ELECTRIC DRIVE SYSTEM POWERED BY Li-ION BATTERIES FOR AQUATIC BIOMASS HARVESTER

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SISTEM DE ACȚIONARE ELECTRICĂ PENTRU ECHIPAMENT DE RECOLTAT BIOMASA ACVATICA, ALIMENTAT DIN BATERII Li-ION

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DOI: https://doi.org/10.35633/inmateh-69-58

Keywords: *electric harvester, specific energy consumption, mixed load, efficiency*

ABSTRACT

The development of an electric vehicle harvester for aquatic vegetation is a technical challenge for researchers due to specific requirements: high-torque operation at low travel speeds, high maneuverability, high load capacity, low draught, and affordable price. The collective of authors proposed an electro-hydraulic architecture based on paddles driven by hydraulic motors for propulsion and auxiliary services also driven by motors and hydraulic actuators. The proposed energy source for the aquatic harvester is electric batteries, it was developed a system of 33 kWh Li-Ion batteries connected in parallel, which power an electronic converter and a 14.5 kW rated power electric motor that drives a hydraulic double-circuit pump. The vehicle can be controlled remotely. The paper presents the prototype made and the results obtained during laboratory tests performed for the electric powering system.

ABSTRACT

Dezvoltarea unui echipament electric pentru recoltat biomasa lacustră reprezintă o provocare tehnică pentru cercetători, datorită cerințelor specifice: operare cu cuplu ridicat la viteze mici de deplasare, manevrabilitate ridicată, capacitate mare de încărcare, pescaj redus și preț abordabil. Colectivul de autori a propus o arhitectură electro-hidraulică bazată pe zbaturi antrenate de motoare hidraulice pentru propulsie și de servicii auxiliare acționate tot cu motoare și cu actuatoare hidraulice. Sursa de energie propusă pentru echipamentul de recoltat biomasa acvatica fiind bateriile electrice, a fost dezvoltat un sistem de baterii de 33 kW tip Li-Ion conectate în paralel care alimentează un convertizor și un motor electric de 14,5 kW putere nominală care antrenează o pompă hidraulică cu dublu circuit. Vehiculul poate fi comandat de la distanță. Lucrarea prezintă prototipul realizat și rezultatele obținute în timpul testelor de laborator efectuate pentru sistemul de acționare electrică.

INTRODUCTION

The main objective of this article is to describe the electric drive of an electric-powered aquatic harvester, underlining key features, technical solutions, novelty, and benefits of the proposed architecture.

The aquatic harvesters are used mainly for eliminating the weed developed alongside the lake shores, restricting navigation, and worsening the water for the fish (*Waltham, et al., 2020*).

According to specific literature, weed infestation, such as microalgae, phytoplankton underwater vegetation, and floating vegetation represents an additional oxygen-consuming load on water bodies, that in situations of low daytime photosynthesis, cannot be compensated by the natural oxygenation process, leading to a saturation of zero percent oxygen in the water body.

Several harvesters were developed previously, most of them based on Diesel power, which could be replaced by electric-powered vehicles to improve environmental care (*Marin and Biriș, 2021*). For larger harvesters, the diesel-hydraulic solution is usually used. Even though these kinds of machines fulfill their role as harvesters very well, the polluting factor and costs of diesel fuel cannot be ignored.

For small lake needs, the most suitable solution is, where the electric drive was noticed, the remote operation, and the fact that the harvester can be transported with a regular trailer attached to a normal car. Still, this solution is not able to cut the weed on the lakes, which is the major challenge in maintaining a clean and open lake or river.

Speaking about electrical-operated ships *(Athina, et al., 2022*), one can find that the electric harvester can have built-in sensors for sensing the quality of the water, and, based on the information provided, can perform automated tasks to clean the water until a specified quality is attained.

An electric drive for a boat must contain the same components as an electric drive for cars, mainly electric energy storage, an electronic power converter, one or several electric motors, and mechanical converters such as hydraulic pumps, gearboxes, and actuators *(Sonam, et al., 2016),* (*Un-Noor, et al., 2017*).

Some researchers are implementing a fuel-cell range extender based on hydrogen, similar to the surface EV solutions *(Shigeyuki, et al., 2019).* The authors claim an energy capacity of 65 kWh which can power a 2.6-tone boat for 13 hours at a speed of 8 km/h.

The solution for weed harvester propelling is the one that uses paddles for pulling the boat, instead of a normal propeller, mainly because high torque can be obtained at low speed *(Pratama and Hesty, 2019).*

To drive the paddles at low rotational speed, the most suitable solution is to use hydraulic motors instead of electric motors *(Yun, et al., 2016).*

Boats using electric drives for propulsion are seldom used, especially special boats with particular needs, such as the towing boat *(Moussodji and De Berdarditis, 2015)* which has a power converter that operates the bow thrusters to ensure fine maneuverability in stationary water.

The crop harvesters are using the remote control, especially when they want to optimize the crop field route, and when using multiple synchronized harvesters *(Juostas and Jotautiene, 2022)*.

One of the key features that electric drive is endorsing is the diagnosis of the system, online and offline, and even remote diagnosis which can be performed by a specialist located in the office and connected with the harvester by GSM data *(Gong, et al., 2021).*

The energy storage system recommended to be used by the EV industry is the Li-ION batteries, especially those which are providing compliance with the R100 EU rules of safety and are suitable for use in electric boats, as well *(Zhicheng, et al., 2019).*

The solution to extending the range of the vehicle is the multiplication of the used batteries. The classic solution for small voltage and high energy is the parallel connection of the Li-Ion packs *(Lv, et al., 2019).*

Within the paper, is presented a proposed electro-hydraulic architecture based on paddles driven by hydraulic motors for propulsion and auxiliary services also driven by motors and hydraulic actuators. The work presents the main electrical components of the prototype and their corresponding laboratory tests.

MATERIALS AND METHODS

The selected solution was comprised of an electric motor powered by a power inverter supplied from several Li-Ion energy storage batteries, connected to a hydraulic pump with two circuits, one serving for paddles control via a hydraulic double circuit proportional distributor, and the latter for auxiliary services, as cutting, loading, and orientation. The solution can be seen in Figure 1.

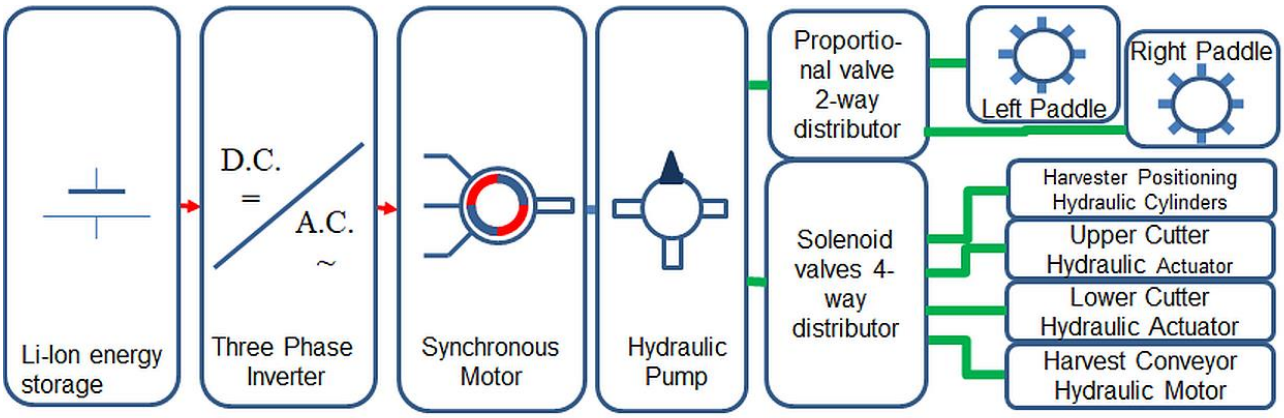


Fig. 1 - The principle of operation of the aquatic harvester

The harvester has to be controlled using a remote control board that provides special controls for the throttle (linear forward and backward, with two independent channels), and on-off switches for auxiliaries. Some low-level diagnose have to be available remotely.

Dimensioning of the equipment is thoroughly described in *(Tudor, et. al., 2022)*. The energy storage battery type Li-Ion consists of three packs previously homologated for hybrid trucks, parallel-connected for larger energy capacity (33kWh) while maintaining a low battery voltage (<60 Vdc). The proposed autonomy of the boat is 90 minutes of operation. The three-phase inverter and the interior permanent magnet synchronous motor IPSM are designed to be used on electric boats operating at less than 60 Vdc nominal voltage. The hydraulic pump has two circuits, one for propelling the boat paddles and one for auxiliary services.

The harvester has three main operating modes:

- Harvesting, with throttle active at low speed and high torque, and with cutting and loading active;
- Transfer, with the full throttle active, based on continuous regulation of the right and of the left paddle in order to control the direction;
- Charging, with throttle and auxiliary inactive.

For modes of Harvesting and Transfer, the electric motor has to be controlled at a steady speed, while the load is controlled by the hydraulic system using the proportional valves and the solenoid valves, as requested. The motor shall be started by an individual command from the remote control panel.

Charging is adapted to use a single-phase 6 kW supply, which is available more often near the lake shores than the three-phase 22 kW ones. The charger must be placed on the dock, thus keeping only the ultra-low voltage on the boat, and avoiding the dangerous voltage (230 Vca).

Furthermore, the load capacity of the harvester must be better than 2 m^3 of biomass, assuming that a payload of 400-500 kg of aquatic vegetation is loaded.

RESULTS

Li-ION Batteries for Energy Storage

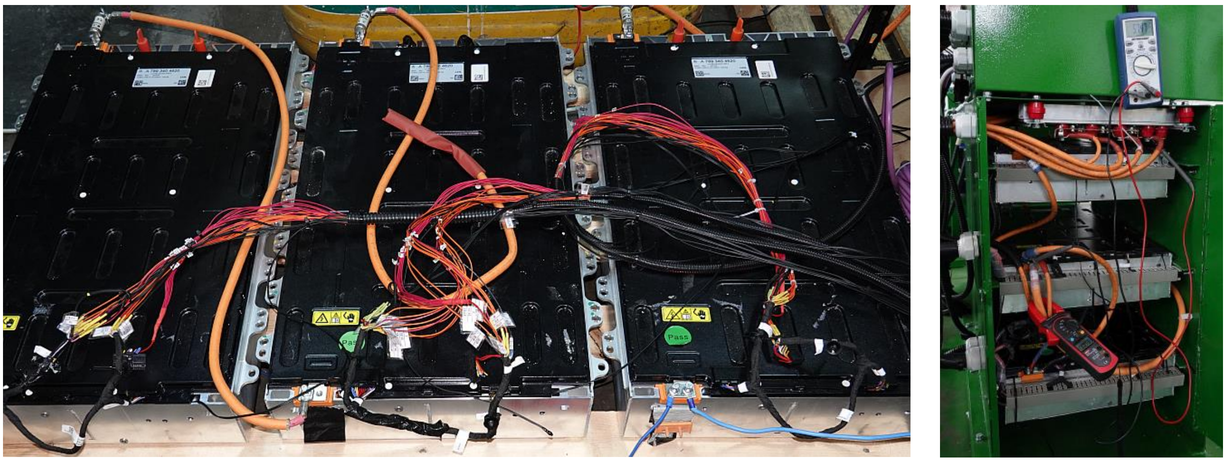
Based on autonomy requirements and the estimator of the needed power for harvesting, some packs developed for mild hybrid trucks were selected from the available REESS batteries, with these characteristics:

Table 1

REESS module characteristics

Open-circuit voltage V_0	58.7 Vdc
Rated capacity C	188 Ah
Rated energy stored E_0	11 kWh
Mass	51.7 kg
Rated cell voltage V_{c0}	3.67 Vcc
Max/min cell voltage	4.2 Vdc / 2.5 Vdc
Dimensions Lxlxh	643x372x116 mm

One pack consists of 2 parallel prismatic modules of 3.72 Vdc and 94 Ah, 16 of those being series connected. The modules are placed on an aluminum case providing liquid cooling. The top of the pack is covered with a black plastic sheet. The power connections are made using two plates.



a. b.

Fig. 2 - The batteries for energy storage during lab testing and the final assembly during the indoor test

There are several solutions for cell charge balancing, charging and discharging control, overheating overvoltage, and under-voltage. There are named, globally, as BMS systems (Battery Management Systems). In our application, three dependent units are used, each one for its battery, especially for redundancy. The BMS are using some DC contactors, current transducers, and thermistors to connect with the battery. There are located inside a cubicle separated from the batteries but located nearby (Figure 3a.).

Also, for the battery charger was selected a solution with one 6.6kW external charger, connected using a DC line and serial and control communication link. The charger is presented in Figure 3b.

a. b.

Fig. 3 - The BMS cubicle and the DC charger

The experiments with the battery pack were performed in the lab with the devices connected on a test bench supplied by a bidirectional converter able to perform charging and discharging (cycler). The results are presented in Figure 4.

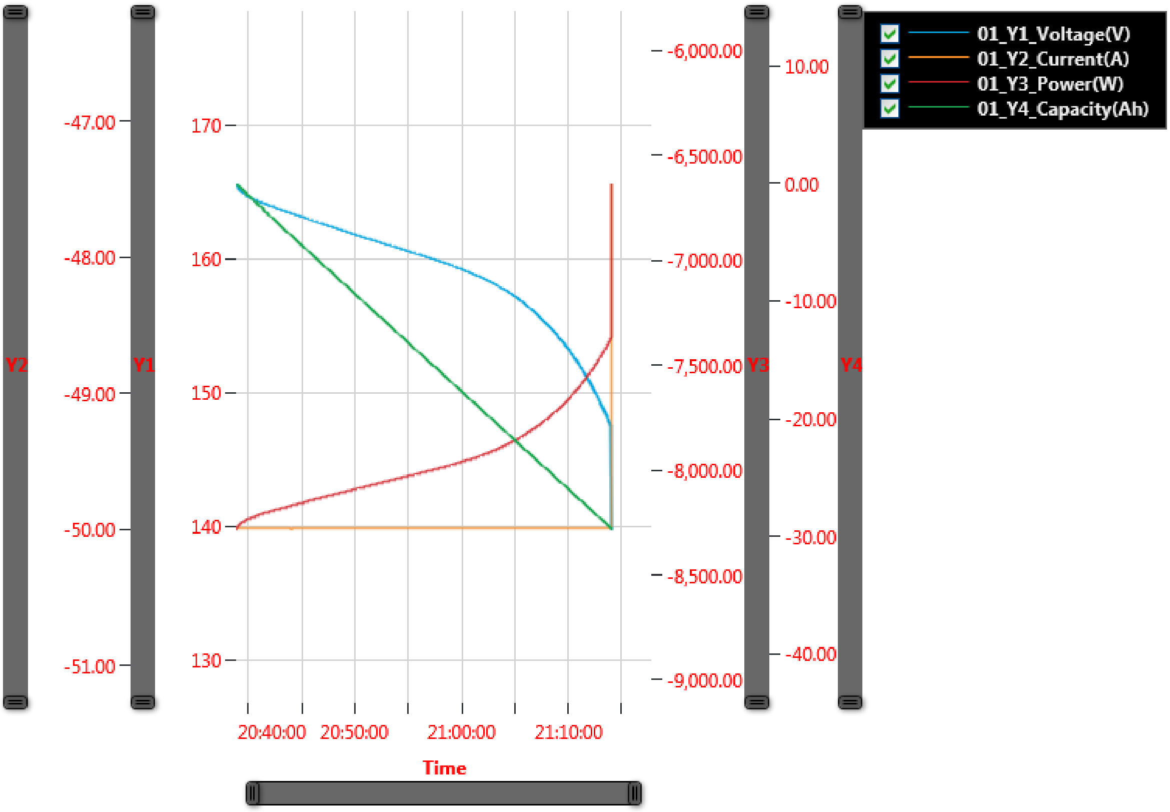


Fig. 4 - Discharge test performed on the bench with batteries connected in series

On the test, the batteries were series connected, thus the voltage starts from 164 Vdc. The initial current provided to the regeneration converter is 50 Adc, but, due to the current limitation from the minimum cell voltage, the current drops down to 48 Adc after 38 minutes.

When the minimum cell voltage protection was triggered, the BMS unit stops the charger. This test simulates the BMS behavior when batteries voltage drops below the lower limit of cell voltage.

Additional tests were performed with the whole equipment mounted on the harvester vehicle, where the batteries were connected in parallel and charged with the charger presented in Figure 3b. The interest was in the CC-CV curve of the charging current (Constant Current - Constant Voltage), as presented in Figure 5.

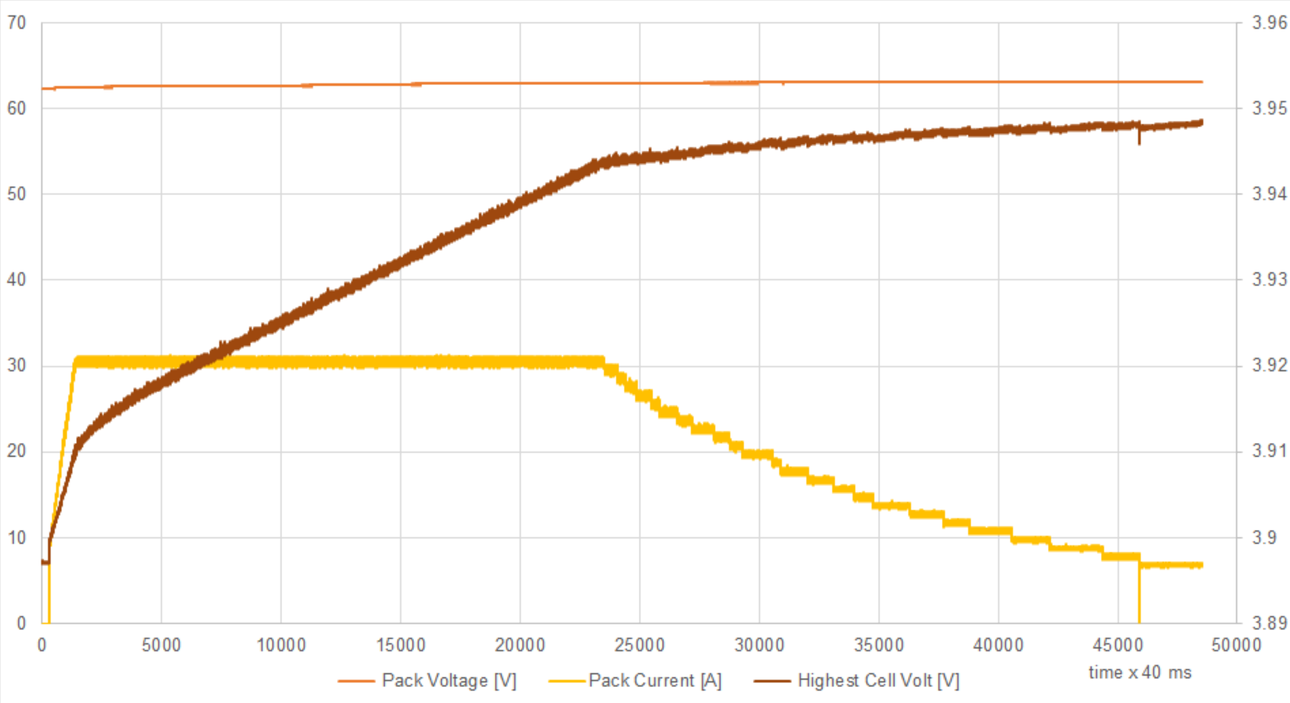


Fig. 5 - CC-CV charging up to max-cell voltage

The charging is performed with Constant Current until the cell voltage is near the maximum value (moment 24000 in Figure 5) when cell voltage balancing is enabled and the requested current limit was reduced. After the cell voltage reached the maximum value for more than 1 s, the constant voltage operation was enabled, and the current limit was reduced to zero, as can be seen in Figure 5 at moment 46000. Because of the cell balancing the charging was re-launched at a lower voltage.

IPMSM motor and three-phase inverter

The electric motor selected for this application was an Internal Permanent Magnet Synchronous Motor developed for electric boats and a dedicated control inverter, both being able to be operated when supplied from a 60 Vdc battery. The motor is a three-phase Y permanent magnet synchronous motor. For overheating, it has a temperature sensor, and for speed control, it has a sin/cos encoder.

The inverter is dedicated to the speed and torque control of 3-phase AC and IPMSM motors. Intended for use as electric traction or hydraulic pump motor controllers for mobile, on-vehicle applications that use a 24-96 Vdc nominal battery supply. The control technique is Field Oriented Control (FOC) algorithms, which can generate the maximum possible torque and efficiency on a wide speed range. The inverter is using the motor's encoder position information in the control loop, as there is extremely important to know the magnet's localization for the optimal control of the motor.

Their main characteristics are:

Table 2

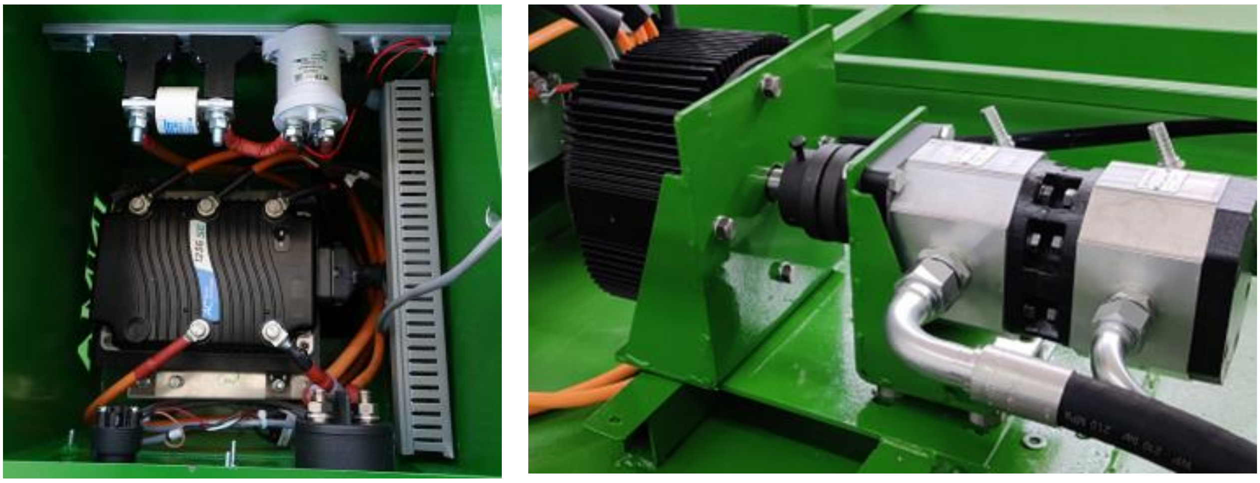
Motor and Inverter characteristics

MOTOR		INVERTER	
Motor's rated power	14.5 kW	Inverter's rated power	24 kW
Maximum power	44 kW	Maximum power	34 kW

MOTOR		INVERTER	
Maximum speed	6000 rpm	Maximum frequency	300 Hz
Rated voltage	48-120 Vdc	Rated voltage	48-96 Vdc
Rated current	250 Aac	Rated current	250 Aac
Maximum current	550 Aac	Maximum current	350 Aac
Mass	20.15 kg	Mass	4.12 kg

To control the electric motor at a specific speed, there must be several external components involved, such as a microprocessor controller, DC contactor, DC power switch, fuse, heatsink, and vents. All those were located in the cubicle near the electric motor, joining the power inverter. The cables between the inverter and the motor are 0.3 m long. The inverter is presented in Figure 3a.

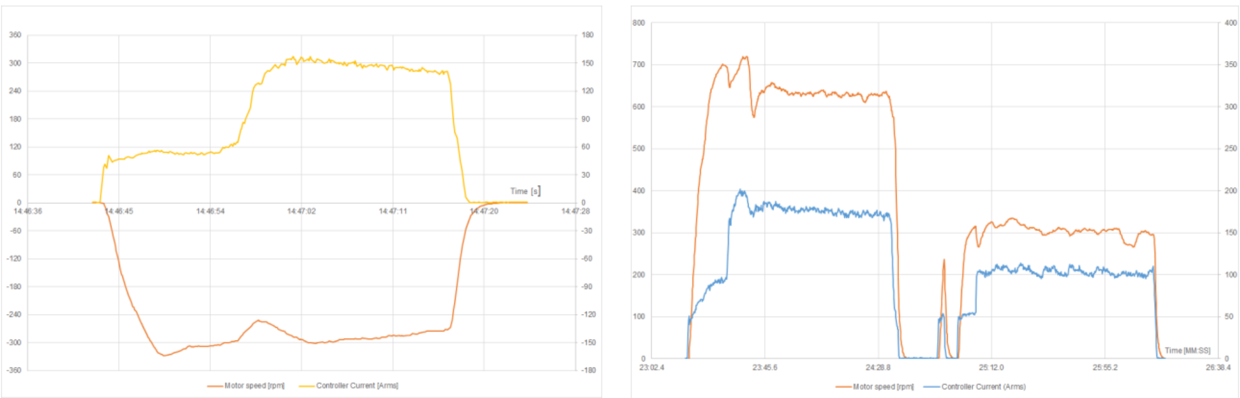
The electric motor is coupled with the hydraulic pump using an axial elastic transmission. The mounting system is revealed in Figure 3b.



a. b.

Fig. 6 - The inverter and the electric motor mounted on the harvester during indoor tests

The electric drive consisting of a motor and inverter is controlled by a dedicated microcontroller which is receiving commands from a remote control and starts the motor with a preregistered speed and current slope when selected. Figure 7 is presenting some stability tests for the electric drive, analyzing the stability of the speed regulator under variable load.

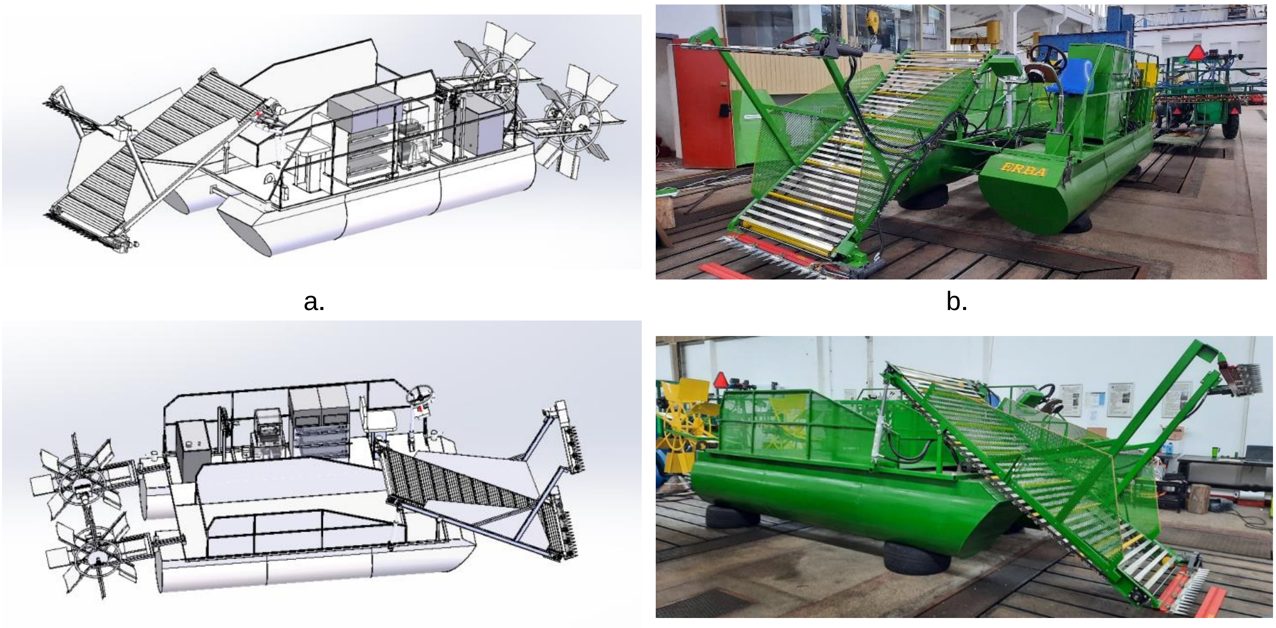


a. b.

Fig. 7 - Motor speed (left axis) and inverter current (right axis) when applying a hydraulic load at 300 rpm and 600 rpm

It could be observed that the electric motor can maintain the speed while the hydraulic load goes on (Figure 7a, moment 14:46:56) and off as imposed by the driver, the speed is quite stable and the current is adjusted adequately. The start is smooth, from 0 to 300 rpm in 6 seconds, and the stop is faster, being performed in 3 seconds.

The whole aquatic harvester boat is a complex machine, which involves several electric and hydraulic powering systems which can fulfill all the requested tasks. Figure 7 is presenting the general 3D project and the picture of the boat in the laboratory where the indoor tests were performed for adjustments of the electronics and the settings of the proportionality of the hydraulic valves.



a. b.

c. d.

Fig. 8 - The aquatic harvester boat design and prototype during indoor tests

CONCLUSIONS

The prototype of an aquatic harvester boat powered by an electrohydraulic powertrain supplied by traction batteries was completed. All the electric functions were tested using the methodology. The power requested by the hydraulic systems is maintained in the designed range when the electric motor's speed and the hydraulic valves are correlated. There were measured individual loads from 0.7 up to 1.2 kW for auxiliaries and 1-3 kW for each paddle, thus making the rated power of the motor of 14.5 kW suitable for the boat operating in Harvester mode.

For Transfer mode, because the shape of the boat is particular, the currents must be measured while the paddles are pushing the boat, including the influence of the paddle insertion on the water. Further adjustments of the powertrain could be performed, if necessary.

For Charging mode, it is expected to have a 5 h charge from 20 to 90 % of the battery's state-of-charge SOC. Faster charging can be performed if a power outlet is available, in that case, the liquid cooling of the batteries becomes mandatory.

The weight of the vehicle is optimum for the requested payload, autonomy, and specific operational functions. A balancing adjustment was performed indoors and must be verified while on the water.

The boat is prepared for outside tests in water when autonomy, speed, and harvesting efficiency shall be evaluated and optimized.

ACKNOWLEDGEMENT

This work was supported by a grant from the Romanian Research and Innovation Ministry, through Sectorial Plan, contract no. 1PS/2021 and through Programme 1 – Development of the national research and development system, subprogramme 1.2 – Institutional Performance – Projects for financing excellence in RDI, contract no. 25PFE.

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