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ELECTRIC DRIVE SYSTEM FOR AQUATIC HARVESTER POWERED BY Li–ION BATTERIES

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Abstract: The aquatic harvester electric vehicle for 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 energy source requested is the electric batteries such as a system of Li–Ion batteries connected in parallel. An electronic converter is also used to supply an electric motor that drives a hydraulic double–circuit pump. The vehicle can be controlled remotely. The work presents the prototype made and the results of laboratory tests with it. This article's main objective is to describe the electric drive of an electric–powered aquatic harvester, underlining key features, technical solutions, novelty, and benefits of the proposed architecture.
Keywords: electric, harvester, specific energy consumption, efficiency, paddle–driven, Li–ion batteries

1. INTRODUCTION

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 2020). This article's main objective is to describe the electric drive of an electric–powered aquatic harvester, underlining key features, technical solutions, novelty, and benefits of the proposed architecture.

According to the authors 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 developed, but most of them are based on Diesel power, which has to be replaced by electric–powered vehicles to improve environmental care. (Marin F. 2021), (Aquatic weed harvester 2022). For larger harvesters, the diesel–hydraulic solution is used (Eco-Cutter|Aquatic Weed Harvester 2022). 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 we noticed the electric drive, the remote operation, and the fact that the harvester can be transported with a regular trailer attached to a normal car (Watergator 2022). 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 (D. Athina 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, actuators, and so on (Un-Noor 2017).

Some researchers are implementing a fuel–cell range extender based on hydrogen, similar to the surface EV solutions (M. Shigeyuki 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 a weed harvester 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 2016).

Boats using electric drives for propulsion are seldom used, especially special boats with particular needs, such as the towing boat (Moussodji 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 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 2021).

ISSN 1584 – 2665 (printed version); ISSN 2601 – 2332 (online); ISSN-L 1584 – 2665

The energy storage system recommended to be used by the EV industry are 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 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 reserves is the parallel connection of the Li–Ion packs (Lv 2019). In the paper presented, in the second section, the 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.

2. MATERIALS AND METHODS

The authors propose a technical solution comprised of a three–phase voltage inverter supplied from Li–Ion batteries, this inverter will provide power to a permanent magnet electric motor that has as a load a hydraulic pump. The pump is a two–circuit kind, one circuit will go to a set of proportional valves that turn the hydraulic motors of the two paddles, the second circuit will power hydraulic actuators for the conveyor, for positioning of the conveyor and the cutting knives. Figure 1 shows the basic schematic of the harvester.

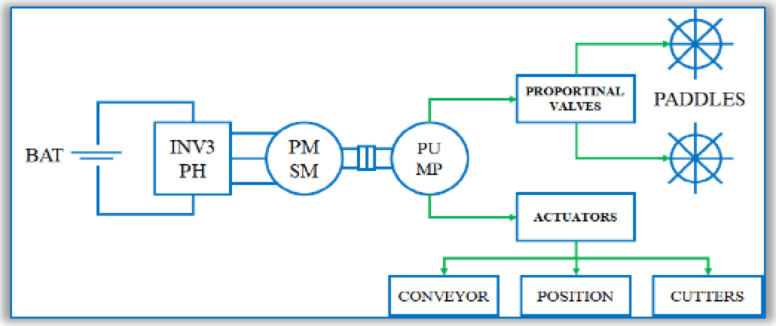


Figure 1 – Main functions of the ERBA aquatic harvester

The harvester has an onboard drive post but can also be controlled with a radio controller from land, with a range of 50–100 meters, depending on direct line of sight. The remote controller has controls for all the command signals of the harvester, the throttle for the paddles, and inputs for controlling the actuators. A low–level diagnostic of the vehicle is realized with LED's on the remote controller.

The selection of the hardware, design parameters and software is described in the earlier work of the authors (Tudor, et. al., 2022). The battery storage of the harvester consists of three electric vehicle homologated Li–Ion packs, with a total capacity of 33 kWh at 60 Vdc voltage, in conformity with boating regulations. The expected autonomy of the harvester is about 90 minutes of operation. The inverter and the motor are specially made for vehicular applications, resulting in high efficiency, which improves autonomy.

The harvester can operate in three different regimes:

- harvesting – when the boat is at full throttle and active cutters and conveyer;
- cruising – when the driver controls the throttle and has the auxiliaries offline;
- charging – when the entire system of the boat is offline and the batteries are charging through the dedicated charger.

During the harvesting and cruising modes, the speed of the electric motor is controlled to be at a fixed value, while the hydraulic system is controlled with the proportional valves and the actuators.

The charging regime is adapted for a single–phase 6 kW supply, which is available more often than a DC power supply or three–phase AC outlet. The charger is off–board, avoiding the electrical risk which comes from having onboard chargers and pulling high–voltage supply cables on the boat.

3. RESULTS

Li–ION Batteries for Power Supply

Based on the imposed autonomy and the characteristics of the harvester, the choice of batteries consists of 3 packs of Li–Ion batteries CATL16, each with an energy capacity of 11 kWh that are designed for the automotive industry. These batteries are already homologated for road vehicles and thus have all the necessary safety features, the main characteristics of these batteries are presented in Table 1.

Table 1. 16CATL battery pack characteristics

Rated energy stored E_0	11 kWh
Rated capacity C	188 Ah
Open–circuit voltage V_0	58.72 Vdc
Rated cell voltage V_{c0}	3.67 Vcc
Max cell/pack voltage	4.2 Vdc / 67.2 Vdc
Min cell/pack voltage	2.8 Vdc / 44.8 Vdc
Max discharge current	500 A / 10 s

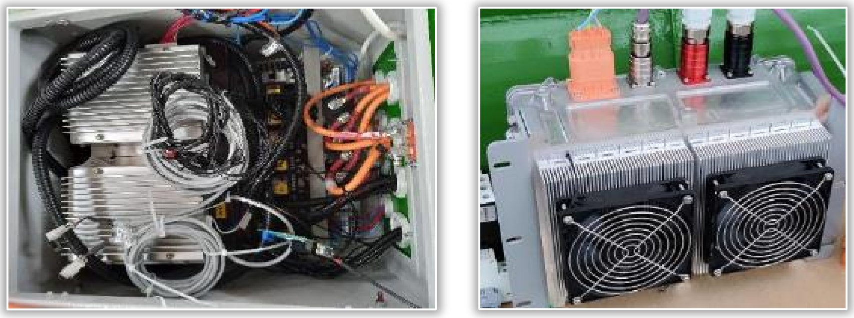
ISSN 1584 – 2665 (printed version); ISSN 2601 – 2332 (online); ISSN-L 1584 – 2665

The three battery pack where connected in parallel with power diodes to avoid cross charging between them when not in use. In Figure 2a it can be seen the three batteries during initial tests in laboratory, while in Figure 2b is the final arrangement of the batteries onboard the harvester.

(a) (b) (c)

Figure 2 – The batteries for energy storage, and BMSs during lab testing and the final assembly at the indoor test

In contrast with the lead acid battery, Li–ion batteries require special charging and balancing control, to prevent overvoltage and over–current and also to monitor and control the temperature of the battery pack. These functions are realized with the help of a system called battery management systems, BMS. For the application presented in this paper, a solution with one BMS for each battery was selected. These BMS have the advantage that the mode of connection of the batteries can be selected, either series or parallel, and the BMS will reconfigure for the selected mode. The BMS also monitors all the parameters of the batteries and controls the main contactor of each pack to avoid damage. Figure 3a presents the BMS onboard the harvester placed inside an IP65 box while Figure 3b presents the 6 kW external charger.



(a) (b)

Figure 3 – The BMS cubicle and the external charger

Experimental tests were performed in the laboratory using a dedicated CHROMA battery cycler, which permits running different profiles for charging and discharging the batteries. The results of a charging session are presented in Figure 4.

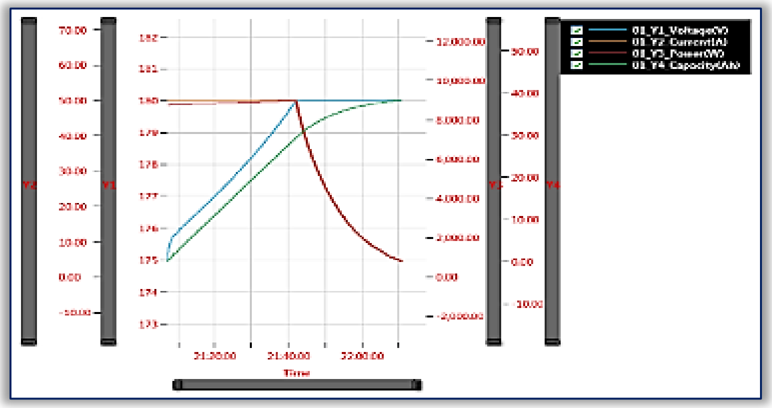


Figure 4 – Charge test performed on the bench with 3 batteries connected in series

Because the batteries had been connected in series during the test, the voltage increased from 175 Vdc to the predetermined 180 Vdc. The minimum cell voltage causes a current constraint, which causes the initial 50 Adc current to decline to 5 Adc after 32 minutes. The charger cycler unit deactivates the charging process if the maximum cell voltage protection is not activated. When the battery voltage is approaching the higher limit of the cell voltage, this test does not replicate the behavior of the BMS.

ISSN 1584 – 2665 (printed version); ISSN 2601 – 2332 (online); ISSN-L 1584 – 2665

Additional tests were performed with the whole equipment mounted on the harvester vehicle. The constant current – constant voltage curve (CC–CV) obtained is presented in Figure 5.

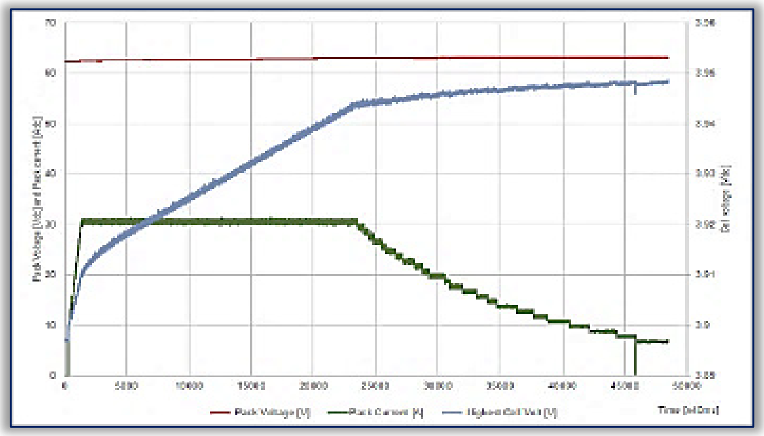


Figure 5 – Pack charging up to max–cell voltage

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 is 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.

Three–phase inverter and permanent magnet motor

A permanent magnet motor intended for use in boat applications is the motor used in this application. One benefit of the dedicated three–phase inverter powering the motor is that it can be powered by a power supply of 60Vdc, which is the same voltage as the battery. The motor has a temperature sensor and speed sensor built in, and it uses field–oriented vector control, which ensures maximum torque across the whole speed range. The motor case's efficient cooling system eliminates the need for extra fans. Table 2 lists the primary attributes of the motor and inverter.

Table 2. Motor and Inverter characteristics

MOTOR		INVERTER	
Maximum speed	6000 rpm	Maximum frequency	300 Hz
Rated voltage	48–120 Vdc	Rated voltage	48–96 Vdc
Motor's rated power	14.5 kW	Inverter's rated power	24 kW
Rated current	250 Aac	Rated current	250 Aac
Maximum power	44 kW	Maximum power	34 kW
Maximum current	550 Aac	Maximum current	350 Aac
Maximum speed	6000 rpm	Maximum frequency	300 Hz

In Figure 3a the inverter is shown located inside its housing, joined by the auxiliary components required for proper operation such as a DC contactor for supplying the inverter, a high current fuse for short–circuit protection and a starting key and switch. An CAN communication is available and it is used for monitoring and control. In Figure 3b the motor is coupled to the hydraulic pump with an elastic coupling. The motor and inverter are closely positioned to minimize the length of the cables.

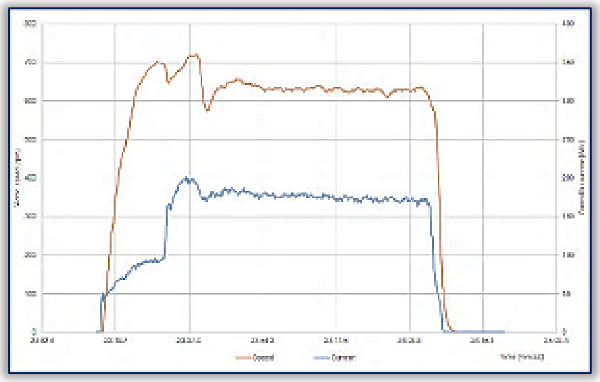
a. b.

Figure 6 – The inverter and the electric motor mounted on the harvester during indoor tests

The electric drive and the hydraulic systems of the harvester are controlled by a dedicated control unit consisting of a multiprocessor architecture with an included radio receiver for use with the remote controller. This distributed system permits each subsystem of the harvester to be controlled separately,

ISSN 1584 – 2665 (printed version); ISSN 2601 – 2332 (online); ISSN-L 1584 – 2665

motor and inverter, paddles, cutters and conveyor. Figure 7 presents a test performed under varying loads on the motor to validate the controller tuning parameters.



a.

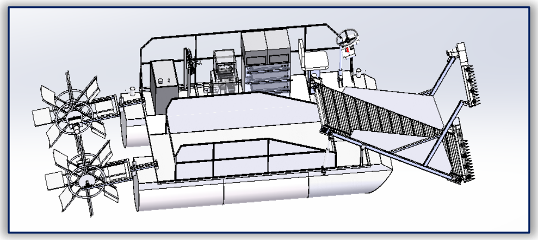
b.

Figure 7 – The controller current (right axis) and motor speed (left axis) ran at 600 and 300 rpm, respectively

It could be observed that the electric motor can maintain the speed while the hydraulic load goes on (Figures 7a and 7b) 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 300rpm in 6 seconds, and the stop is faster, being performed in 3 seconds.

The entire aquatic harvester boat is a smart equipment with many hydraulic and electrical powering systems that can perform all necessary functions. The whole 3D project and the image of the boat in the laboratory where the inside testing were conducted to modify the electronics and the hydraulic valves' proportionality settings are shown in Figure 7. The main components of the boat are: two floats, an welded frame, two paddle wheels for propulsion and direction change, two blades cutting system, lamellar conveyor, a collection bin for biomass, an additional steering system with rudder, a converter for converting electrical energy into mechanical energy, three electric batteries, hydraulic actuators, double pump for hydraulic system, 5 hydraulic motors for acting the consumers, sectional and proportional distributors, electronic control, remote control. The overall dimensions of the harvester prototype (length×width×height) is 7800x2500x1800 mm×mm×mm, total weight 1880 kg, cutting width 110 mm and storage bin capacity 2.5 m^3.

(a)



(b)

Figure 8 – The aquatic harvester boat design and prototype during indoor tests

4. CONCLUSIONS

An electrohydraulic drivetrain fueled by traction batteries was used to develop and test a prototype aquatic harvester boat in an indoor condition. Every electric and control function underwent testing and verification. When the hydraulic and electric systems are coupled, full power transfer is achieved. Individual loads of 1.2 kW for auxiliaries and 2x3 kW for each paddle were recorded in harvesting mode, demonstrating that the 14.5 kW electric motor was the right choice.

In order to determine the impact of the paddles' position—lower or higher above the water—on the cruise mode, the battery current delivered to the electric drive was measured. If more changes are required, this position can be adjusted.

If a greater power charge and power supply are available, faster charging may be possible. In this scenario, the batteries must also be cooled and the temperature must be properly monitored and managed. In charging mode, a charging time of roughly 5 hours is predicted to charge the battery from 20% to 90%.

For the intended payload, autonomy, and certain operational functions, the harvester weight is optimal. It is necessary to confirm a balancing correction made indoors while out on the water. The boat is ready for open–water testing where its speed, autonomy, and harvesting efficiency will be assessed and improved.

ISSN 1584 – 2665 (printed version); ISSN 2601 – 2332 (online); ISSN-L 1584 – 2665

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.

Note: This paper was presented at ISB–INMA TEH' 2022 – International Symposium on Technologies and Technical Systems in Agriculture, Food Industry and Environment, organized by University "POLITEHNICA" of Bucuresti, Faculty of Biotechnical Systems Engineering, National Institute for Research–Development of Machines and Installations designed for Agriculture and Food Industry (INMA Bucuresti), National Research & Development Institute for Food Bioresources (IBA Bucuresti), University of Agronomic Sciences and Veterinary Medicine of Bucuresti (UASVMB), Research–Development Institute for Plant Protection – (ICDPP Bucuresti), Research and Development Institute for Processing and Marketing of the Horticultural Products (HORTING), Hydraulics and Pneumatics Research Institute (INOE 2000 IHP) and Romanian Agricultural Mechanical Engineers Society (SIMAR), in Bucuresti, ROMANIA, in 6–7 October, 2022.

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ISSN 1584 – 2665 (printed version); ISSN 2601 – 2332 (online); ISSN–L 1584 – 2665