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# Electric Power System of a Hybrid All-terrain Vehicle

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**ABSTRACT**
The work is devoted to the electric power system of a hybrid ATV. Currently, electric cars are popular, however, they have a small power reserve compared to cars powered by an internal combustion engine. Consideration of the electric power system of a hybrid vehicle is an urgent task to this day. The paper considers the possibility of using various sources of electrical energy, as well as the energy efficiency of using these sources. A microcontroller control system is also used in the electric power system. The possibility of modernization of the electric power system is described.

***Keywords:*** *Hybrid vehicle, Microcontroller control system, Electric power system, Energy efficiency.*

## 1. INTRODUCTION

The present hybrid all-terrain vehicle (ATV), in its essence, is an autonomous vehicle. An autonomous vehicle is a vehicle that can operate independently and perform necessary functions without any human intervention. Autonomous systems are known today due to the latest automotive industry achievements. Automated systems of different degrees of autonomy are integral parts of future developments and prospects in many areas.

Autonomous vehicles are widely used in many areas such as construction, agriculture, search-and-rescue operations, fire-fighting, and etc. Modern autonomous vehicles have a large number of sensors, computing equipment, special apparatus, which require electrical energy to operate [1].

This article considers the electric power system of a hybrid ATV. ATV with electric propulsion and elements of unmanned autonomous systems is shown in Figure 1.

**Figure 1** Hybrid ATV

The main task of an electric power system is to produce electricity and deliver it to consumers. Autonomous systems receive energy separately from the main grid. Various generators operating on different types of gaseous or liquid fuels, solar or wind energy can serve as sources of electric power.

Figure 2 shows the vehicle drive diagram.

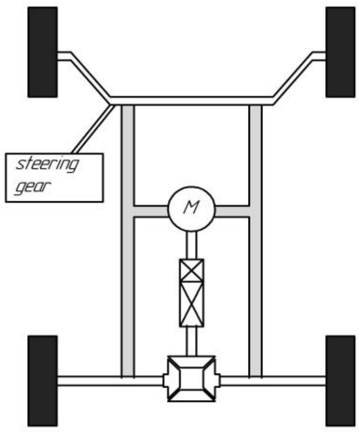


**Figure 2** ATV drive.

As can be seen from Figure 2, the vehicle has the rear-wheel drive. The sources of ATV electric power are the diesel generator and accumulator batteries. The electrical energy consumers are the computer, brushless synchronous DC motor with permanent magnets on the rotor, electric brake, lighting equipment, steering gear, a microcontroller, and various sensors.

## 2. ELECTRIC POWER SYSTEM

### *2.1. Electrical energy consumers*

The main consumer of electrical energy in the hybrid ATV is an electric motor.

Figure 2 shows that the ATV is driven by the BLDC electric motor, i.e. brushless DC electric motor with permanent magnets. The motor power is 1 kW. The reducing gear and differential are also used to drive ATV. The BLDC electric motor is used for the following reasons [2]–[5]:

• Lack of brush-collector unit;

• Long service life;

• Better characteristics and efficiency (efficiency is about 90%);

• More compact;

• Sufficiently low noise level during operation compared to other motors of the same rating;

• Absence of mechanisms that require regular maintenance.

However, BLDC electric motor also has disadvantages:

• More complex control system;

• High price due to expensive components (e.g. permanent magnets);

• Additional switching devices are required for operation (switches, encoders).

Another main consumer is the computer. It is used to debug and control the operation of all ATV devices.

The ATV design also includes such consumers as the electro-hydraulic brake, steering gear, lighting equipment, sensors and lower level microcontroller systems.

### *2.2. Electric power sources*

The sources of electric power are the diesel generator and accumulator batteries. Electric power sources must have sufficient power to provide operation of the required electrical energy consumers.

In the present ATV, the total power of electrical energy consumers is 2.4 kW. The 5 kW diesel generator is used in the electric power system to provide the necessary power. The diesel generator of such power was specially chosen since it allows to upgrade the electric power system without significant costs, i.e. the system has a power margin [6]. This diesel generator can be started manually and automatically. Manual start is carried out by turning the key in the ignition lock, and automatic start is carried out by a control signal transmitted to electromechanical relay.

A battery is a device designed to accumulate energy and use it afterwards [7]. In the battery, energy of a chemical reaction is converted into electrical energy, and vice versa. There are many different types of accumulator batteries available today.

The present ATV uses AGM (Absorbent Glass Mat) batteries. AGM batteries are extremely vibration resistant, hermetically sealed, spill-proof and zero-maintenance [8]–[11]. Moreover, AGM has a long service life. AGM batteries are designed to eliminate electrolyte movement by holding it in place, reduce battery maintenance costs, and are claimed to have higher charging power, among other benefits.

Accumulator battery designed to power consumers such as a computer, steering gear, electric brake, and etc. consists of two parallel-connected batteries with a voltage of 12 V and a capacity of 100 A·h each. The parallel connection gives a battery with a voltage of 12 V and a capacity of 200 A·h. The discharge characteristics of one battery are shown in Figure 3.

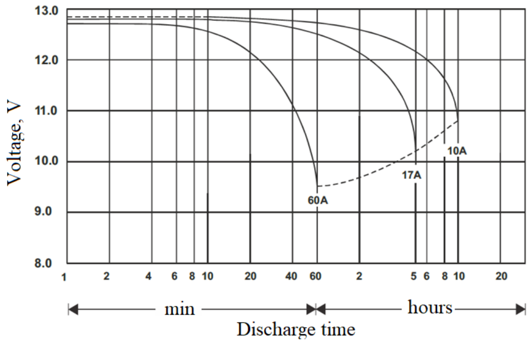


**Figure 3** Battery discharge characteristics.

The traction battery consists of several series-connected batteries. This connection allows to get the required total voltage. When connected in series, batteries of the same voltage and capacity are connected to increase the entire assembly voltage (Figure 4).

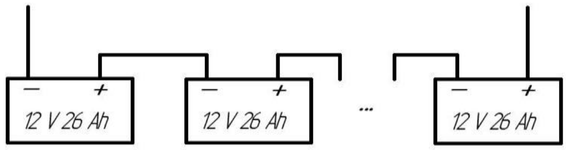


**Figure 4** Series-connected batteries.

The positive terminal of the first battery is connected to the negative terminal of the second battery and so on until the required voltage is obtained. The output voltage is the sum of all battery voltages added together while the total capacity remains the same. Thus, there are five batteries of 12 V were connected to obtain 60 V at the output of the series-connected batteries.

AGM batteries are connected as the previous ones. The capacity of each AGM battery is 26 A·h. Series-connected AGM batteries give a battery of 60 V and 26 A·h.

### *2.3. Block diagram of the electric power system*

There are two electrical energy sources in the hybrid ATV, and consumers of both direct and alternating current. Therefore, the system block diagram should include blocks of electrical energy converters.

Block diagram of the ATV electric power system is shown in Figure 5, where EPS is the electric power source, PC is the computer, BLDC EM is the electric motor, VS is the voltage sensor, AB is the accumulator battery, NS is the network switch, FT is the fuel tank, FLS is the fuel level sensor, EPS is the electric power steering system, CS is the control system.

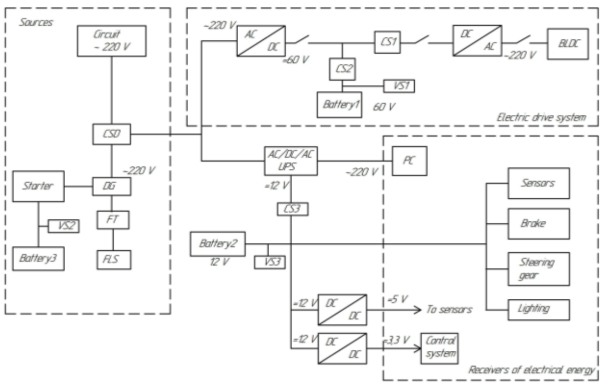


**Figure 5** EPS block diagram.

Devices such as the brake and steering gear require a 12 V DC power source, and the microcontroller requires a 3.3 V supply. DC/DC converters are used to obtain these voltages. DC/DC converters are electrical devices designed to convert one DC voltage value to another DC voltage value.

The block diagram in Figure 5 contains fuel level sensors, current sensors, and voltage sensors. All these sensors are required to obtain information about the electric power system state for the control system. There are switching devices in the electric power steering system. They execute both switching and protective functions.

The system receives AC electrical energy in two ways:

- From the network;
- From the diesel generator.

The mode of operation from the network was implemented to save the diesel generator resources. This mode allows to tune and debug the vehicle without starting the diesel generator, and this mode also provides the necessary recharging of the accumulator batteries. There is a special device ("network switch") to switch between the network and the diesel generator. The network switch consists of the switching equipment of the microcontroller control system. One or another mode of electric power system operation is selected with the microcontroller, depending on the circumstances.

The diesel generator is started by using a starter. The starter receives electrical energy from its battery.

Fuel control in the diesel generator is carried out by using the fuel level sensor. The signal from the sensor is fed to the microcontroller.

### *2.4. Control system*

Information about the electric power system state is obtained with various sensors. Information from the sensors enters the control system. Thereafter, the control system controls the electric power system based on the information received. For example, information about the remaining amount of fuel is determined with the fuel level sensor. If the fuel runs out, the electric power system receives power from the batteries.

The electric motor is controlled with an electric propulsion system. It is necessary to know the parameters of the electric motor at the current time for the proper control. To do this, there are voltage, current and temperature sensors as feedback.

Thus, all the necessary information about the system enters the control system. The control system is designed for the complete automation of a power plant. The system controls electricity to prevent power outages as much as possible and minimize fuel consumption. The system is designed for remote control of the diesel generator, automatic switches, as well as some consumers.

The control system performs the following automatic functions:

- Starting/stopping of the diesel generator;
- Control of consumers;
- Prevention of power outages;
- Remote starting and stopping of the diesel generator;
- Switching from diesel generator to batteries;
- Measuring of parameters: U, I.

The control system receives information on the system state from the starter battery voltage to the electric motor battery current. Information about system parameters at a certain moment allows to conclude about many things. For example, it is possible to predict the remaining run time of the vehicle. To do this, you need to know the remaining fuel in the diesel generator fuel tank and the current capacity of the battery. The remaining fuel is easily determined with the fuel level sensor, since the sensor output voltage is proportional to the fuel level. And the current capacity of the battery is determined through the voltage and current of the battery [12]–[15].

There is an automatic circuit breaker in the electric motor DC circuit for protection against overload and short circuit. When the breaker is triggered, the control system receives a signal. Based on the signal, the control system turns off the diesel generator and operates in a standby mode. Safety fuses and circuit breakers are used to ensure consumers protection.

The control system performs the following modes:

• Tuning and debugging mode, i.e. the electric power system receives electrical energy from the network;

• Diesel generator mode, i.e. the electric power system receives electrical energy from the diesel generator. This mode is the electric power system main mode;

• Battery mode, i.e. the power system receives electrical energy from the batteries. This mode is activated when the diesel generator cannot operate, for example, when there is no fuel;

• Standby mode.

The run time in the battery mode is determined based on the capacity of the batteries themselves and the corresponding consumers. It is convenient to convert capacity from A·h to W·h for the calculation. The capacity of the traction battery is determined by (1).

$$200A \cdot h = 200A \cdot h \cdot 12V = 2400W \cdot h \qquad (1)$$

The capacity of the traction battery is determined by (2).

$$26A \cdot h = 26A \cdot h \cdot 60V = 1560W \cdot h \qquad (2)$$

Thus, the minimum battery life is determined by (3) and (4).

$$t_{26\,A \cdot h} = \frac{1560W \cdot h}{1000W} = 1{,}56h \qquad (3)$$

$$t_{200\,A \cdot h} = \frac{2400W \cdot h}{1400W} = 1{,}71h \qquad (4)$$

Thus, the ATV run time in the battery mode is at least 1.56 h. During this time, the vehicle should possibly refuel the diesel generator resources, or park in a safe place and continue to operate in the standby mode.

## 2.5. Control system algorithm

The electric power system of the autonomous vehicle is controlled by the STM32F446RE microcontroller. ST microcontrollers are widely used, thus, various development environments are currently available that facilitate the entire path of microcontroller configuration and tuning.

Preferably, the ATV electric power system is powered by the network, i.e. from the socket. This mode allows to reduce the usage of diesel generator and batteries resources. The electric power system is powered by the batteries after the unplugging. This mode is not the main one, because the battery life of the electric power system at full load is limited to 1.5 hours. The main function of this mode is to perform a safe transition from the network mode to the diesel generator mode. This mode carries out the standby mode as well.

The standby mode is the ATV electric power system operation mode when the network power is not available and the diesel generator cannot produce electricity (for example, no fuel in the fuel tank). The system sends a signal to the upper control level and the vehicle stops its main task, moves to a safe place and then waiting for the operators.

The diesel generator mode is the main operation mode after the network mode. The electric power system receives electrical energy from the diesel generator. It is necessary to secure that the starter battery is not discharged and that there is sufficient fuel in the fuel tank to start the diesel generator. This is done with the fuel level and voltage sensors.

The system operation algorithm, which allows correctly and efficiently selecting and switching between the electric power system modes, is shown in Figure 6.

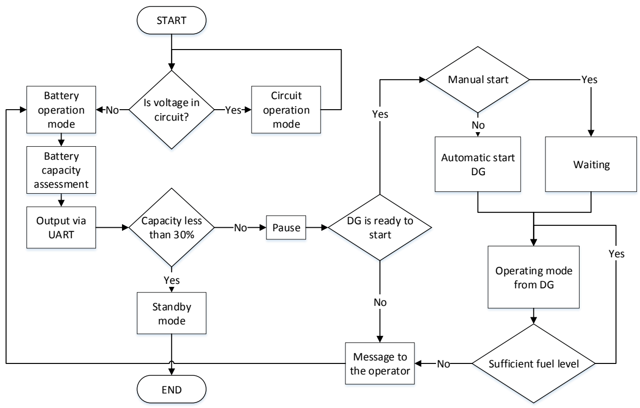


**Figure 6** Algorithm flowchart.

The presence of voltage from the network on the bus is checked at the beginning of operation. If there is voltage on the bus, the electromechanical relay is switched, i.e. network mode ensures; otherwise, the system is powered by batteries. Next, the current state of the batteries is assessed and the obtained data is output via the UART serial interface. The battery state is sent to the program for visual display of the system state with the UART.

The next step is to check the battery state. The deep discharge of the battery significantly reduces its lifespan, thus, it is advisable not to allow the battery to be used to such a state. To this end, the battery capacity is checked.

If the battery capacity is below 30 %, the system goes into standby mode. If the battery capacity is within acceptable limits, the specific time delay is waited and the request to start the diesel generator is made. The time delay is required in order to exclude the possibility of the diesel generator and the network operation at the same time. If the diesel generator is not ready to start, the operator is informed and the system operates in the battery mode. Otherwise, it is possible to start the diesel generator in manual mode and in automatic mode. Once started, the system operates in the diesel generator mode until the fuel tank runs out of fuel or until the autonomous vehicle completes its tasks.

## 3. DIESEL GENERATOR ENERGY EFFICIENT USAGE

The main disadvantage of the diesel generator is that a large amount of fuel is consumed when operating at low loads[16]–[18]. The specific fuel consumption curve for the diesel generator is shown in figure 7 [19].

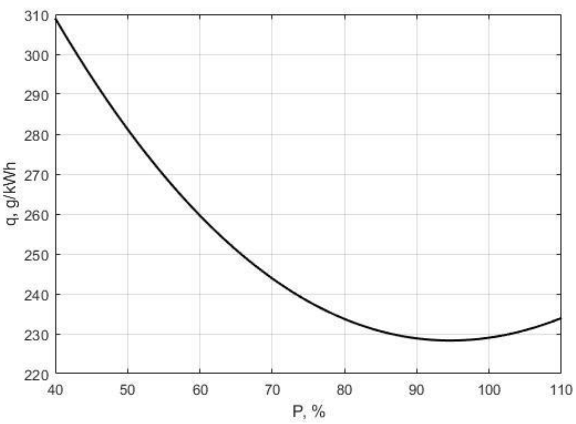


**Figure 7** Specific fuel consumption curve.

Figure 7 shows how many grams of fuel are required to produce 1 kW·h of energy at various diesel generator loads, which are expressed as a rated power percentage [20]. Note, that the lowest fuel consumption is observed when the diesel generator is loaded from 80 % to 90 % of its rated power.

In our case, the 5 kW diesel generator should operate with the load of about 2.5 kW. This corresponds to 50% load. The following scheme is proposed to reduce the fuel consumption: electric propulsion is carried out using an electric motor powered by batteries at low ATV speeds, and wheels is driven directly by the internal combustion engine at high ATV speeds. The schematic diagram of this method is shown in Figure 8, where ICE is the internal combustion engine, SG is the synchronous generator, BLDC is the brushless DC electric motor with permanent magnets, R is the reducing gear, ES is the excitation system, W is the wheel.

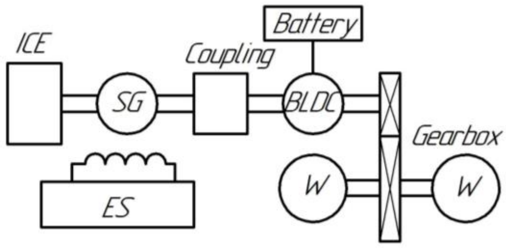


**Figure 8** Fuel consumption reduction schematic diagram.

In Figure 8 it is assumed that the shaft is common (through shaft). The electromagnetic friction clutch is used as a coupling. Thus, the clutch is open and the ATV is driven by the BLDC electric motor powered by the battery at low speeds; and the clutch is closed and the BLDC electric motor is switched off at high speeds. The drive is carried out directly by the internal combustion engine. This scheme allows significant fuel consumption reduction and, thus, the vehicle autonomy improving.

## 4. CONCLUSION

The electric power system significantly increases the ATV run time, which is an important parameter for autonomous objects. At the next stage, it is planned to install 3 kW electric motor instead of the 1 kW electric motor to improve the ATV technical characteristics. This upgrade allows not only improving the ATV technical characteristics, but also reducing the specific fuel consumption.

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