The parameters of the off-grid power system with a biomass gasifier engine for the autonomous power supply of forest harvesters

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Abstract. The paper analyses the results of the simulation modelling of autonomous power supply system of forest electric drive harvesters. MATLAB with the use of dynamic modelling Simulink tools was employed for the simulation modelling. The modelled system incorporates gasifier for solid fuelwood, a heat engine, an electric generator, a battery, and electric drive engines for the mechanisms of a mobile wood chipper. The authors determined that the minimum 12 A h Battery is required to ensure the uninterrupted operation of an off-grid power system with a gasifier, a 300 kW heat engine and a 200 kW engine wood chipper. The model allows for measuring the system performance indicators in various operating modes. The specific consumption of fuelwood was 2.217 kg/kW h in the specified mode.

1. Introduction
A sustainable power supply in industrial facilities that are geographically remote from centralized networks is the hot issue for the Russian Federation. For instance, the timber industry can widely employ autonomous energy systems [1]. One of the problems of the Russian timber industry is that the wood resources are insufficiently used. Ordinarily, forests are far away from centralized energy supply networks. In this context, wood is transported over long distances and only the finest wood is removed from the forest, while the logging waste is not managed. Thinning and sanitary felling are not properly maintained, which is especially true for remote forests. [2].

Thus, a possible solution to the problems stated above could be the use of low-quality fuel wood for autonomous power producing facilities [3]. These could be mini-power plants that use wood gasifiers. The issues to be solved are: how efficient these power plants are in various operating modes; how feasible it is to employ the power plants compared to traditional sources of energy; finally, how to design autonomous energy systems and determine their optimal operation modes. Simulation modelling is known to be one of the most effective tools to solve these issues [4-6].

This study focuses on framing an autonomous power system with a generator gas engine for the autonomous power supply of forest harvesters. Possible application and technical design of these machines are given in works [7, 8].

2. Research methods
2.1. Object of study
The object of study is the energy module of a mobile wood chipper. The energy module is an independent unit. The energy module equipment is located on a separate trailer chassis to make the transportation possible. The weight of the production machine can be reduced by placing the energy module apart from it.

The main elements of the energy module are: 2 or more wood chip gasifiers; a gas heat engine, e.g. a reciprocating internal combustion engine, or an external combustion engine; DC electric generator with a system of controlled independent excitation; electric energy accumulator; DC engines of a gas generator fan drive, a drive of a gas generator screw feeder; container with a fuel chips supply; power cable to connect it with the forest harvester. The main electric load of the energy module is a 200 kW DC engine of a mobile wood chipper.

The advantage of a DC engine with independent excitation as a wood chipper drive is that it has rather rigid mechanical characteristic. This, among other things, explains the outburst of the main drive.

A generator-engine system is used to power the main DC engine. The source of independent power to the charge coil is a battery. Advantages of the generator-engine system are reliability, soft start without rheostats and semiconductor converters, simple regulation of the engine speed and its smooth acceleration by changing the excitation current of the generator. Meanwhile, the excitation voltage of the engine itself is constant.

A buck-boost converter can be used to change the voltage of the generator field winding.

A flywheel should be installed on the shaft of the prime mover to smoothen the pulsations of the moment since the main load of the machine is extremely variable.

2.2. Modelling in MATLAB
MATLAB with the use of dynamic modelling Simulink tools and the Simscape element library was employed for the simulation modelling. Figure 1 shows the main model system with a 300 kW generator that includes several subsystems.

The generator gas engine subsystem is the source of generator torque. Torque is adjusted by the true rotation frequency of the generator shaft, maintaining a given speed. Likewise, this subsystem evaluates how much generator gas the engine consumes. The engine starts by a signal from the gas generator, when it comes to the nominal operating mode.

The generator gas subsystem assesses the required fuel chip consumption. The gas generator uses electric power from the battery to startup the power module; after the startup, it is powered by the electric generator. The excitation system maintains a given reference voltage of the generator armature by changing the voltage on the field winding. The battery powers the excitation system.

The computing unit calculates the average specific consumption of primary fuel (wood chips) in kilograms per 1 kW h of electricity generated by the generator. Additionally, it evaluates the total primary fuel consumption for the entire modelling period.

The main engine subsystem models the electric load of the forest harvester. Figure 2 shows the model of the mobile wood chipper main engine. A roll or drum style wood chipper is connected to a DC engine. The chipper load torque is set as a graph and depends on the chopped wood characteristics.
Figure 1. Model of micro off-grid power system: Ifg – generator’s excitation current, A; Ia – generator’s armature current, A; Igg – current, consumed by gas generator drives, A; Vbat – battery voltage, V; w – generator rotor speed, rad/s; Va – generator armature voltage, V; Vf – field voltage, V; Tstg – generator startup signal; Tstm – engine startup signal; Qlw – low heat value of primary fuel operating weight, J/kg; Ggas – generator gas consumption in engine, kg/s; Gch – primary fuel consumption (chips) in gas generator, kg/s.

Additionally to the chipper load torque itself, the subsystem models the load of other mechanisms of the mobile wood chipper. Figure 3 shows the modelling of the load torque for the hydraulic pumps of a mobile wood chipper.

Figure 2. Main mobile wood chipper DC engine.

Figure 3. Modelling of load torque for the mobile wood chipper main DC engine.
Other mobile chipper drives are hydraulic. The hydraulic system incorporates two hydraulic pumps. The first one ensures the movement of the chassis and the lifting of the container when the chips are uploaded. The second supports rotation of the feed chipper rollers and work of the hydraulic manipulator.

The proposed model uses a HV battery with a controlled switch (figure 4) for energy-efficient dynamic regulation of the electric load; so, when the load current reduces to a certain level, the controlled switch turns on the battery in the load circuit to charge and turns it off when the load current increases to the level chosen. Simulink used relays and a Boost Converter element in the Switching devices mode to create a slave key, to which the relay sends a control signal.

The gas generator, i.e. the fossil fuel engine system, is quite inertial, due to the inertia of the change in gas generator productivity on gas. Moreover, gas generators may work stably with a maximum efficiency in a certain nominal rating. Thus, the gas flow rate entering the engine should be within a certain range. In the given circumstances, it is difficult to regulate dynamically the engine power according to the load on the shaft.

It is feasible for stationary power systems to accumulate generator gas in the receiver with or without gas compression. However, the use of the receiver increases the metal consumption, which is not recommended for a mobile power system. In order to reduce the excess energy loss with a sharp decrease in load, the excess energy can be accumulated using a flywheel connected directly to the generator shaft or through a hydraulic clutch. Excess energy can be acquired as electrical energy with lithium-polymer or other type batteries, and supercapacitors (ionistors).

The battery is used not only to power the independent excitation system but also to power the gas generator fan engines and the screw feeder engine when the power system starts up and begins producing rated fuel gas capacity.
3. Results

3.1. The operating modes of the energy module

The operating mode of the energy module is dependent on the operating mode of the technological machine, in this case, on a mobile wood chipper. The authors had modelled the operating cycle for the energy module system – a mobile wood chipper that lasts 3600 seconds. The cycle comprises the start of the cold energy module and employing it with a variable load. It takes 292 seconds to fill in the gas generator with chips through screw feeders, warm it up and achieve the rated gas output, later the generator and the main engine start up. Then the mobile wood chipper begins to chop wood, moving intermittently around the logging site. By the end of the cycle, the machine container with wood chips is fully filled in; hence, the machine moves to unload the wood chips from the container.

Figure 5 presents time based historical graphs for the DC engine parameters of a mobile wood chipper. One can see how rapidly the armature current changes according to the variable moment at a given operating mode with a variable load. The armature voltage is stable, and increases at the initial start-up of the generator. During the entire working cycle, the voltage is stable, the amplitude of the voltage change is not more than 4% of the nominal. The rangeability in engine speed is not more than 10% of the nominal speed despite the abruptly changing load on the wood chipper engine shaft. The change in electrical efficiency repeats the change in the load on the engine shaft.

![Figure 5](image)

The authors defined the minimum required battery capacity that ensures autonomous work of the energy module. To do this, they obtained graphs for changes in the battery charge level with various capacities. Figure 6 gives an example of such a graph. As a result, a 12 Ah battery was found minimal required to start a cold energy module. Figure 6 shows that with an initial battery charge level of 80% of the nominal, it will drop down to 56%. A further decrease in the charge level will cause a more voltage drop. Therefore, the recommended battery capacity is more than 12 Ah for a given operating mode of the power system. Upon the system start, the battery is fully charged from the generator armature current.
The model proposed allows for simulating any operating mode for the power system and selecting the required battery capacity.

![Figure 6. Changing the charge level of a 12 A h battery.](image)

### 3.2. Framework of the power system

Table 1 gives the main parameters of the power system with a generator gas engine for the autonomous power supply of forest harvesters. As a result of modelling, the following parameters were proved to be feasible for the system’s proper work.

| Table 1. The main parameters of the power system and the engine of the harvester. |
|-------------------------------|-------------------------------|-------------------------------|-------------------------------|
| Quantity                      | Measuring unit | Value                  | Quantity                      | Measuring unit | Value                  |
| DC generator                  | Engine of harvester           |
| Power                         | kW                          | 250                     | Power                         | kW             | 200                     |
| Generator current             | A                           | 477                     | Rotor speed                   | rad/s          | 78.5                    |
| Generator voltage             | V                           | 460                     | Nominal armature voltage      | V              | 440                     |
| Rotor speed                   | rad/s                       | 150                     | Nominal armature current      | A              | 470                     |
| Generator impedance           | Ohm                         | 0.0762                  | Armature resistance           | Ohm            | 0.02271                 |
| Armature inductance           | H                           | 0.00042                 | Armature inductance           | H              | 0.00119                 |
| Field voltage                 | V                           | 85                      | Field voltage                 | V              | 85                      |
| Field coil resistance         | Ohm                         | 5.65                    | Moment of inertia             | kg m²           | 16.02                   |
| Inductance                    | H                           | 9.54                    |                              |                |                         |
| HV Battery                    |                              |                         | Nominal wet generator gas    | kg/s            | 0.16                    |
|                              |                              |                         | output at a relative chip    |                 |                         |
|                              |                              |                         | moisture of 30%               |                 |                         |
| Charge nominal current        | V                           | 460                     | Fuel lower heating value of   | kJ/kg           | 12261                   |
| Battery cell nominal current  | V                           | 96                      | the working mass              |                 |                         |
| Capacity                      | A h                         | 12                      | Lower heating value of the    | kJ/kg           | 4162                    |
|                              |                              |                         | wet generator gas             |                 |                         |
|                              |                              |                         | Gasification operating       | °C              | 600                     |
|                              |                              |                         | temperature                   |                 |                         |
|                              |                              |                         | Gasifier active zone volume   | m³              | 0.216                   |
|                              |                              |                         | Chip weight in one gasifier   | kg              | 480                     |
The specific consumption of primary fuel (wood chips) per 1 kW h of electricity generated by the generator was determined as an indicator of the energy efficiency of the power system. The average specific consumption of wood chips with an initial relative humidity of 30% in the gas generator for the first hour of the power system work was equal to 2.448 kg/kW h. This value decreases with the further work of the power system, since the maximum fuel consumption is at startup. The average specific consumption of wood chips is 2.217 kg / kW h with uninterrupted work of the machine system for 4 hours. The total consumption of wood chips for the first hour of power system work was 273.7 kg, for 4 hours of work it was 1044 kg.

4. Conclusion
The study proposed the main parameters of the off-grid power system for the autonomous energy supply of the forest harvester. The power system was verified for performance with those parameters by means of simulation modelling. Moreover, the simulation experiment helped determine the minimum battery capacity required for these system parameters and operating mode. The authors determined the specific consumption of primary wood fuel per 1 kW of the electric energy produced by the generator for the first hour of system work as well as for the first four hours of uninterrupted work.

5. References
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