vegetable tractor, on which a 16 kW motor powered by a 17 kW Li-ion battery was mounted, the result was a maximum autonomy of 5 hours without load and 3.6 hours with a load of 2000 kg.

In figure 10 it is shown the charging graph, when the battery is charging the current is shown with negative values.

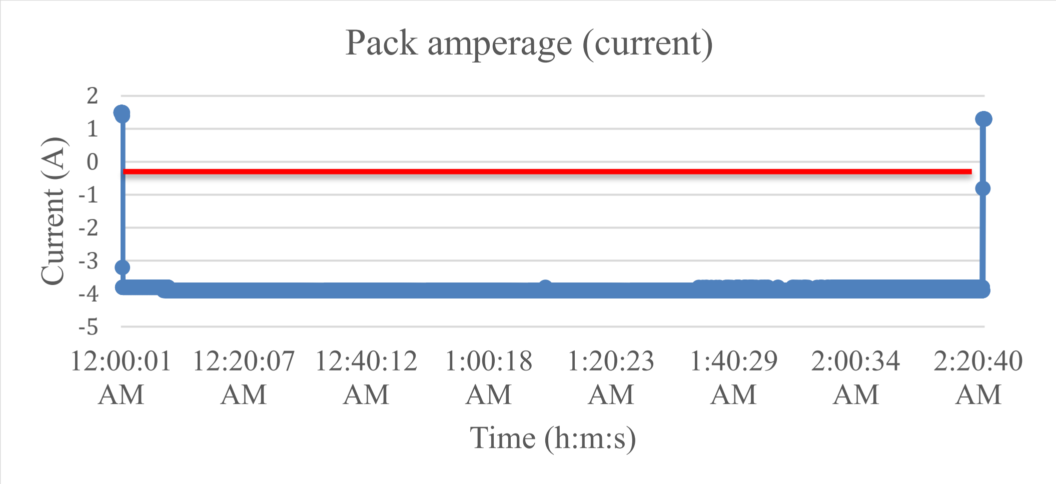


Fig. 10. The amperage graph of the tractor when it is powered from 220v with 32 A

The charging time depends a lot on the network through which it is powered. If it is powered by 220 V and 6 A, the maximum charging time is about 12 hours, but it drops to 3 hours if it is charged by 220 V and 32 A.

6. Conclusions

In conclusion, electric tractors offer numerous benefits that make them a viable and sustainable option for modern farming practices. Reduced reliance on fossil fuels not only lowers operating costs but also increases efficiency. The use of batteries and controllers allows precise control and adjustment of the tractor's performance. In addition, the economic and environmental impact of electric tractors cannot be overlooked. The cost savings and long-term financial benefits make them an attractive option for farmers. In addition, reducing greenhouse gas emissions and air pollution contributes to a healthier environment and promotes sustainable agricultural practices. Overall, electric tractors have the potential to revolutionize the agricultural industry and pave the way for a greener and more sustainable future. At this moment, the production, integration, and use of electric current as a 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, especially from the point of view of the impact on the environment.

Environmental concerns are becoming an increasingly important topic for modern man. It's only a matter of time before internal combustion engine vehicles are overshadowed by electric vehicles.

REFERENCES

[1] *P. Kan-Rice*, ”Electric tractors reduce carbon emissions at research and extension centers”, News for UC Agriculture & Natural Resources employees, Aug. 29, 2022.

[2] *P. Knox*, ”Electric tractors and battery-powered tools will reduce emission of greenhouse gasses and air pollution”, University of Georgia Extension, Apr. 18, 2023.

[3] *M. Iyer*, ”Electrifying Tractors: Good for the Community, Good for the Consumer, Good for the Earth”, Advanced Clean Tech News, Apr.13, 2022.

[4] ”Global Electric Farm Tractor Market to Reach $234.0 Million by 2028”, https://www.reportlinker.com/p06467469/Electric-Farm-Tractor-Market-A-Global-and-Regional-Analysis-Focus-on-Product-Application-Adoption-Framework-Startup-Patent-Value-Chain-and-Country-Wise-Analysis-Analysis-and-Forecast.html?utm_source=GNW, (accesed Jul. 10, 2023).

[5] ”Germany Electric Farm Tractors Market Trends, Competitive Analysis and Forecasts Report 2023-2028 Featuring AGCO, CNH, Deere & Co, Kubota, Solectrac, & Escorts Among Others”, https://www.businesswire.com/news/home/20230607005633/en/Germany-Electric-Farm-Tractors-Market-Trends-Competitive-Analysis-and-Forecasts-Report-2023-2028-Featuring-AGCO-CNH-Deere-Co-Kubota-Solectrac-Escorts-Among-Others---ResearchAndMarkets.com (accesed Jul. 11, 2023).

[6] *J. Liu, C. Xia, D. Jiang, G. Shang, J. Han, Y. Sun*, ”Determination and Application of Maximum Efficiency Curve of Crawler Electric Tractor Motors”, Hindawi, Mathematical Problems in Engineering, vol. 2021, Dec. 23, 2021.

[7] *N. Nitta*, ”Could Electric Tractors Revolutionize Farming?”,| Smithsonian magazine, Apr. 19, 2023.

[8] *N. Sasakova, G. Gregova, D. Takacova, J. Mojzisova, I. Papajova, J. Venglovsky, T. Szaboova, S. Kovacova*, ”Pollution of Surface and Ground Water by Sources Related to Agricultural Activities”, Frontiers in Sustainable Food Systems, vol. 2, Jul. 27, 2018.

[9] ”Why Should You Use Eco-Friendly Tractor?”, https://sites.google.com/view/switch-to-eco-friendly-tractor (accessed Jul 11, 2023)

[10] ”Electric Tractor Demonstration Supports Market Development and Pollution Reduction”, https://www.caclimateinvestments.ca.gov/2021-profiles-1/2021/4/27/advanced-technology-demonstration-and-pilot-electric-tractor-development-amp-demo-san-joaquin-valley (accesed Jul 12.2023)

[11] *D. L. Bessette, D. C. Brainard, A. K. Srivastava, W. Lee, S. Geurkink*, ”Battery Electric Tractors: Small-Scale Organic Growers’ Preferences, Perceptions, and Concerns”, MDPI vol. 15, Energies 2022, Nov. 15, 2022.

[12] *B. Liu, Y. Hu, X. Lyu, W. Fan, K. Zheng*, ”AMB-Supported Flywheel Battery for Electric Tractors: Structure Design and Driving Method”, IOP Publishing Ltd, Journal of Physics: Conference Series vol. 2477, Nov. 27, 2022.
[13] *H. Mousazadeh, A. Keyhani, A. Javadi, H. Mobli, K. Abrinia, A. Sharifi*, ”Evaluation of alternative battery technologies for a solar assist plug-in hybrid electric tractor”, ELSEVIER Transportation Research Part D: Transport and Environment, vol. 15, Dec. 2010, p. 507-512.
[14] *S. Yin, P. Mao, W. Li,* ”A Method for Electric Tractor Molding Based on Terminal Sliding Mode Control Algorithm”, MDPI World Electr. Veh. J. 2023, vol. 14, Apr. 3, 2023.
[15] *H. Yang, Y. Sun, C. Xia, H. Zhang*, ”Research on Energy Management Strategy of Fuel Cell Electric Tractor Based on Multi-Algorithm Fusion and Optimization”, MDPI Energies 2022, vol. 15, Sep. 1, 2022.
[16] *R. Regis de Melo, F. L. Tofoli, S. Daher, F. L. M. Antunes*, ”Wheel Slip Control Applied to an Electric Tractor for Improving Tractive Efficiency and Reducing Energy Consumption”, MDPI sensors, vol. 4527, Jun 22, 2022.
[17] ”Electronic equipment controls guiding tractor of tomorrow”, https://www.farmprogress.com/farming-equipment/electronic-equipment-controls-guiding-tractor-of-tomorrow (accessed Feb. 03. 2023).
[18] *M. Liu, C. Wei, L. Xu*, ”Development of Cooperative Controller for Dual-Motor Independent Drive Electric Tractor”, Hindawi, Nov. 12, 2020.
[19] *O. Lagnelov, G. Larsson, D. Nilsson, A. Larsolle, P.A. Hansson*, ”Performance comparison of charging systems for autonomous electric field tractors using dynamic simulation”, ELSEVIER Biosystems Engineering, vol. 194, Jun. 2020, p 121-137.
[20] *K. M. Kowalski*, ”Weight, dawn-to-dusk demands pose challenges to electrifying farm vehicles”, Energy news network, Aug. 18, 2021.
[21] *A. Rahman, A. H. Jaafar*, ”Development of Rapid Charging System for EV Battery”, International Journal of Recent Technology and Engineering, vol. 7, Mar. 2019.
[22] *M. Kopier*, ”Charged up to feed the world”, OEM Off-Highway Drivetrains, Apr. 20, 2015.
[23] *S. Kilcarr*, ”Calculating the costs and savings of electric trucks”, FleetOwner, Sep. 20, 2016.
[24] ”Electric tractor saves Wente Vineyards $ 2,600 per year”, https://www.futurefarming.com/tech-in-focus/electric-tractor-saves-wente-vineyards-%E2%80%892600-per-year/ (accessed Jun 05.2023).
[25] ”FARMER Program to help farmers upgrade equipment, reduce pollution”, https://ww2.arb.ca.gov/news/farmer-program-help-farmers-upgrade-equipment-reduce-pollution (accessed Jul. 04.2023)
[26] ”Biden-Harris Administration Proposes Strongest-Ever Pollution Standards for Cars and Trucks to Accelerate Transition to a Clean-Transportation Future”, https://www.epa.gov/newsreleases/biden-harris-administration-proposes-strongest-ever-pollution-standards-cars-and (accessed Jul. 05.2023).
[27] ”Frito-Lay Transforms California Facility into Showcase for Sustainability”, https://www.prnewswire.com/news-releases/frito-lay-transforms-california-facility-into-showcase-for-sustainability-301725247.html (accesed Jul. 06.2023).
[28] ”What is Sustainable Agriculture?”, https://sarep.ucdavis.edu/sustainable-ag (accesed Jul. 06.2023).
[29] ”WHAT MAKES FOR THE BEST ELECTRIC FARM TRACTOR?”, https://www.powerproequipment.com/brands/what-makes-for-the-best-electric-farm-tractor (accessed Jul. 05.2023).
[30] *K. E. Nagieb*, ”Harnessing the Sun: Solar-Powered Tractors and Harvesters Shaping Sustainable Agriculture”, Linkedin, Jun. 12, 2023.
[31] ”What is Sustainable Agriculture?”. https://www.ucsusa.org/resources/what-sustainable-agriculture (accesed Jul.07.2023).

[32] “1239E_datasheet”. https ://cdn.curtisinstruments.com/ products/ datasheets/ 1239E_ datasheet_en.pdf (accesed Jul.07.2023).
[33] *M. Ehsani, Y. Gao, S. E. Gay, A. Emadi*, ”Modern Electric, Hybrid Electric, and Fuel Cell Vehicles”, CRC Press, 2005.