Czech Technical University in Prague

Faculty of Electrical Engineering

Department of Economics, Management and Humanities

Improvement of the Voltage Quality in a Timber Processing Enterprise

Master Thesis

Study program: Electrical Engineering, Power Engineering and Management
Field of study: Management of Power Engineering and Electrotechnics
Scientific supervisor: Doc. Ing. Július Bemš, PhD

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MASTER'S THESIS ASSIGNMENT

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II. Master's thesis details

Master's thesis title in English:

Improvement of the voltage quality in a timber processing enterprise

Master's thesis title in Czech:

Improvement of the voltage quality in a timber processing enterprise

Guidelines:

1. Identify and collect necessary technical information from woodworking company;
2. Calculate load of specific sawmill, propose power supply and ways for improvement of voltage quality;
3. Evaluate economic efficiency of proposed improvements;
4. Perform sensitivity analyses on important input parameters.

Bibliography / sources:

A.A. Pizhurin. Spravochnik elektrika derevoobrabatyvayushego predpriyatiya (Woodworking enterprise electrician's guide), 2002.
R. A. Brealey, S. C. Myers, and F. Allen, Principles of Corporate Finance, 10th ed. McGraw-Hill/Irwin, 2010.

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III. Assignment receipt

The student acknowledges that the master's thesis is an individual work. The student must produce her thesis without the assistance of others, with the exception of provided consultations. Within the master's thesis, the author must state the names of consultants and include a list of references.

. Date of assignment receipt	Student's signature

Declaration

I hereby declare that this master's thesis is the product of my own independent work and that I have clearly stated all information sources used in the thesis according to Methodological Instruction No. 1/2009 – "On maintaining ethical principles when working on a university final project, CTU in Prague".

Date *Signature*

Abstract

This paper describes a solution to the problem of the woodworking plant power supply. Due to the long distance from a big source of energy voltage level is sensitive to sharp changes of the power in the system. Deep voltage drops appear during the starting process of motors.

In this work was considered information about the woodworking industry and main sawing equipment. Construction of the daily load diagram was provided base on the selected sawing equipment. For the sawmill was considered two variants of power supply: connection to the weak network and supply by a diesel generator. After the selection of main electrical equipment such as transformer and cable line, and diesel generator, different ways to maintain voltage level was researched and evaluated. Two options for each supply variant such as the setting of equipment with high power and the setting of lower power equipment with soft starters were considered.

In the last part of the work, the economic efficiency of each project was evaluated and sensitivity analysis was provided. According to the results, projects show high sensitivity to the discount rate and electricity and fuel price changes.

The most profitable option is the setting of lower power equipment with soft starters, this project is good in both technical and economic aspects.

Keywords

Sawmill, power supply, load diagram, transformer, diesel generator, soft starter, economic efficiency, NPV, sensitivity analysis

Contents

List of Abbreviations

	Russian	English
ER		Electric Receiver
LC		Load Cycle
TMG	Transformator maslyanyi germetichnyi	Oil sealed transformer
PVC		Polyvinyl chloride
SS		Soft starter
NPV		Net present value
EAA		Equivalent annual annuity
IRR		Internal rate of return

Introduction

The Russian Federation has a large territory. There is a big electrical network for supplying all this territory. But big distances of the transmission lines lead to high losses in the system and high sensitivity of far consumers to disturbances.

The timber processing plants are usually located close to wood sources at a long distance from the big source of electrical energy. In this case, there can be two variants: connection to the weak network or supply by a diesel generator. Asynchronous motors are used for wood processing machines and conveyors because they are cheap and effective. However, asynchronous motors have a high starting current, up to 7 times higher than the nominal current, and require more energy during the starting process, which can lead to deep voltage drops. On the woodworking plant, voltage drops can lead to final product defects or even damage of high-cost equipment, because of the decrease of machine power during the starting process of the parallel motor.

The aim of this work is to consider possible ways to improve the voltage quality of the supplying network and evaluate its economic efficiency.

The following tasks are solved during this work:

1. Research of the woodworking industry and power supply features of this type of plants;
2. Selecting of woodworking machines and their motors;
3. Construction of the load diagram for 24 hours;
4. Proposal of measures to increase voltage quality;
5. Investment appraisal.

I assume that the object of this paper is located in the Tomskiy region and at a long distance from the big source of energy.

1 Timber Industry and Electricity Supply

1.1 The Concept of the Woodworking Industry, Its Composition, and Factors of the Location of Enterprises

The woodworking industry is a branch of the lumber industry and includes:

1. Logging;
2. Primary wood processing;
3. Sawmill (lumber production);
4. Production of wooden houses;
5. Production of building parts made of wood (doors, parquet, etc.);
6. Plywood production;
7. Production of matches;
8. Furniture production.

The woodworking industry is divided into two big groups: the creation of lumber and furniture (mechanical processing) and the wood chemical industry and the production of pulp and paper products (chemical processing). [1]

Deep processing of wood is the main task of the woodworking industry, and the industry is also looking for ways to maximize the use of woodworking waste, additional reserves of wood, and ways to save it in all sectors of the economy.

Woodworking enterprises in most cases specialize in the production of a certain type of product, therefore they are divided into woodworking plants, furniture factories, house-building factories, ski factories, etc. [1]

For the location of a woodworking enterprise, it is necessary to take into account the availability of high-quality raw materials and methods of high-quality processing of these raw materials.

The main factors affecting the location of the enterprise are:

- Proximity to the resource base;
- Availability of electricity and water supply sources;
- Availability of transport links;
- Close location to potential and real consumers;
- Need for job creation. [1]

1.2 The Woodworking Enterprise Technological Process

Subchapter was written based on the information from [2].

The growth in the volume of timber harvested in warehouses determines the need to locate a timber processing shop close to the place of logging. The economic feasibility of installing this workshop is determined by the concentration of raw materials, the availability of electricity, and the need for the most comprehensive and full use of the harvested wood.

The following factors also support this decision:

- With proximity to the source of raw materials, the price of wood is lower in comparison with the cost of a similar one which is processed in the workshops of consumers;
- Reducing the cost of transporting raw materials to consumers;
- Higher quality raw materials that were not spoiled during storage and transportation, which makes it easier to handle.

The timber processing shops at the enterprise are located with access to the transport infrastructure, which provides year-round access to loading and dispatching finished products. [2]

The main tasks of the woodworking enterprise are: sawmilling, sawing out rough blanks, debarking logs and pulpwood, and so on.

The types of machines, installations and production lines, their number and mutual arrangement depend on the type and amount of raw materials, average output, type of products manufactured by the enterprise, and other factors. [2]

Logging production is influenced by natural factors. This effect leads to fluctuations in the productivity of both individual installed machines and the entire technological process. Changes in the characteristics of the developed cutting areas lead to fluctuations in the harvested raw materials and their quality parameters.

In the case of a repeated decrease in the volume of raw materials, what is typical for the depletion of the forest resource base of the enterprise, or a decrease in the volume of output with certain parameters, a significant restructuring of the technological process of the shop with the replacement of the corresponding equipment is possible. [2]

In this regard, the technological processes of such enterprises should be flexible to smooth out the negative effects of possible nature changes.

In timber industry enterprises, woodworking shops mainly specialize in the processing of a certain type of raw material and the release of products of the same name and limited specification. This option allows mechanizing and automating the production process of the shop as much as possible. However, the creation of such workshops has several additional difficulties:

- The creation of workshops with the same type of products and processing of one type of raw material does not allow the rational use of raw materials of lower quality and waste wood processing, as this will lead to changes in the technological process;
- The creation of various specialized workshops leads to an increase in their number at the enterprise, which in turn will lead to an increase in the capital costs of the enterprise;

- Due to the insufficient amount of raw materials of certain parameters, the equipment located in specialized workshops is not fully loaded, which indicates the irrational use of available resources and a decrease in the technical and economic indicators of the enterprise. [2]

Taking into account all of the above factors, we can conclude that the creation of specialized workshops negatively affects the work and performances of the enterprise. The best option is to create universal workshops that can work with various types of raw materials and are aimed at producing products with several names. [2]

1.3 The Timber Processing Enterprise Power Supply

The information about woodworking enterprise power supply is presented in [3]. This book specializes in sawmill power supply, so I will refer to it during my work frequently. Information for subchapters 1.3-1.4 was taken from [3].

The correct choice and competent exploitation of electrical equipment allow the rational use of available energy resources.

Sawmills and woodworking mills are major consumers of electricity in the modern world. In recent years, the power availability of these enterprises has increased several times. Since these enterprises have a high number of large electrical equipment, they usually have their substation on the territory of the plant. This substation can also supply power to nearby villages or residential areas. This substation is an object of high responsibility, therefore, the rules for the selection and exploitation of its equipment are tightened.

Taking into account the direction of the Russian Federation's energy sector development in the field of energy efficiency, one of the main directions of energy saving is the increase of electrification and automation of technological processes of enterprises. After all, the main factor in the production of finished products, respectively, in making a profit, is the uninterrupted operation of lines and other equipment of the enterprise. [3]

The agreement between the energy supply company and the timber processing enterprise is the main document regulating the issues of energy consumption, maximum load, consumption volumes and others. According to the Decree “On the stabilization of the financial situation in the electric power industry of the Russian Federation”, the contract must specify the term for payment for electricity consumption. [3]

The design organization can request from the power supply company technical specifications for connecting to the power system when they are designing an enterprise. This document should content: connection point; voltage of lines supplying the enterprise; expected voltage level, calculation of short-circuit currents, requirements for reactive power compensation, protection, automation and power consumption modes; special conditions (need for backup power supply, etc.). [3]

1.4 Reception Points and Sources of Electrical Energy

Usually, the main source of electricity for a sawmill is a district substation 35-110 kV. However, if it is impossible to provide the level of energy supply required for the 1st category consumers, the enterprise has its power plant (diesel generator, etc.), which can be used as a temporary power source, but also as and a source of constant autonomous power supply. [3]

The sources of electricity for the enterprise workshops are the main step-down substation, distribution points, workshop substations. On-load voltage control transformers are installed at the main step-down substation, which connects the networks of the power supply company (35-110 kV) and high-voltage distribution networks (6-10 kV) of the enterprise. The design of the main step-down substation includes many points: the choice of the substation scheme, the layout of the switchgear equipment. It is recommended to use deep injection circuits, which are characterized by the maximum close placement of the higher voltage source, reducing the number of intermediate transformation stages.

Technical solutions for the power consumption of the enterprise are carried out based on basic projects developed by design organizations, also for the assembly of main step-down substations, distribution substations and workshop substations, modular equipment is mainly used. In the case of atypical solutions, it is recommended to transfer the project for consideration to a specialized design organization. [3]

1.5 Sawmill Equipment

Brief information about sawmill equipment for subchapter 1.5 I have found in [2].

The equipment used in sawmills can be classified into main and auxiliary. The main equipment includes machines for shaping the dimensions of lumber and auxiliary equipment that provides the technological process (transport equipment, machine tools for mechanical repair shops, and for the preparation of cutting tools).

The main equipment group includes equipment for cutting lumber into sawn timber; equipment for shaping the section and length of sawn timber. Equipment for cutting lumber into sawn timber is divided into four main groups, sawmills, band saws; circular saws for longitudinal sawing of logs and beams; aggregate equipment for sawing logs and beams, which includes milling canters and milling machines. Depending on the design and technological features, log saws can be single-saw and multi-saw. The equipment for the formation of the section and length of sawn timber includes edging and cross-cutting machines. [2]

To implement the technological process of sawmilling and increase labor productivity, the sawn timber is prepared for cutting: in winter, it is recommended to thaw the logs (in heated pools); calibration of logs; debarking saw logs. In this case, additional equipment is used - cylindering (calibration) and debarking machines. [2]

1.5.1 Frame Saw

In Russia, frame sawmills have traditionally been used, which is associated with the large size of sawn timber supplied for cutting, its large reserves and the volume of sawmilling. Until recently, they accounted for about 90% of the country's total production capacity. [2]

Frame sawmills can be horizontal and vertical in design. The most widely used vertical ones are classified according to the following criteria:

- stationary - stationary, portable and mobile;
- in height one-story, one-and-a-half and two-story;
- at the location of the drive - with a bottom or top drive;
- by the number of connecting rods - single and double connecting rods;
- by the design of the parcel mechanism - with continuous, one-push and two-push feed;
- by the number of parcel rollers - four-roller and eight-roller (the latter are used only in short frames when sawing logs with a length of 1 m);
- by the number of delivery - one-piece and two-piece. [2]

The main indicators that determine the technical characteristics of frame sawmills include the width of the saw frame clearance, crankshaft speed, drive power, feed mechanism system, the maximum value of the constructive feed of the log (package) per one revolution of the crankshaft of the sawmill frame, the weight of the saw frame, and its dimensions, the presence of special devices.

However, in recent years, frame sawmills have been replaced by other types of log saw equipment, mainly band saw machines, which have many advantages over other machines and are more efficient. [2]

1.5.2 Circular Saws for Longitudinal Sawing of Logs and Beams

Circular sawing machines are of two types: for sawing small-sized raw materials; for sawing medium and large logs. In the Scandinavian countries, such equipment is traditionally used for cutting small-sized sawn timber. Machines of the second type have one saw of large diameter (1000-1650 mm) or two, mounted in a vertical plane one above the other with mixing the center of the saw. In the first case, you can cut logs up to 70 cm in diameter, and with two saws - up to 10 cm in diameter. [2]

To ensure the rigidity of the saw blade, the washer diameter must be at least (5 - $\sqrt{D_п}$) ($D_п$ - saw diameter, m) in practice, it varies from 25 to 40% of the saw diameter and is taken equal to 1/3 of the saw diameter. [2]

In terms of design, installation and maintenance, circular saws are much simpler than band saws, but they have a large sawing width for the stability of large diameter circular saws, their greater thickness (4-6 mm) is also required. And in some machines, for example, "Grizzly" (USA), "Canada-2000" (Canada), saws with plug-in teeth are used, which give an even wider kerf.

Of the latest developments, circular saws 2TSDB-60, 2TSDB-80, 2TSDB-100, Moloma-1200, TsDS300-4, 5, USK-1 (Russia), Finnish machines Laimet, Kara and Kara Master deserve attention. [2]

2 Calculation Part

2.1 Choice of Sawmill Equipment

I have used the project of the Altaylestekhmash plant as the main timber processing equipment. This company offers ready-made projects and assemblies to order for all the necessary stages of production. I decided to place two installations of this type.

All information about the equipment was taken from [4] and [5].

This project includes:

1. Beam machine Altai SBC-480
2. Multi-saw 2-shaft machine Altai 2Ts16-350
3. Edge-trimming machine Altai KS-1000

Also, to facilitate the work of staff, the project is equipped with roller tables for feeding logs to the machine and further transporting materials between machines.

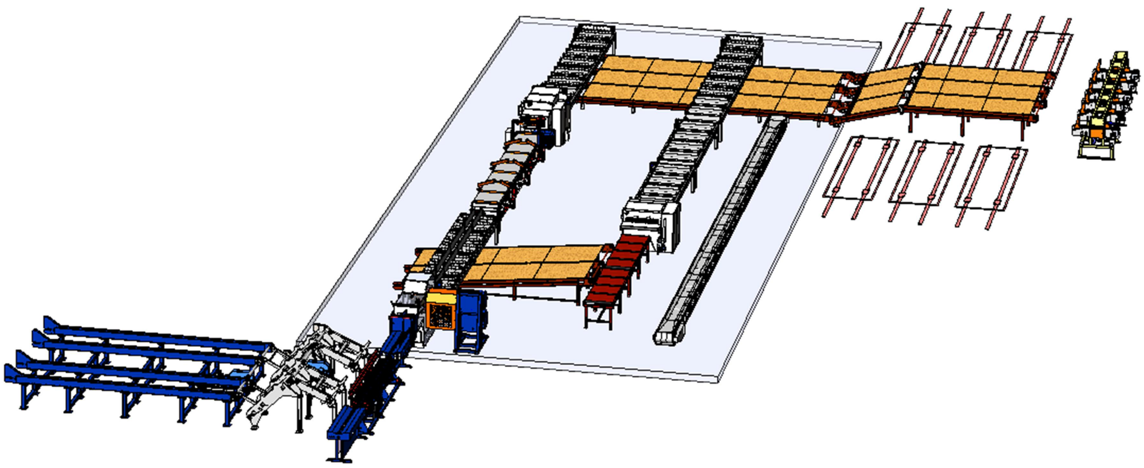

Figure 1 – Project of the Line [5]

The project has the following performance parameters:

- Round wood diameter, mm - 450
- Max. board width, mm - 210
- Productivity, m3 per shift - 100

Round timber is fed to a two-shaft log saw SBC-480, the maximum diameter of the logs is 450 mm.

At the exit from the log saw, we get a carriage and an unedged board.

Further, along the chain conveyor, the carriage is fed to the 2Ts16-350 two-shaft multi-saw machine and is sawn into boards (timber) with a maximum width of 210mm.

Unedged board is fed through a chain conveyor to the multi-saw KS-1000 edge cutter.

The scheme is represented in Appendix A [5].

Below are the parameters of each machine and the schemes of their work, presented on the manufacturer's website [4].

Machine for longitudinal sawing of logs SBC-480

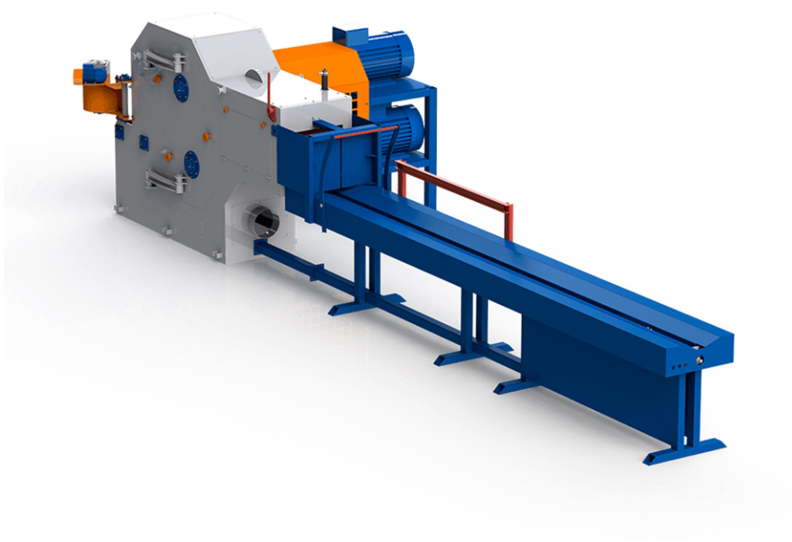

Figure 2- Machine SBC-480 [5]

The machines "Altai-SBC-340" and "Altai-SBC-480" are multi-saw, designed for longitudinal sawing of logs to obtain carriages and unedged boards.

The supply of raw materials to the saw unit is carried out using a chain transport system. The multi rip saw on circular saws ensures reliable operation even with 24/7 loading. Its design meets all modern safety requirements. Easy adjustment of the distance between the saws, provides fast lumber of the desired size.

Table 1- Technical characteristics of the SBC-480 machine [4]

Parameters	**Value**
Diameter of the sawn logs, mm: minimum at the top maximum in the butt	 150 450
Minimum length of logs to be sawn, mm	3000
Estimated productivity of raw materials per shift 8h. With an average diameter of 40 cm, m3	100

Parameters	Value
Main drive power (2 motors), kW	45-75 (37-75)
Feed drive power, kW	3
Saw rotation frequency, rpm	1450
Transport parameters: L, W, H, mm	 8000x2350x2050

Figure 3- Scheme of operation of the SBC-480 machine [4]

Two-shaft multi-saw machine White Shark 2Ts16-350

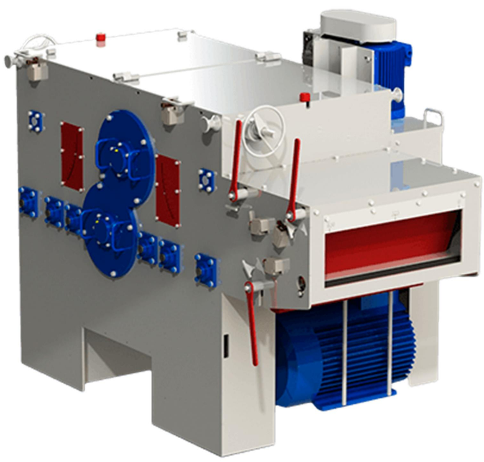

Figure 4- Machine Altai-2Ts16-350 [5]

"Altai-2Ts16-350" machines are multi-sawing two-shaft, designed for longitudinal sawing of a gun carriage and three-edged slab to obtain edged lumber (edged boards, slats, beams and bars).

Table 2 - Technical characteristics of the Altai-2Ts16-350 machine [4]

Parameters	**Value**
Installed power, kW	93
Maximum cross-section of the carriage, mm	650x210
Minimum carriage length, mm	1500
Main power engine, kW	30, 37, 45
Saw rotation frequency, rpm	3000
Longitudinal feed drive, type	electromechanical
Feed motor power, kW	3
Transport parameters: - height, mm - width, mm - length, mm - total weight, kg	 1675 1290 2080 2215

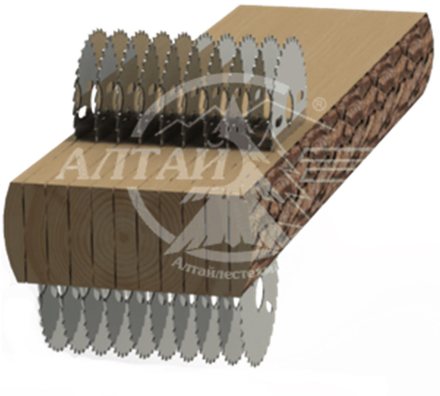

Figure 5- Scheme of the machine Altai-2Ts16-350 [4]

Single-shaft multi-saw machine Altai KS-1000

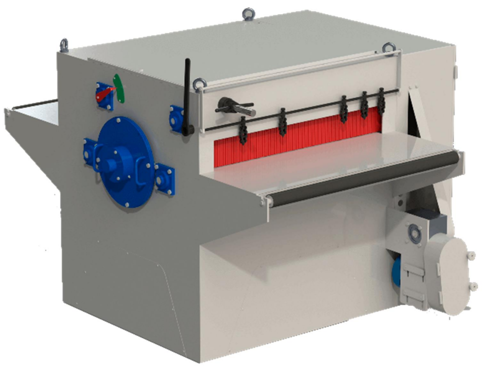

Figure 6- Machine Altai KS-1000 [5]

"Altai-KS-1000" machines are multi-sawing edging, designed for longitudinal sawing of unedged boards and slabs to obtain edged lumber (edged boards, slats, bars, three-edged slab).

Table 3- Technical characteristics of the Altai KS-1000 machine [4]

Parameters	**Value**
Maximum cutting height, mm	100
Maximum distance between extreme saws, mm	940
Saw drive motor power, kW	22, 30, 37, 45, 55
Feed motor power, kW	1.1
Transport parameters: - height, mm - width, mm - length, mm - total weight, kg	 1300 1600 2000 1400

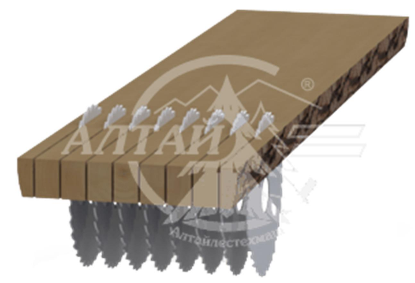

Figure 7- Scheme of the machine Altai KS-1000 [4]

2.2 Methodology for Calculating Energy Consumption Parameters

Subchapters 2.2.1 – 2.2.3 were written based on information from [3].

2.2.1 Graphs of Electrical Loads

Under the conditions of operating enterprises, parameters of actual power consumption modes are revealed, using load graphs; work shifts, daily load graphs are used. Typical parameters of the graphs: maximum half-hour load of P_{max}, kW; its value during the period of maximum loads of the power system P_{max}*, kW (these loads, as a rule, coincide); average shift load P_{shift}, kW, determined by the formula (2.1); average daily P_{day}, kW (2.2); operating factors (exploitation, maximum, reactive power), calculated when processing graphs. [3]

Graphs of loads for work shifts (days), as a rule, differ markedly and therefore their parameters for a single schedule represent a selective, very approximate estimate of the actual values. The most reasonable is the actual load of the elements of the power supply system, the exploitation indicators are determined by a set of graphs. The load P_{shift} for the most loaded shifts determines the utilization rate K_u - the main operational coefficient of the electrified equipment of woodworking enterprises. [3]

$$P_{shift} = \frac{\sum W}{\sum T_w} \quad (2.1)$$

$$P_{day} = \frac{W_{day}}{24} \quad (2.2)$$

$$K_u = \frac{P_{shift}}{P_{nom}} \quad (2.3)$$

where $W_{day}$is the daily electricity consumption, kW * h; $\sum W$is the total volume of power consumption for the analyzed maximum loaded work shifts, kW * h; $\sum T_w$- their duration, h; P_{nom} - total power of power electrical receivers (reserve electric power units are not taken into account), kW. [3]

2.2.2 Method for Calculating Electrical Loads

Electrical loads determine the choice of energy sources; necessary capital investments and consumption of materials for the construction of the power supply system; placement of main electrical equipment, selection of current-carrying elements, switching and protection devices. The initial data for calculating loads are the composition of electrified equipment set by the technological services, its performance indicators (coefficients). [3]

The estimated load of the electrical receiver (ER) is equal to its rated power (specified in the passport). The power of the electric drive of intermittent operating modes is set to LC = 1 (2.4).

$$p_{nom\,100} = p_{nom} \cdot \sqrt{LC} \quad (2.4)$$

where $p_{nom\,100}$ is the nominal power of the electric drive at LC = 1, kW; p_{nom} - nominal (passport) power, kW; LC - the duration of the working period (load cycle) in p.u. [3]

The rated reactive power $q_{nom\,100}$, kvar, is calculated by the formula (2.5), and the value of the current I_c, A, according to (2.6):

$$q_{nom\,100} = p_{nom\,100} \cdot \frac{tg\varphi_{nom}}{\eta_{nom}} \quad (2.5)$$

$$I_c = \frac{\sqrt{p_{nom\,100}^2 + q_{nom\,100}^2}}{\sqrt{3} \cdot U_{nom}} \quad (2.6)$$

where $\eta_{nom}, tg\varphi_{nom}$ - nominal efficiency and reactive power factor (corresponding to $cos\varphi_{nom}$); U_{nom} - rated mains voltage, kV. [3]

In the absence of specific data $q_{nom\,100}$, it is allowed to take $0{,}75p_{nom\,100}$ (continuous duty motors) and $0{,}9p_{nom\,100}$ (intermittent duty motors).

The design load of the group (four ER and more) is found according to (2.11; 2.13) as the product of the average shift loads P_{shift}, kW by the maximum coefficient Km. The calculation is carried out by sequential application of formulas (2.7 ... 2.15)

$$K_u = \frac{\sum_{i=1}^{n} p_{nomi\ 100} \cdot K_{ui}}{\sum_{i=1}^{n} p_{nomi\ 100}} \quad (2.7)$$

$$tg\varphi_{gr} = \frac{\sum_{i=1}^{n} p_{nomi\ 100} \cdot K_{ui} \cdot tg\varphi_i}{\sum_{i=1}^{n} p_{nomi\ 100} \cdot K_{ui}} \quad (2.8)$$

$$P_{shift} = K_u \cdot \sum_{i=1}^{n} p_{nom\ i\ 100} \quad (2.9)$$

$$Q_{shift} = P_{shift} \cdot tg\varphi_{gr} \quad (2.10)$$

where $p_{nomi\ 100}$ is the rated power of the i-th electric drive; $K_{ri}, tg\varphi_i$ - coefficients of usage and reactive power of the same electric drive; n is the number of electronic signatures in the group (reserve ones are not taken into account); K_u, $tg\varphi_{gr}$- group coefficients of utilization and reactive power; P_{shif} , Q_{shif} - average shift loads of the maximum loaded shifts, kW, kvar. [3]

The design load P_c, kW is determined (2.11)

$$P_c = P_{shift} \cdot K_m \quad (2.11)$$

$$n_{ef} = \frac{\left(\sum_{i=1}^{n} p_{nomi\ 100}\right)^2}{\sum_{i=1}^{n} p_{nomi\ 100}{}^2} \quad (2.12)$$

The maximum factor for active power is determined by the group usage factor K_u (2.7) and the effective number of ER n_{ef} (2.12). The graph (Figure 8) Is used for non-automated determination and design load. [3]

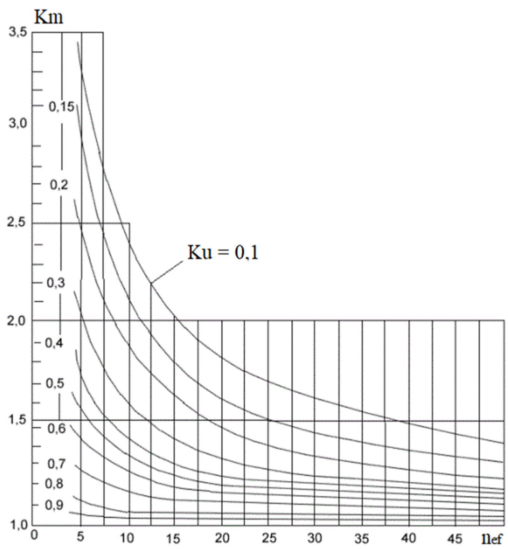

Figure 8- Dependence of the maximum coefficient Km on the effective number of electric drives $\boldsymbol{n_{ef}}$ at different values of the group usage coefficient $\boldsymbol{K_u}$. [3]

When determining the calculated current I_c (total power S_c), the load Q_c is taken according to (2.13):

$$Q_c = Q_{shift} \cdot K_{mQ} \tag{2.13}$$

$$K_{mQ} = 1 + \frac{1}{6\sqrt{n_{ef}}} \tag{2.14}$$

In manual calculations, dependence (2.14) is usually roughened, taking $K_{mQ} = 1.1$ at n_{ef} less than 10 and $K_{mQ} = 1$ at $n_{ef} \geq 10$.

The calculated current I_c, A is found by (2.15)

$$I_c = \frac{\sqrt{P_c^2 + Q_c^2}}{\sqrt{3} \cdot U} \tag{2.15}$$

To calculate the load of the workshop, it is necessary to know the LC (duration of load cycle) of electrical receivers. The LC calculation was carried out, using video materials on the operation of machines provided by equipment manufacture and are freely available. Drives have intermittent operation mode (S6), there are standard LC for this type of operation mode: 15%, 25%, 40% and 60%.

To determine the LC ER, the formula (2.16) is used:

$$LC = \frac{t_w}{t_c} * 100\% \tag{2.16}$$

where t_w is the useful work time of the electric drive, t_c is the duration of the entire cycle.

2.2.3 Methods for Calculating Electric Lighting

Indoor lighting in a production area, called work lighting, can be general, local, or combined. Sometimes, along with work lighting, emergency lighting is also installed. With general lighting, the required illumination is created over the entire area, that is, both at workplaces and in auxiliary areas. In this case, the illumination can be uniform over the entire area or its individual sections can be illuminated to a greater extent. In this case, the lighting is called localized.

To provide general uniform illumination, the light sources are suspended above the working surfaces at the same distance from each other. In this case, the lamps are chosen of the same brand, and the lamps are of the same power. With localized lighting, the brands of lamps, their location, and lamp power are selected in accordance with the requirements for the illumination of workplaces. [3]

General lighting is necessary for rooms where the working surface is every section of the floor (assembly shops, warehouses, etc.), where it is needed for general observation of machines and mechanisms, as well as where workers do not need to distinguish between small parts. General lighting is used in cases where local lighting is unacceptable for production reasons (large machines, woodworking machines, machines with long working surfaces) and in non-production public premises.

With local lighting, the required illumination is created only on the working area, for which the lamps are placed directly at the workplace. Local lighting can cause abrupt transitions from highly lit areas to clogged lit areas. To avoid this, the rules and regulations for electrical installations provide for creating general lighting in rooms with local lighting. In this case, the lighting is called combined. The illumination generated by general-purpose luminaires should be at least 30 lux with incandescent lamps and 100 lux with fluorescent lamps. [3]

Combined lighting is used when the precision of processing parts requires illumination of more than 50 lux; working surfaces occupy a very small part of the total area; general lighting creates shadows and highlights; working surfaces are located vertically or obliquely, and also require periodic changes in the direction of the incident light.

Emergency lighting is arranged in rooms in which work cannot be stopped or when it is necessary to urgently evacuate people when the working lighting is turned off. Emergency lighting created for the continuation of work should ensure the illumination of the room at least 10% normal, for the evacuation of people on the main aisles and stairs - at least 0.3 lux, in open places - at least 0.2 lx. In small industrial premises, stationary emergency lighting can be replaced with portable electric lights. [3]

When calculating electric lighting, they proceed from the size of the illuminated area, the nature of production or household premises and the minimum illumination standards. For the territories of workshops and other premises of the woodworking industry, the following standards of minimum illumination of working surfaces are adopted:

- sawmill, joinery, furniture, ski, plywood, match and house-building production - 10 lux;
- sections of chippers, vacuum reactors, resin production shop, compressor and pumping stations - 5 lux;
- finishing department - 15 lux;
- sections for the preparation of the impregnating solution, workshops for wood laminated plastics, a particleboard workshop (except for the manufacture of shavings and final processing of boards), workshops; wood fiberboards; wood flour; lamination of boards and plywood, as well as instrumentation rooms - 10 lux. [3]

Power density calculation method

The basis for calculating the illumination by this method is the specific power, i.e. the power spent on lighting 1 m^2 of the area of an object.

For various buildings, workshops, and premises the following norms of specific power for lighting in W / m^2 are taken. [3]

Forest exchanges in places with manual loading 1.3 - 1.5; places of various works with mechanisms 1.5 - 2.0; timber warehouses 0.15 - 0.2; factory areas, dead-end and sorting railway tracks 0.1; repair shops when performing minor works 10-20; the same, when performing work that does not require distinguishing between small details 8 -10; the same, with other works 5-8; smithy 5-7; woodworking shop 7 - 8; wood dryer 5-7; garages 3-5; toilets, washbasins, showers, baths 4-5; canteens, recreation rooms 12 - 15; passages, stairs, corridors, storerooms, warehouses and rooms for storing large and bulky materials 1.2 - 1.5; offices, shops, meeting rooms 5-7; treatment rooms 25 - 30; power plants, substations 10 - 15; living rooms, dormitories 6-8; classrooms, auditoriums, and nurseries 18-20.

The total power is determined by using formula (2.17)

$$\sum_{i=1}^{n} P_{cal\ il} = p \cdot S \tag{2.17}$$

where p - specific power for lighting, W / m^2; S – area of the workshop, m^2. [3]

2.3 Calculation of Electrical Loads of the Sawmill

As the main drives of woodworking machines, I have chosen Siemens motors of the 1MJ7 and AOM series. Motors of these series are manufactured in explosion-proof design, which indicates the possibility of their use in technological dangerous processes. The use of spark arresters ensures trouble-free operation of electric motors in conditions in which devices used by other manufacturers are out of order and perform maintenance much faster. The presence of such equipment at a woodworking enterprise is necessary to avoid hazardous situations associated with fire, both wood and its processing products (chips, suspended dust, etc.) [6].

AOM series motors are used as auxiliary motors, as their power range is 0.25-37 kW, and for drives of a higher power, the 1MJ7 series is used, their range is 18.5-200 kW.

All engine specifications were taken from [6] and [7].

For the SBC-480 machine, it is necessary to select two 45kW and one 3kW motors.

For the Altai-2Ts16-350 machine, two main drives with a power of 37 kW are required, and the motor for feeding is accepted as for the previous machine.

In the case of the Altai KS-1000 machine, I have selected 2 motors of the AOM series with a capacity of 37 kW and 1.1 kW.

The technical characteristics of all engines are summarized in Table 4.

Table 4 – Technical characteristics of Siemens motors [6]

P, kW	Type	n, rpm	η,%	cosφ	I, A 380/400V	M, Nm	$\frac{M_{start}}{M_{nom}}$	$\frac{I_{start}}{I_{nom}}$	$\frac{M_{max}}{M_{nom}}$	J, $kg * m^2$	M, kg
45	1MJ7223-2CB	2955	93.9	0.9	77	145	2.3	6.9	2.7	0.24	335
37	AOM-200L	2950	92,2	0,90	68/64	120	2.5	6.9	2.5	1.172	280
11	AOM-160MK	2915	86.4	0.87	22.5/21	36	2	5	2.1	0.032	115
7,5	AOM-132S	2900	85	0.87	15.5/14.5	24.7	2	6	2.5	0.015	81
5,5	AOM-132SK	2890	83	0.87	11.5/11	18.2	1.8	5.8	2.4	0.012	76
3	AOM-100L	2850	81.0	0,90	6.2/5.9	10.1	3.0	6.7	3.2	0.0043	38

2,2	AOM-90L	2865	81	0.88	4.7/4.5	7.3	2.5	6	2.7	0.0026	29
1,5	AOM-90LK	2870	79	0.87	3.3/3.2	5	2.2	6.1	2.7	0.0021	27
1.1	AOM-80M	2825	78,0	0,87	2.5/2.3	3.72	2.1	5.3	2.6	0.0012	20
0,75	AOM-80MK	2850	75	0,85	1.8/1.7	2.5	2	5.3	2.6	0.001	19

Using method from 2.3.2 I have calculated the load of the workshop. Table with all values is represented in Appendix B.

Applying formulas (2.7 – 2.15) I determined the load of the line.

$$K_u = \frac{125,39}{225,18} = 0,557$$

$$tg\varphi_{gr} = \frac{62,89}{125,39} = 0,502$$

$$P_{shift} = 0,5568 \cdot 225,18 = 125,39 \text{ kW}$$

$$Q_{shift} = 125,39 \cdot 0,5016 = 62,89 \text{ kvar}$$

$$n_{ef} = \frac{(225,18)^2}{5668,51} = 8,95$$

After I have found K_u and n_{ef}, I can conclude that $K_m = 1,4$, according to the graph on Figure 8.

$$P_c = 125,39 \cdot 1,4 = 175,55 \text{ kW}$$

$K_{mQ} = 1.1$, because $n_{ef} < 10$

$$Q_c = 62,89 \cdot 1,1 = 69,18 \text{ kvar}$$

$$I_c = \frac{\sqrt{175,55^2 + 69,18^2}}{\sqrt{3} \cdot 0,38} = 286,68 \text{ A}$$

$$S_c = \sqrt{175,55^2 + 69,11^2} = 188,69 \text{ kVA}$$

To calculate power, which is needed for workshop illumination I have to know the area of it. According to Appendix A, I have made a plan of the workshop (Figure 9)

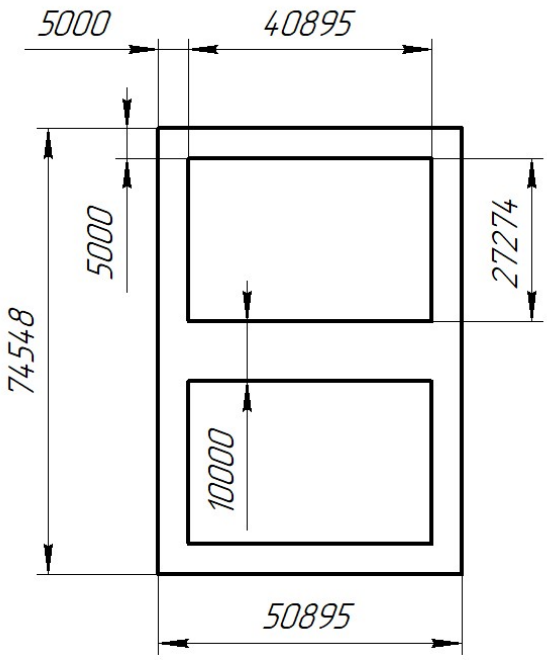

Figure 9 – Plan of the sawmill

$S = 74{,}548 * 50{,}895 = 3794{,}12 \text{ m}^2$

According to (2.17), the total active power for illumination is

$$\sum_{i=1}^{n} P_{cal\ il} = \frac{8 \cdot 3794{,}12}{1000} = 30{,}35 \text{ kW}$$

The reactive power can be found as:

$$Q_{cal\ il} = P_{cal\ il} \cdot tg\varphi_{lamp} = 30{,}35 * 0{,}484 = 14{,}69 \text{ kvar}$$

where $tg\varphi_{lamp}$ - reactive power factor of the lamp ($cos\varphi_{lamp} = 0{,}9$).

The total power of the workshop:

$$S_{workshop} = S_C + \sqrt{P_{cal\ il}^2 + Q_{cal\ il}^2} = 188{,}69 * 2 + \sqrt{30{,}35^2 + 14{,}69^2} = 411{,}09 \text{ kVA}$$

But also we should take into account auxiliary buildings for workers. On sawmill we have 3 shifts, so we have to hire operators for each of them. There should be at least 2 operators for one machine and 2 masters for a shift. Also, we have 2 shifts for cookers. In total, we have 22 operators and 2 masters for one shift. As an accommodation, I've chosen wagons for oil workers, which are ready for life. The main electricity consumers in these wagons are heating devices such as stove and convectors. For heating equipment power factor is equal to 1. Information about wagons was taken from [8]

Table 5 – Wagons load [8]

Wagon	**Amount of wagons**	**Equipment**	**Amount**	**Nominal power, kW**	**Power factor cosφ**	**Usage coefficient**	**P_{shift}, kW**
Kitchen	1	Industrial stove with 4 burners	1	16,8	1	0,3	5,04
		Convector	3	1,5	1	0,5	2,25
		Water boiler 100l	1	1,5	1	0,2	0,3
Living wagon for 6 people	11	Convector	4	1,5	1	0,5	33
		Water boiler 100l	1	1,5	1	0,2	3,3
Living wagon for 4 people	1	Convector	3	2	1	0,5	3
		Water boiler 100l	1	1,5	1	0,2	0,3
Living wagon for 2 people	3	Convector	3	1,5	1	0,5	6,75
		Water boiler 100l	1	1,5	1	0,2	0,9
Canteen	1	Convector	3	1,5	1	0,5	2,25

$$S_{wagons} = \sum P_{shift\,i} = 57{,}09\ kW$$

The total load of the sawmill:

$$S_{total} = S_{workshop} + S_{wagons} = 411{,}09 + 57{,}09 = 468{,}18\ kVA$$

I've built a theoretical daily load diagram based on videos which can be found on [4].

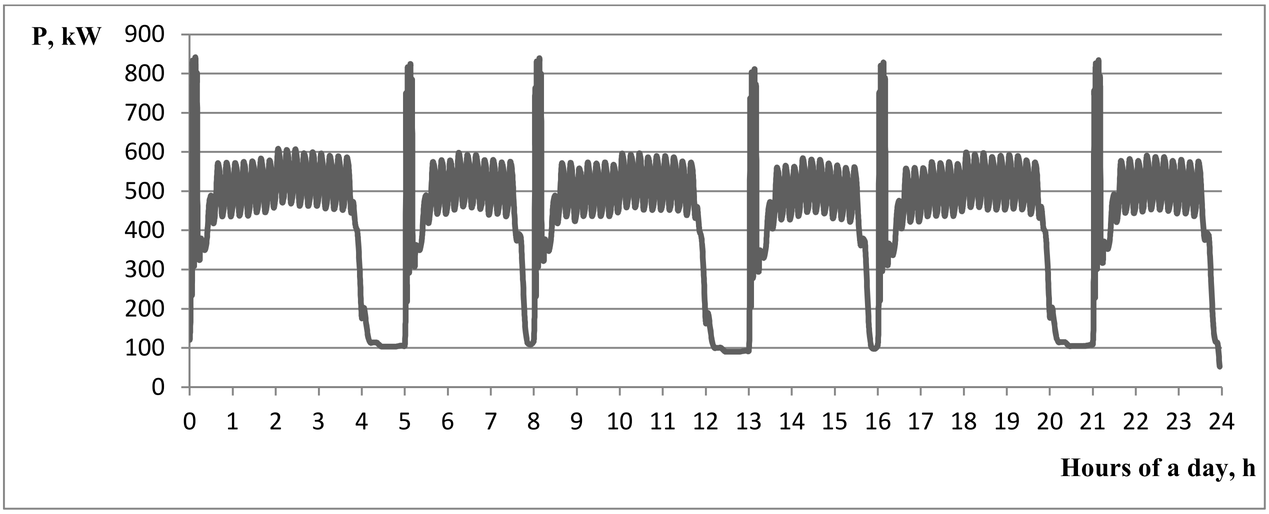

Figure 10 – Daily load diagram

On this graph, it is seen that at the beginning of the shift and after the lunch break starting of the motors sharply increases the load.

2.4 Selection of Main Electrical Equipment

In this work, I consider two different types of power supply: electric network and diesel generator. In these alternatives, I have a difference just in high voltage equipment, while low voltage equipment is the same.

2.4.1 Power Supply Options for the Enterprise

As it was said in 1.1, wood processing enterprises are usually placed near sources of wood. As a consequence, it can lead to a long distance from the electricity source.

The first option for a power supply is the connection to the electrical network. In this case, I have to consider the network as weak due to remoteness from the big electricity source. It means that there are high losses of power and voltage in lines and a high level of sensitivity to disturbances in the sawmill system. It is estimated that there is a complete distribution substation 10 kV/0,4 kV on the territory of the sawmill.

The second option is to install a diesel generator. The sawmill is placed far enough from cities and villages, but it is still not a good choice from an ecological point of view. However, we have an independent source of power and can install it in any place in the country. Diesel generator depends on system disturbances as well, but the stability of generator should be taken into account in this case.

When motors start they have a sharp increase of current what leads to a sharp decrease of voltage in this local system. This decrease can lead to significant damage of wood processing equipment due to a decrease of machine power. For both options, it is needed to choose the way to decrease start current or voltage losses in the supply system of the enterprise.

2.4.2 Selection of Substation Equipment when Powered from a Weak Network

In the variant with network connection, I have to choose the type of complete substation with the definite number of transformers and correct power. The category of power supply reliability should be taken into account. The sawmill is the recipient of the third category, which means that it can have just one source of energy.

According to the rule from [10], the load coefficient for transformers of the third category receivers is equal to 0.9 – 0.95.

Based on calculations in 2.4, I can calculate the power of transformers using information from [11].

$$S_{tr} = \frac{S_{total}}{n_{tr} * k_{load}} \tag{2.18}$$

where S_{total} – total load of the sawmill, kVA; n_{tr} – number of transformers; k_{load} – load coefficient of the transformer.

$$S_{tr} = \frac{468{,}18}{1 * 0{,}9} = 520{,}2\ kVA$$

The closest power to this value is 630 kVA, which means that I'll have some extra power that can be connected to this transformer.

Parameters of the complete substation with transformer 630 kVA are represented in Table 6.

Table 6 – Parameters of substation and transformer [12]

Parameter	**Value**
Type	TMG
Nominal power, kVA	630
Nominal voltage of HV side, kV	10
Nominal voltage of LV side, kV	0,4
Scheme of connection	Delta/Yn-11
Material of windings	Aluminum, copper
Permissible operating temperature	from -45 to +40 °C
Idle power losses, W	1050
Short-circuit power losses, W	7600
Idle current, %	2
Short-circuit voltage, %	5,5
Overall dimensions of a transformer, mm	1820x1150x1910
Overall dimensions of substation, mm	3040x2100x2400

Usually when projects are designed the engineer can stop here and choose a transformer of such power to save money on a transformer and installed power fee.

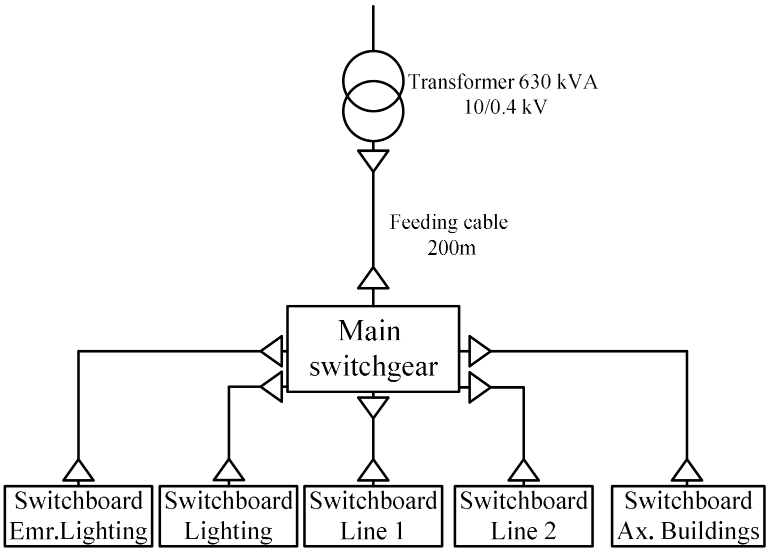

Figure 11 – Supplying scheme of the sawmill with connection to the network

But as can be seen on Figure 10, during the start of the motors, power can reach 830 kW what can lead to an overload of the transformer and significant voltage losses, especially if there will some additional load on the transformer. That is why I have to research different ways to decrease starting current or to substitute equipment with another with the higher power.

2.4.3 Selection of Equipment when Powered by Diesel Power Plant

A diesel generator has to be able to produce enough power for starting of motors, that’s why I’ve chosen the generator according to load during the motors’ starting.

The generator ADG-ENERGY AD-1250WP has nominal active power 900 kW. The main parameters are represented in Table 7.

Table 7 – Parameters of the diesel generator ADG-ENERGY AD-1250WP [13]

Parameter	**Value**
Company	ADG-ENERGY
Model	AD-1250WP
Main power, kW	900
Main power, kVA	1125
Reserve power, kW	1000
Reserve power, kVA	1250
Voltage, V	400/230
Type of current	alternating
Number of phases	3
Nominal frequency, Hz	50
Nominal current, A	1805
Power factor, $\cos\varphi$	0,8
Fuel consumption with 100% power, l/h	240
Fuel consumption with 75% power, l/h	174,4

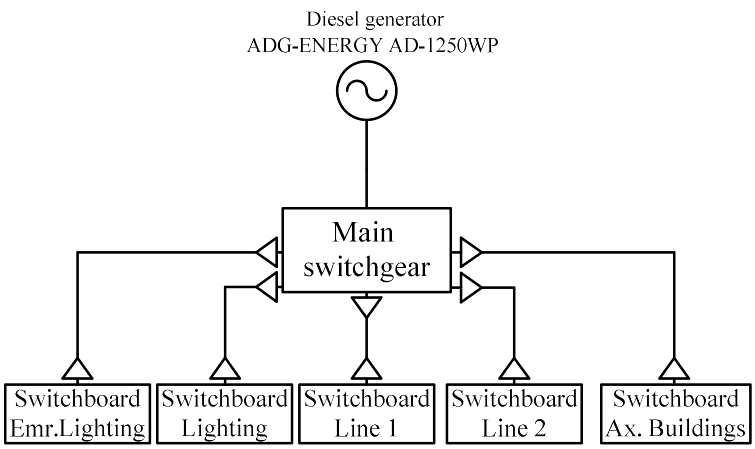

Figure 12 – Supplying scheme of the sawmill with diesel generator

2.4.4 Choice of Feeding Cable

Feeding cable is chosen according to [14]

$$I_c = \frac{S_{tr}}{\sqrt{3} * U_{nom}} \quad (2.19)$$

where S_{tr} – nominal power of transformer, kVA; U_{nom} – nominal voltage of cable, kV.

According to this formula:

$$I_c = \frac{630}{\sqrt{3} * 0{,}4} = 909{,}33\ A$$

The cross-section of the cable line is selected according to the economic current density. Economically feasible section F, mm^2, is determined from the expression:

$$F_{ec} = \frac{I_c}{j_{ec}} \quad (2.20)$$

where j_{ec} - the economic current density, A/mm^2.

In [10] the economic current density for copper cable is equal to 2.5 A/mm^2.

$$F_{ec} = \frac{909{,}33}{2{,}5} = 363{,}73\ mm^2$$

According to the catalog of products of different cable companies, the permissible current of $400mm^2$ cable is 611 A, which is not enough that is why there should be several feeding cables.

$$n_{cables} = \frac{I_c}{I_{cable}} \quad (2.21)$$

where I_{cable} - permissible current of cable, A.

If we will increase the number of cables, we can decrease the cross-section of the cable. I've taken that the cable cross-section is equal to 240 mm^2. The permissible current of this cable is 471 A.

$$n_{cables} = \frac{909{,}33}{471} = 1{,}93$$

The number of cables is equal to two. The parameters of the cable are represented in Table 8. [15]

Table 8 – Parameter of the cable [15]

Parameter	**Value**
Type	VVGng (PVC-insulated cable)
Cross-section, mm^2	240
Number of cores	3
Permissible current (air), A	472
Permissible current (ground), A	471

Permissible short-circuit current, A	26800
Resistance, Ohm/km	0,078

2.5 Calculation of Voltage Quality Improvement Options

In connection with the possible remote location of sawmills from large sources of electricity, there is a problem of high voltage losses in the process of power transmission, as well as increased sensitivity of the voltage level to sharp increases in power at the enterprise. A significant decrease in the voltage level in the network can lead to disruption of the operation of sawmills, namely, to a decrease in the power of the equipment for a short time. In case of insufficient power, the cutting mechanism (saw) can get stuck in the log being cut, while the feed conveyor will move the log in a standard mode, which will lead to damage to expensive equipment.

Considering the above factors, it is necessary to choose a way to maintain the voltage at the required level throughout the entire technological process.

Two ways to avoid voltage drops in the power supply network, which can be implemented on the territory of the enterprise, are accepted for consideration:

1. Replacement of the transformer and the feeding cable line
2. Soft starter (SS)

2.5.1 Substitution of the Transformer and the Feeding Cable Line

In the process of calculating the required power of the transformer, the main indicator is the workload of the enterprise. However, it is also necessary to take into account short-term increases in the power flow, such increases include the moments of starting the motors. The starting current can be many times higher than the operating current of the motor, especially heavy starting of the motor is characterized by an increase in current up to 7-10 times. Such an increase in current can lead to a significant overload of the transformer and increase the voltage loss on the windings of the transformer, which in turn will lead to a malfunction of the cutting mechanisms (saws) at the sawmill.

Voltage losses in a transformer can be calculated using the formula [16]:

$$\Delta U = \frac{P \cdot R_{TR} + Q \cdot X_{TR}}{U_{nom}} \tag{2.22}$$

where P - the active power flow through the transformer, kW; Q - the flow of reactive power through the transformer, kvar; R_{TR} — active resistance of the transformer, Ohm; X_{TR} - transformer reactance, Ohm; U_{nom} - rated voltage of the upper side of the transformer, kV.

Active and reactance depends on the power of the transformer and are defined as [16]:

$$R_{TR} = \frac{\Delta P_{sc} \cdot U_{nom}^2 \cdot 10^3}{S_{TR}^2} \quad (2.23)$$

$$X_{TR} = \frac{u_{sc} \cdot U_{nom}^2}{100 \cdot S_{TR}} \quad (2.24)$$

where ΔP_{SC} - the short-circuit loss of the transformer, kW; u_{SC} - short-circuit voltage of the transformer,%; S_{TR} - rated power of the transformer, kVA.

From these formulas, it can be seen that the resistance and power of the transformer are inversely proportional. Therefore, in the case when it is necessary to reduce voltage losses in the transformer windings during short-term overloads that arise, it is necessary to consider the option of replacing the installed transformer with a transformer of a higher power.

With an incorrectly selected cable cross-section, voltage losses can be quite high. Voltage losses in the cable line are calculated according to the following formula [16]:

$$\Delta U = \frac{P \cdot R \cdot l + Q \cdot X \cdot l}{U} \quad (2.25)$$

where P - the active power flow in the power system, kW; Q - the flow of reactive power in the power system, kvar; R - the specific active resistance of the conductor, Ohm/km; X - the specific reactance of the conductor, Ohm/km; l - conductor length, km; U - the rated mains voltage, kV.

In this case, the specific active resistance is determined by the formula [16]:

$$R = \frac{\rho}{S} \quad (2.26)$$

where ρ - the specific resistance of the material, $\frac{Ohm \cdot mm^2}{m}$; S - conductor cross-sectional area, mm^2.

From the formula presented above, we can conclude that the voltage loss in the cable and the cable cross-section have an inverse relationship, the larger the conductor cross-sectional area, the lower the voltage loss.

During design, the influence of inrush currents on the cable load may not be taken into account, as a result of a sharp increase in the power (current) flux.

In this case, to avoid increased losses of electricity and voltage in the cable, it is necessary to recalculate taking into account inrush currents, and select a cable with a large cross-section.

In this case, the next step of transformer available power for chosen complete substation 10/0.4kV is 1000kVA. The parameters of this transformer are represented in Table 9. [12]

Table 9 – Parameters of substation and transformer [12]

Parameter	**Value**
Type	TMG
Nominal power, kVA	1000
Nominal voltage of HV side, kV	10
Nominal voltage of LV side, kV	0,4
Scheme of connection	Delta/Yn-11
Material of windings	Aluminum, copper
Permissible operating temperature	from -45 to +40 °C
Idle power losses, W	1550
Short-circuit power losses, W	10200
Idle current, %	2
Short-circuit voltage, %	5,5
Overall dimensions of transformer, mm	2000x1250x2100
Overall dimensions of substation, mm	3040x2100x2400

It is not necessary to change the substation building because the size of new transformer is suitable for the previous building. According to formulas (2.22) – (2.24) I've calculated the difference in the voltage losses by substitution of transformer:

$$R_{TR\,630} = \frac{7600 * (0{,}4 * 10^3)^2}{(630 * 10^3)^2} = 0{,}00306\ \text{Ohm}$$

$$R_{TR\,630} = \frac{10200 * (0{,}4 * 10^3)^2}{(1000 * 10^3)^2} = 0{,}00163\ \text{Ohm}$$

$$X_{TR\,630} = \frac{5{,}5 * (0{,}4 * 10^3)^2}{100 * 630 * 10^3} = 0{,}014\ \text{Ohm}$$

$$X_{TR\,1000} = \frac{5{,}5 * (0{,}4 * 10^3)^2}{100 * 1000 * 10^3} = 0{,}0088\ \text{Ohm}$$

$$\Delta U_{TR\,630} = \frac{P \cdot 0{,}00306 + Q \cdot 0{,}014}{400} = (7{,}66 * P + 34{,}92 * Q) * 10^{-6}$$

$$\Delta U_{TR\,1000} = \frac{P \cdot 0{,}00163 + Q \cdot 0{,}0088}{400} = (4{,}08 * P + 22 * Q) * 10^{-6}$$

Let's assume that P is equal to 100kW and Q is equal to 50 kvar to compare voltage losses.

$$\Delta U_{TR\,630} = (7{,}66 * 100 * 10^3 + 34{,}92 * 50 * 10^3) * 10^{-6} = 2{,}51\ \text{V}$$

$$\Delta U_{TR\,1000} = (4{,}08 * 100 * 10^3 + 22 * 50 * 10^3) * 10^{-6} = 1{,}51\ \text{V}$$

$$\frac{\Delta U_{TR\ 1000}}{\Delta U_{TR\ 630}} = \frac{1{,}51}{2{,}51} = 0{,}6$$

I can conclude that by substitution of transformer we can reduce voltage losses by 40%.

Also, I have to change the feeding cable to fit a new possible nominal power flow.

In this case, the number of cables is two as it was previously. According to (2.19), nominal current of transformer:

$$I_c = \frac{1000 * 10^3}{\sqrt{3} * 0{,}4 * 10^3} = 1443{,}4 \text{ A}$$

$$I_{cable\ c} = \frac{1443{,}4}{2} = 721{,}7 \text{ A}$$

The calculated current of the cable is too high, so I have to increase the number of cables to 3.

$$I_{cable\ c} = \frac{1443{,}4}{3} = 481{,}13 \text{ A}$$

I've chosen cable according to permissible current. The previous type of cable has a permissible current 472 A, that is why the cross-section of the cable has to be increased.

Table 10 – Parameter of the cable [15]

Parameter	**Value**
Type	VVGng (PVC-insulated cable)
Cross-section, mm^2	300
Number of cores	3
Permissible current (air), A	542
Permissible current (ground), A	533
Permissible short-circuit current, A	33490
Resistance, Ohm/km	0,06

In formula (2.25), I can neglect the reactance of the cable because it is much lower in comparison with resistance.

For the cable lines with cross-section 240 mm^2:

$$\Delta U_{240} = \frac{P \cdot \frac{0{,}078}{2} \cdot 0{,}2}{0{,}4 * 10^3} = 0{,}0000195P$$

$$\Delta U_{300} = \frac{P \cdot \frac{0{,}06}{3} \cdot 0{,}2}{0{,}4 * 10^3} = 0{,}00001P$$

$$\frac{\Delta U_{300}}{\Delta U_{240}} = \frac{0{,}00001P}{0{,}0000195P} = 0{,}5128$$

By cable substitution, I can reduce voltage losses in feeding cables by 48.72%.

2.5.2 Soft Starter

Asynchronous electric machines with a squirrel-cage rotor have a fairly low cost and optimal power-to-weight ratio. They are also distinguished by ease of maintenance and repair, reliability. One of the main disadvantages of motors of this design is a 5-10 times increase in current during start-up. In this case, the magnitude of the voltage in the network decreases. To eliminate undesirable phenomena, various devices and schemes for connecting electric motors are used.

Various methods are used to start induction motors. In practice, the following methods are most widespread:

a) changes in the design of electric motors (rotors with deep grooves, such as "double squirrel cage");

b) direct start;

c) starting at reduced voltage;

d) frequency start.

Special design motors are significantly more expensive than conventional electrical machines, which severely limits their use. [17]

A soft starter is electrical equipment for starting and accelerating the engine and matching the starting torque on the shaft with the load. The soft starter circuit is built based on power thyristors or simmistors. The device is a transformerless stepless voltage converter. Soft starters are used:

- For connecting powerful asynchronous electric motors to a low power network.
- For smooth starting, acceleration and stopping of electrical machines.
- If it is necessary to start the engine under load.
- To reduce inrush currents. [17]

Soft starters make it possible to abandon expensive and imperfect schemes for starting electric motors, as well as significantly expand the scope of application of inexpensive and functional asynchronous machines with a squirrel-cage rotor. They are used in the drive of technological equipment:

1. Easy start. The starting currents under these conditions do not exceed three times the rated value.
2. Heavy start. At the start of the electric motor, the current increases by 4-5 times, the transient processes in the circuits last more than 30 seconds.
3. Particularly difficult start. In this case, the starting current exceeds the rated one by 7-10 times. The transient process takes a long time.

Soft starters have a relatively low cost, small size and weight in comparison with frequency converters. [17]

The principle of operation of the SS

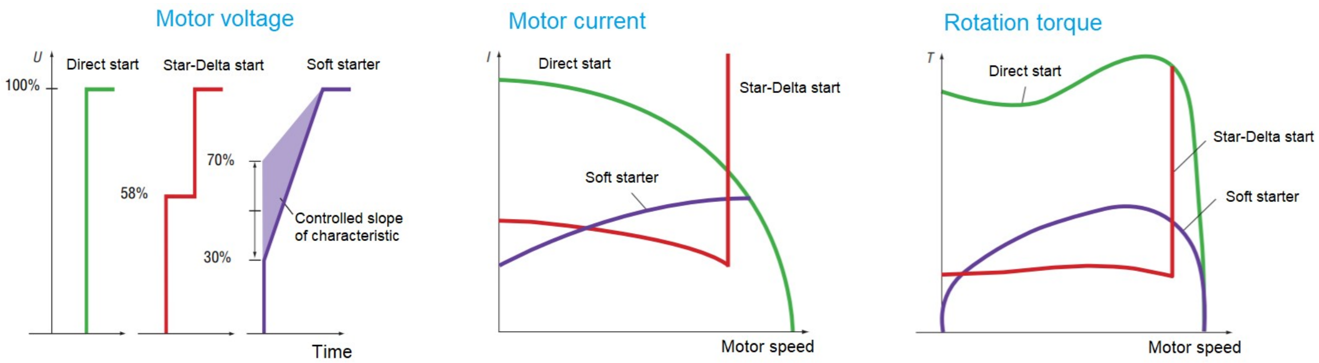

Figure 13 - Principle of start regulation by soft starter [18]

The power section of the soft starter consists of power thyristors connected in antiparallel and bypass contactors. The voltage change is achieved by adjusting the conductivity of semiconductor devices by supplying firing pulses to the control contacts.

The SS also includes:

- Generator of control impulses. This unit generates signals that change the angle of conduction of semiconductor devices when starting and stopping the electric motor.
- Control device based on controller or microprocessor. Its main functions are to send commands to the pulse generator, provide communication with other devices, receive signals from sensors, and provide a protective shutdown of an electrical machine in emergency and abnormal operating modes.

The start of an electric machine is carried out at a voltage of 30-60% of the nominal. In this case, there is a smooth engagement of the gears of the transmission mechanism, a gradual tension of the drive belts. Further, the control unit gradually increases the conductivity of the thyristors until the electric motor is fully accelerated. When the rated shaft speed is reached, the contacts of the shunt switching devices close. The current begins to flow bypassing the thyristors. This is necessary to reduce the heating of semiconductor devices, increase the service life of the soft starter, and reduce energy consumption. [17]

When the motor stops, the contactor switches on the thyristors in the circuit. From the pulse generator, signals are received that smoothly reduce the conductivity of the thyristors until the electric machine stops.

According to the method of voltage regulation, one-, two-, three-phase devices are distinguished:

1. Soft starter with voltage regulation in one phase. They are used in the electric drive of equipment with a power of 11 kW. Such soft starters ensure the reduction of dynamic

shocks and the absence of jerks at the start of the drive. The disadvantages of devices of this type are asymmetric load at start-up, high starting currents.

2. Two-phase soft starters. They are used in drives with power up to 250 kW to reduce dynamic loads during start-up. Provide some reduction in starting currents, engine heating. It is used in equipment with moderate starting conditions without stringent current-limiting requirements.

3. Three-phase soft starters. Soft starters of this type reduce the starting currents to 3 times the nominal value, allow a soft stop, and provide an emergency shutdown of the drive. Voltage regulation is carried out in all three phases, which excludes the appearance of asymmetry. The rated power of the drive is limited only by the characteristics of the semiconductor power elements. Such soft starters are used in a drive with especially severe starting conditions, with frequent starts and stops. [17]

Modern soft starters - multifunctional electrical devices. Their main purpose is to reduce starting currents and mitigate dynamic shocks when starting the engine. Besides, SS provides:

- Start at rated torque. In this case, at the start, the maximum voltage is applied to the electric motor, after which the thyristors are turned on. Acceleration to the rated frequency is smooth. Soft starters of this design are used for mechanisms with a significant starting load.
- Dynamic braking. Soft starters with this function ensure that the drive stops without coasting. They are installed in the drive of inertial technological equipment: traction fans, hoists, etc.
- Start as a function of current and voltage. Soft starters of this design allow you to set the limit value of the starting current. The devices are used at low mains power, as well as in the drive of equipment with a low starting torque.
- Protection of the electric motor. Soft starters ensure that the drive stops in the event of phase loss, overloads, exceeding the acceleration time, as well as in the event of other abnormal and emergency modes. Soft starters do not have short circuit protection and are switched on through fuses or circuit breakers.
- Integration into ATS and telemechanics systems. Soft starters with processor control units and devices supporting communication protocols with remote control equipment can be easily integrated into multi-level automation systems for technical processes.
- Adjustment of the shaft rotation frequency. Soft starters with this function do not replace frequency converters. This mode is permissible if the equipment is set up for a short time. [17]

The choice of the soft starter functionality depends on the requirements for the electric drive and is carried out based on technical and economic feasibility. [17]

The main advantage of the soft starter is a decrease in the amplitude of the starting current, in comparison with the existing schemes for starting asynchronous motors.

Also, such devices have the following advantages:

1. Extension of the service life of the engine and technological equipment. The soft starter reduces the heating of windings, contacts, and also eliminates dynamic shocks.

2. Significant reduction in the cost of the hardware of the electric drive. Installing soft starters allows you to save on protection schemes, install less powerful switching devices.

3. Reducing the load on the power grid. Soft starters reduce inrush currents and prevent voltage drops in power grids. This is especially true with the limited power of transformers and the use of autonomous power supplies.

4. Improving production safety. Smooth start and acceleration will reduce injuries in case of equipment breakdowns associated with jerking at startup, the likelihood of water hammer, and other emergencies.

5. Reducing the induced interference at the start. Soft starters reduce the intensity of the magnetic field when the motor is started. Soft starters allow you to refuse filters for control cables.

6. Low cost. Soft starters are several times cheaper than frequency converters of the same power. It is beneficial to use soft starters under a constant load of equipment in conditions where the limitation of starting currents and starting torque are the main requirements.

Soft starters also replace mechanical brakes and kinematic stopping devices. Besides, soft starters allow the use of asynchronous motors with a squirrel cage rotor instead of expensive electric machines with improved starting characteristics or phase rotor. [17]

Selection of soft starter

The highest currents occur during the start of motors with power 37kW and 45kW.

I've decided to use soft starters of ABB Company. The parameters of soft starters are represented in Table 11. [18]

Table 11 – Parameters of soft starters [18]

Parameter	**1**	**2**
Model	PSR72	PSR85
Motor power (400V), kW	37	45
Nominal current, A	72	85
Motor protection circuit breaker (50kA), type	MS495	

Results of using soft starter:

Before installation of soft starter:

$$I_{start} = I_{nom} * \frac{I_{start}}{I_{nom}} \tag{2.27}$$

where I_{nom} – nominal current of the motor, A; $\frac{I_{start}}{I_{nom}}$ – the ratio of starting current and nominal current (from Table 4).

$I_{start\ 37kW} = 64 * 6{,}9 = 441{,}6$ A

$I_{start\ 45kW} = 77 * 6{,}9 = 531{,}3$ A

Using the special program of ABB Company, ABB proSoft, I can analyze conditions of motor starting. [18]

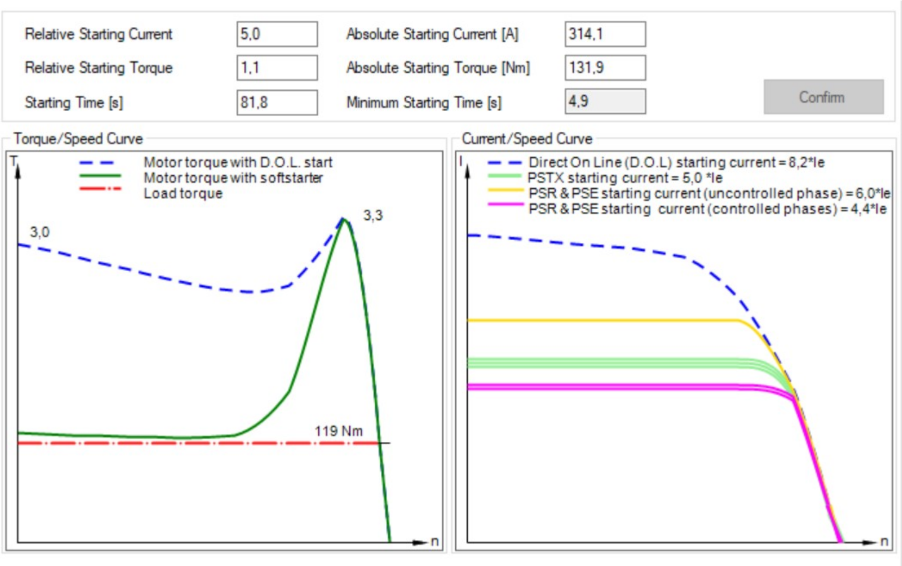

Figure 14 – Analysis of starting motor 37kW

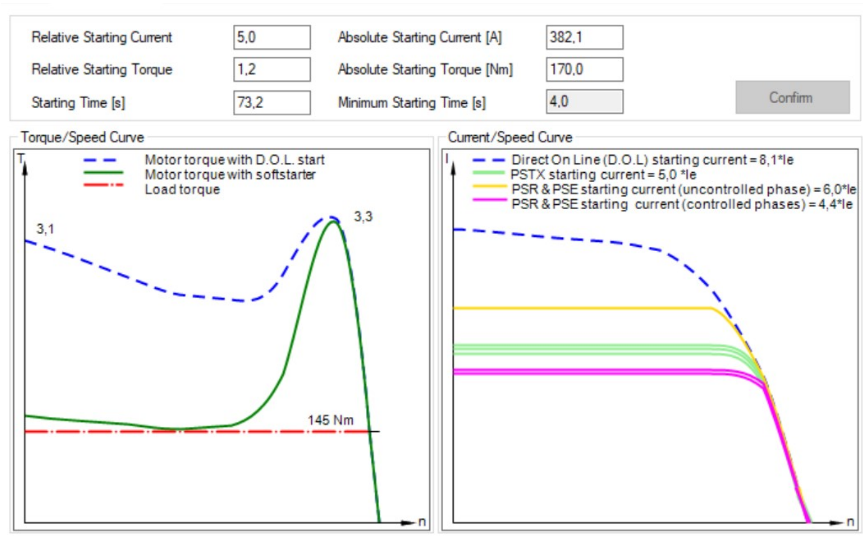

Figure 15 – Analysis of starting motor 45kW

The minimal relative starting current is equal to 5; it can't be less otherwise motor won't start. On Figure 14 and Figure 15, it can be seen that for the chosen model ratio of starting current is equal to 4.4.

$I_{sta \quad 37kW} = 64 * 4{,}4 = 281{,}6$ A

$I_{start\ 45kW} = 77 * 4{,}4 = 338{,}8$ A

After measures of installing soft starter power flow will decrease significantly and won't be higher than nominal power of transformer and losses of voltage will be in an acceptable range.

Also, there can be placed diesel generator with lower power which is equal to a load of sawmill during the day.

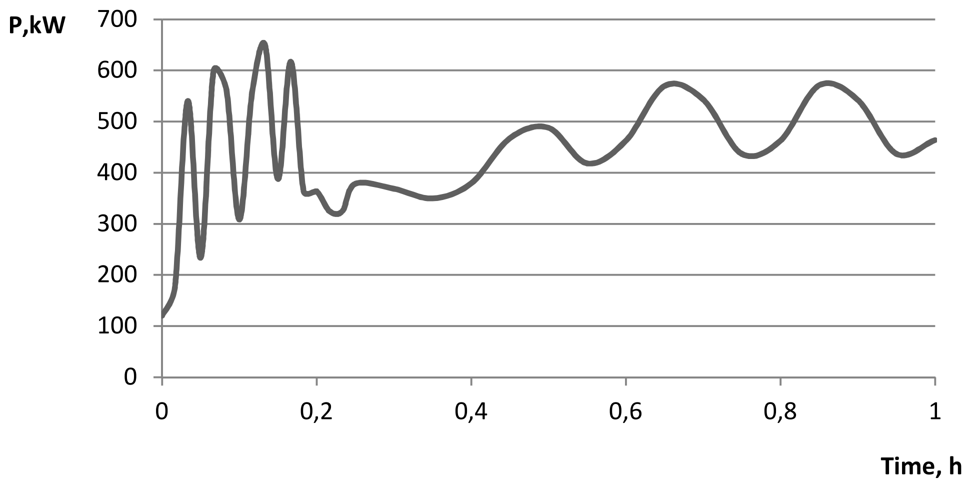

Figure 16 – The graph of the load for the first hour of the shift

According to the graph on Figure 10, it can be seen that maximum power during the shift is not higher than 600kW and on Figure 16 maximum power during motor start is 650 kW, that's why I've chosen the diesel generator AD-600-T400 with a nominal power 600kW and reserve power 660kW. Parameters of the generator are represented in Table 12. [13]

Table 12 – Parameters of diesel generator AD-600-T400 [13]

Parameter	**Value**
Company	RICARDO
Model	AD-600-T400
Main power, kW	600
Main power, kVA	750
Reserve power, kW	660
Reserve power, kVA	825
Voltage, V	400/230
Type of current	alternating
Number of phases	3

Nominal frequency, Hz	50
Nominal current, A	1080
Power factor, $\cos\varphi$	0,8
Fuel consumption with 100% power, l/h	142
Fuel consumption with 75% power, l/h	104,3

3 Economic Part

After all calculations, I have to evaluate the economic efficiency of each option.

As a result of the previous research I have next options:

- Network connection

Substitution of transformer 630 kVA 10/0.4 kV with transformer 1000 kVA 10/0.4 kV or setting soft starter for motors with the highest power, such as Siemens 1MJ7223-2CB with a nominal power 45kW and Siemens AOM-200L with a nominal power 37 kW are two considered variants.

In case if the company will decide to substitute transformer the new cables are also required because of the increase of the highest possible current.

On the other hand, if soft starters will be applied it will decrease consumption of the power during the starting process and lets the company use transformer 630 kVA without significant effect on the voltage quality.

As a side effect of transformer substitution, I can note an increase in energy consumption, which should be taken into account.

- Generator supply

In this case, I have to analyze how the setting of soft starters will affect the required investments and annual expenses if the connection to the network is not available and a diesel generator is used as the main source of energy.

The first project in this case includes investment in the diesel generator ADG-ENERGY AD-1250WP, annual expenses on its maintenance, and cost of fuel.

The second project includes the same values but for the diesel generator AD-600-T400 and the cost of soft starters for the same motors as in the case with the network connection.

3.1 Methodology for Assessing the Economic Efficiency of the Project

3.1.1 Investments

There are several variants of possible measures and I have to consider all of them.

Substitution of the transformer and the feeding cable

In this case, I don't need to buy the whole new complete substation, I can just substitute transformer and feeding cable. But it is obligatory to make a new contract with the distribution company to increase installed power of substation.

The distribution company has to substitute feeding lines 10 kV with another with a bigger cross-section that is why for this variant I have to take into account the price of a new connection to the grid and the price of new transformer installation. This information can be found at [19], I assume that the sawmill is placed in the Tomskiy region and the nearest substation 110/10 kV is located at the distance 50 km.

The transformer price was taken from [12] and the price of cable lines was taken from [15].

Price of VVGng 3×300 mm^2 is equal to 6765 Rub/m.

Table 13 – Investment in transformer substitution

Investment	**Price, Rub**
Transformer	415 000
Cables (200m)	4 058 816
Payment to the Distribution Company	575 568
Total	5 049 384

The lifetime of the transformer and cable lines is 30 years at least. [20]

Also after substitution of the transformer I've calculated extra consumption of electrical energy. According to [21], for this type of factory can be applied next tariffs:

- The third price category – 4.97 Rub/kWh;
- The fourth price category – 5.08 Rub/kWh;
- The fifth price category – 4.97 Rub/kWh;
- The sixth price category – 5.08 Rub/kWh.

For the sawmill, I can choose the third and the fifth category. The third price category for the purchase of electrical energy (power) means that during the billing period hourly accounting is carried out, but hourly planning is not carried out, and the cost of services for the transmission of electrical energy is determined according to the tariff for services for the transmission of electrical energy in one-part terms.

According to the Ministry of Economic Development Russian Federation [22], the expected growth of electricity prices is 3% per year.

Using load diagrams on Figure 10 and Figure 16, I've calculated extra consumption of energy during the start of motors in comparison with energy consumption if soft starters are used.

Table 14 – Extra consumption of energy

Consumption of electrical energy per day, kWh	119
Consumption of electrical energy per year, kWh/year	3 824 676
Cost of electrical energy, Rub/kWh	4,97
Annual cost of electrical energy, Rub/year	19 008 641

For the variant with soft starters, I have to consider investing in a new transformer as well, but without payment to the distribution company to obtain a more reliable result.

Table 15 – Costs of TMG-630

Investments	Transformer, Rub	290 000
	Cables VVG 3×240mm^2 (200 m)	2 086 642
Annual cost of electrical energy, Rub/year		18 792 390

Soft starters

I have four motors with nominal power 45kW and eight motors with nominal power 37kW, so I have to buy the corresponding number of soft starters. Prices of ABB soft starters can be found at [23]. Exchange rate: 1 EUR = 90 Rub.

All installation work can be done by the electrician of the sawmill or hired from the nearest town; the cost of this work won't be very high that is why I can neglect it.

Table 16 – Investment in soft starters [23]

Investment	**Amount**	**Price per unit, EUR**	**Price per unit, Rub**	**Total price, EUR**	**Total price, Rub**
PSR72	8	388,14	34 933	3 105	279 461
PSR85	4	425,7	38 313	1 703	153 252
Total				4 808	432 713

The lifetime of the soft starter is at least 8 years.

Generators

I have to evaluate savings by changing the generator after setting a soft starter.

Using MS Excel and information from Table 7 and Table 12, I've found a polynomial function to evaluate the consumption of fuel of each generator.

Consumption of fuel for AD-1250WP, l/h:

$$Consumption = 91{,}2 * \left(\frac{P}{P_{nom}}\right)^2 + 109{,}2 * \frac{P}{P_{nom}} + 41{,}2 \tag{3.1}$$

where P – actual generated power, kW; P_{nom} – nominal power of the generator, kW.

Consumption of fuel for AD-600-T400, l/h:

$$Consumption = 56 * \left(\frac{P}{P_{nom}}\right)^2 + 52{,}8 * \frac{P}{P_{nom}} + 33{,}2 \quad (3.2)$$

Using the load diagram on Figure 10, I’ve calculated the average power for the most notable periods of the shift and taken these amounts for three shifts.

Table 17 – Daily fuel consumption for AD-1250WP before setting soft starters

$P_{average}$, kW	705	501	126	687	448
$\frac{P}{P_{nom}}$	0,78	0,56	0,14	0,76	0,50
Consumption, l/h	183,8	130,2	58,3	177,7	118,2
Time period, h	0,4	11,35	3,2	0,4	8,55
Fuel consumption, l	73	1478	186	71	1011

Consumption of fuel per day: 2 820 l

Consumption of fuel per year: 1 029 149 l

Table 18 – Daily fuel consumption for AD-600-T400 after setting soft starters

$P_{average}$, kW	557	501	126	538	448
$\frac{P}{P_{nom}}$	0,93	0,83	0,21	0,9	0,75
Consumption, l/h	130,4	116,3	46,8	125,6	103,9
Time period, h	0,4	11,35	3,2	0,4	8,55
Fuel consumption, l	52	1320	150	50	888

Consumption of fuel per day: 2 461 l

Consumption of fuel per year: 898 110 l

The price of diesel is equal to 48 Rub/l according to [24]. According to the Analytical Center for the Government of the Russian Federation [25], the expected growth of diesel price is 5% annually.

Table 19 – Cost of generators [13]

Model	AD-1250WP	AD-600-T400
Cost, Rub	9 778 527	3 048 158
Cost of fuel, Rub	49 399 143	43 109 301

Maintenance cost depends on motohours of a generator. Motohours are the hours of the generator work with the nominal power.

$T_{\max AD-1250WP} = 4250\ h/year$

$T_{\max AD-600} = 6310\ h/year$

Table 20 – Cost of maintenance [26]

Generator	Cost of maintenance for 1000 motohours, Rub	Cost of maintenance, Rub/year
AD-1250WP	165 000	701 205
AD-600-T400	127 500	804 525

A diesel generator can work 23000-25000 motohours before the overhaul, during the lifetime of the generator there can be 2-3 overhauls.

The lifetime of AD-1250WP: 22 years.

The lifetime of AD-600-T400: 16 years.

Table 21 – Cost of overhaul [27]

Generator	The period between overhauls, years	Cost of overhaul, Rub
AD-1250WP	5	290 900
AD-600-T400	4	207 800

3.1.2 Inflation

Inflation is the rate of falling of purchasing power of the currency and the rise of services ad goods prices. [28]

To provide reliable result I have to take into account at least the main rates which can influence on future cash flows. I've analyzed the level of inflation in the Russian Federation for the last five years, using data from [29].

Table 22 – Inflation in Russian Federation [29]

Year	2016	2017	2018	2019	2020	Average
Inflation, %	5.38	2.52	4.27	3.05	4.91	4.026

In March-April 2021, inflation forecasts by professional analysts for 2021 increased markedly and were in the range of 4.2-4.4%. Forecasts for 2022 remained almost unchanged and amounted to 4.0–4.4%. The forecast for 2023 remained at 4.0%. The goal for inflation established by the Central Bank is 4%. [30]

I can conclude that the expected inflation rate can be taken equal to 4%.

3.1.3 Depreciation

Depreciation is the process of deducting the total cost of expensive equipment to divide the cost for tax payment over the lifetime of the equipment. [31]

There are several types of depreciation according to the Tax Code of the Russian Federation [32]:

1) Straight-line method

The depreciation coefficient:

$$K = \frac{1}{T} \tag{3.3}$$

where T – period of depreciation or lifetime of equipment, years.

Depreciation for each year:

$$D = K * Inv \tag{3.4}$$

where Inv – investments in equipment, Rub.

2) Nonlinear depreciation method

There is a specified amount of depreciation for different groups of equipment. According to the Tax Code of the Russian Federation, there are next groups:

Table 23 – Groups of equipment and annual depreciation

Group name	**Useful lifetime, years**	**Monthly depreciation, %**	**Annual depreciation, %**
The first group	1-2	14,3	84,30
The second group	2-3	8,8	66,89
The third group	3-5	5,6	49,92
The fourth group	5-7	3,8	37,18
The fifth group	7-10	2,7	28,00
The sixth group	10-15	1,8	19,58
The seventh group	15-20	1,3	14,53
The eighth group	20-25	1,0	11,36
The ninth group	25-30	0,8	9,19
The tenth group	>30	0,7	8,08

In the Tax Code of the Russian Federation can be found monthly depreciation rate, to convert it to annual can be used next formula:

$$K = 1 - \left(1 - \frac{k}{100}\right)^{m} \tag{3.5}$$

where k – monthly depreciation coefficient, %; m – number of months, equal to 12.

The depreciation for a year:

$$D = B * \frac{K}{100} \tag{3.6}$$

where B – total balance of equipment group, Rub; k – coefficient of annual depreciation,%.

Every year total balance decreases by the amount of annual depreciation. [32]

Depreciation expense is unrelated to cash flows because it is a non-cash expense. [31]

I've decided to use the nonlinear depreciation method.

3.1.4 Taxes of Russian Federation

Corporate tax has to be taken into account. According to the Federal Tax Service website [33], corporate tax is 20% in Russian Federation.

3.1.5 Discount rate

The discount rate is the rate of return which used to discount future cash flows to present value. [34]

The discount rate can be evaluated by using Capital Assets Pricing Model. It gives a measure of risk in relation to overall market fluctuations. [35]

The discount rate is calculated by the next formula: [34]

$$r = r_f + \beta_L * (r_m - r_f) \tag{3.7}$$

where r_f – risk-free rate, equal to 7,54% for maturity time 30 years [36]; β_L – levered beta of investments, for Paper/Forest Products $\beta_L = 1.01$ [37]; $(r_m - r_f)$ – market risk premium, this value is equal to 6,85% for Russia [37].

$$r = 7.54 + 1.01 * 6.85 = 14.46\%$$

This discount rate was counted for the average company because in this work I don't have an exact company and these measures can be applied in any sawmill. However, if there will be exact data, I have to use the next formula to calculate levered beta:

$$\beta_L = \beta_U * (1 + \frac{D}{E} * (1 - tax)) \tag{3.8}$$

where β_U – unlevered beta, equal to 0,72 [37]; $\frac{D}{E}$ – debt to equity ratio; tax – corporate tax rate, %.

3.2 Calculation of the Economic Indicators of the Project

All investment in new equipment can be evaluated by the next parameters:

1. NPV (Net Present Value)
2. EAA (Equivalent Annual Annuity)
3. IRR (Internal Rate of Return)

NPV is the value of future cash flows during the lifetime of the project discounted to the present value. NPV analysis helps investors to understand is the project worth the investments or not. NPV includes all cash flows discounted to the present moment, all revenues, and expenditures. This parameter shows us the time value of the money, we can conclude that it is better to have revenue as soon as possible and see cash outflows later. [38]

NPV is calculated by the next formula:

$$NPV = \sum_{i=1}^{T} \frac{CF_i}{(1+r)^i} - CF_0 \, , \tag{3.9}$$

where CF_0 – investments, Rub; CF_i – cash flow in i-th year, Rub; r – the discount rate of the project; T – the lifetime of the project, years.

EAA is the method how we can evaluate projects with a different lifetime. In this case, we can not say which project is better using NPV. EAA represents some equal equivalent annual payments that result in the same NPV as unequal CF of the project.

$$EAA = NPV * \frac{(1+r)^T * r}{(1+r)^T - 1} \tag{3.10}$$

Annuity factor for 30 years project:

$$a = \frac{(1 + 14{,}46\%)^{30} * 14{,}46\%}{(1 + 14{,}46\%)^{30} - 1} = 0{,}147$$

IRR is the discount rate when NPV of the project is equal to zero. Also, it can be defined as the expected compound annual rate of return that will be earned on a project. [39]

$$NPV = \sum_{i=1}^{T} \frac{CF_i}{(1+IRR)^i} - CF_0 = 0 \tag{3.11}$$

IRR can be found from this formula using MS Excel or a financial calculator.

To calculate NPV of the network connection projects I’ve used the next input parameters:

- Investments
- Depreciation
- Scrap value

I have to take into account this value because the lifetime of the transformer is at least 30 years, but if all maintenance and repairs were provided correctly, it can work for more than 30 years, what means that the company can sell the transformer.

- Payment to the distribution company
- Maintenance: for transformer cost of maintenance is 2% of investments.
- Cost of electrical energy

Calculations of NPV are represented in Appendix C and Appendix D.

For the cases with the diesel generator supply I've taken:

- Investments
- Depreciation
- Scrap value
- Overhaul
- Maintenance
- Cost of fuel

Results of calculations can be found in Appendix E and Appendix F.

Then I've compared these options and found savings as the difference between variants:

Table 24 – Savings for the network connection case

	TMG-1000	TMG-630 + soft starters	Savings
NPV, Rub	-132 307 600	-128 461 149	3 846 451
EAA, Rub/year	-19 470 337	-18 904 295	566 042

In case if soft starters will be applied, the company will save 3 846 451 Rub or 566 042 Rub annually.

Table 25 - Savings for the diesel generator supply case

	AD-1250WP	AD-600-T400 + soft starters	Savings
NPV, Rub	-399 754 651	-345 312 312	54 442 339
EAA, Rub/year	-58 827 745	-50 816 031	8 011 714

In case if soft starters will be applied, the company will save 54 442 339 Rub or 8 011 714 Rub annually.

In these projects, there is no IRR because there are no revenue and all cash flows have the same sign.

3.3 Sensitivity Analysis of the Projects

Sensitivity analysis of the project allows evaluating the impact of initial parameters (investments, operating expenses, discount rate, etc.) changes on the final result and decision.

The first step is to determine initial parameters which can have the highest possible effect on the project calculations. Then I have to make a single change of each selected parameter and evaluate its impact.

Also, I have to determine how savings depends on different initial parameters. I've taken the next parameters which are the most likely to change:

- discount rate
- electricity (diesel) price growth
- scrap value

Results are represented on Figures 17 – 22.

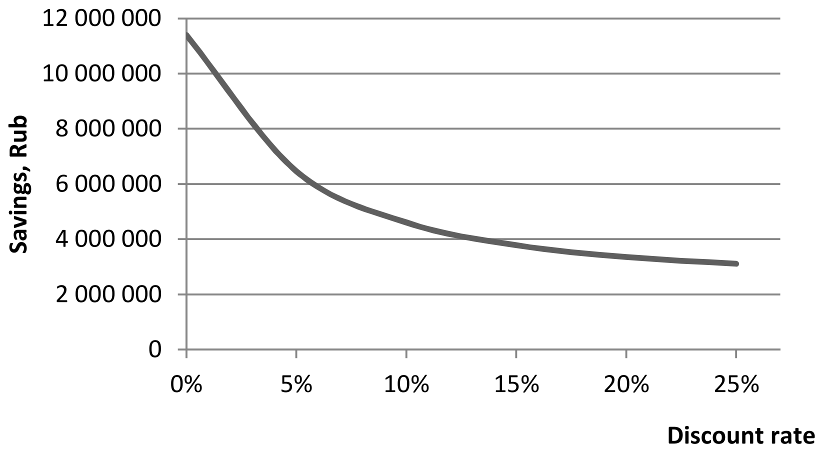

Figure 17 – Dependence of savings on the discount rate for the network connection case

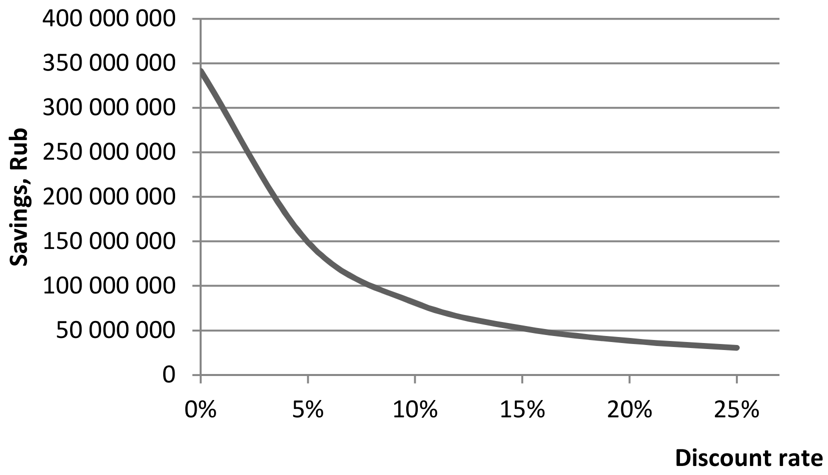

Figure 18 – Dependence of savings on the discount rate for the diesel generator supply case

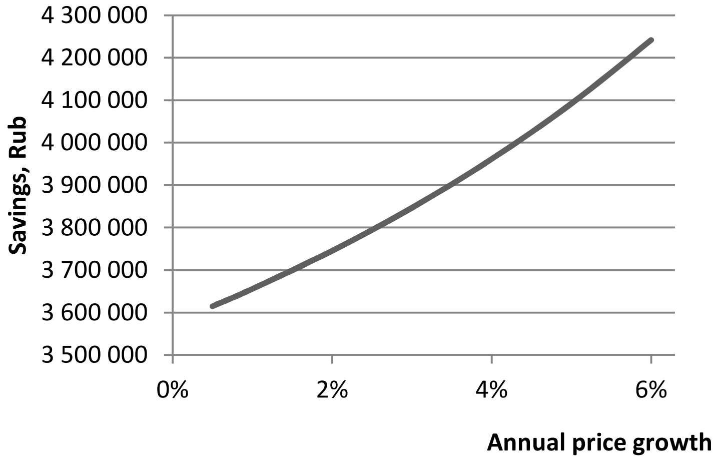

Figure 19 – Dependence of savings on annual electricity price growth for the network connection case

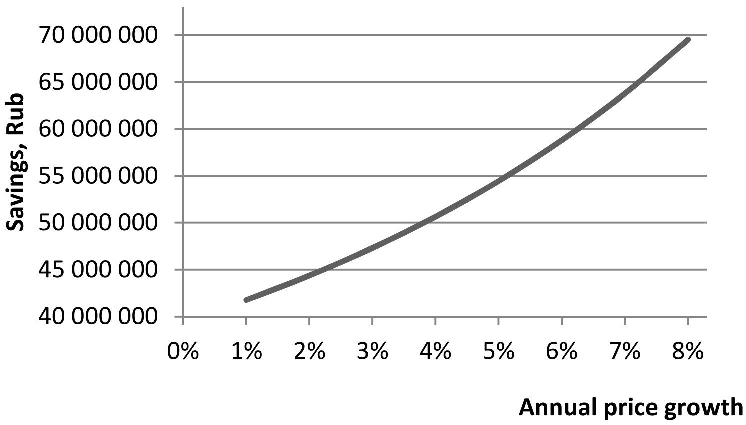

Figure 20 – Dependence of savings on annual diesel price growth for the diesel generator supply case

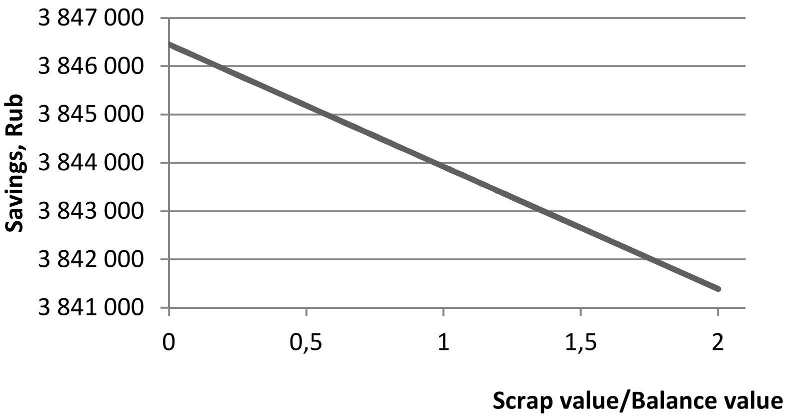

Figure 21 – Dependence of savings on scrap value for the network connection case

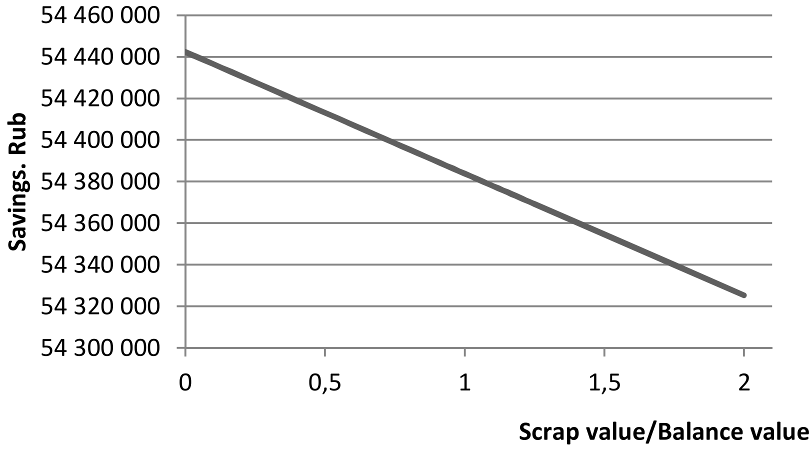

Figure 22 – Dependence of savings on scrap for the diesel generator supply case

From these graphs, I can conclude that savings have the parabolic dependence from discount rate and decrease sharply on the interval from zero percent to almost ten percent and then became smoother. Also, savings have an almost linear dependence on annual electricity and fuel price growth and this factor has a significant effect on savings. On the other hand, I can say that selling the equipment at the end of the project period has a small influence on savings and doesn't change the final result.

All changes to build Tornado diagram are provided with respect to the base case and by the changes of the final result, I can evaluate the sensitivity of the project to selected parameters. The sensitivity indicator is the ratio of the percentage change in the criterion to the change in the value of the variable by the predicted percentage (elasticity of the change in the indicator).

The result of the sensitivity analysis can be represented as a Tornado diagram. On this diagram, the most important parameter is placed on the top and then all others parameters are ranked according to their importance.

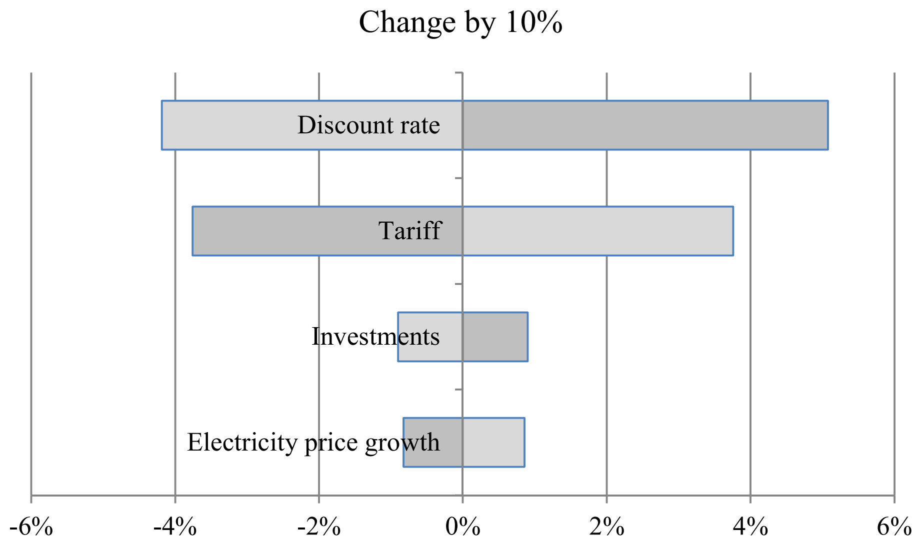

Figure 23 – Tornado diagram for network connection case

According to Tornado diagram, the project is quite sensitive to discount rate changes. In the second place, there is a tariff because the plant has a high level of electrical energy consumption. Sensitivity to changes in investments and percent of annual electricity price growth are almost equal and don't have a big effect on savings.

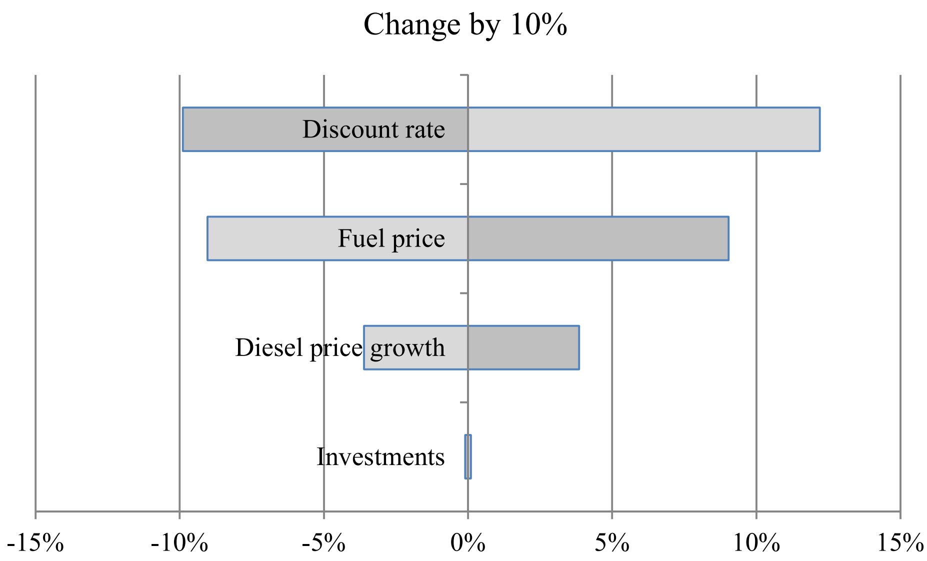

Figure 24 – Tornado diagram for the diesel generator supply case

As can be seen on Figure 24, savings for the diesel generator supply case are even more sensitive to discount rate changes than the network connection case. Also, this project has a high sensitivity to initial fuel price what is logical because the highest annual expenses are for fuel. Diesel price growth has a significant effect on savings, much higher than electricity price growth has in the previous variant. And investments almost don't influence savings because NPV of each project mostly consists of discount cash flows for 30 years.

Conclusion

In this master thesis, the goal was to find a way how to maintain voltage level during the motor starting process in the woodworking enterprise.

The first step was to collect information about the woodworking industry and sawmills' electricity supply features. Sawmills are usually placed near a wood source what can lead to a long distance from a big source of energy. In such situation, there can be a connection to the network or supply by a diesel generator.

The second step was the selection of sawing equipment and their motors. I've used the project of the Altaylestekhmash Company and chosen to use Siemens explosion-proof motors to avoid hazardous situations connected with fire. Then, I've calculated the load of the sawmill using the ordered charts method. Also, I've constructed a theoretical daily load diagram and found the required electrical energy during the motor starting process.

The next step was the selection of main electrical equipment for different supplying options. I assumed that initially network connection was constructed for a transformer with power not higher than 630kVA what can cover load during the day, but not suitable during the starting process. For the case with the diesel generator supply, I've selected AD-1250WP with a nominal power of 900kW.

After that, I've considered several ways how to improve voltage quality. I've considered two types of situations for both supplying options: use equipment with a higher power or use lower power equipment with soft starters. The high power equipment was considered as a basic variant as a typical solution of the problem, but using soft starters was effective as well.

The last step was the evaluation of the economic efficiency of the projects. I've calculated NPV of each project and found out that NPV of the project with high power equipment is higher than NPV of projects with lower power equipment. The differences between NPV of these projects are savings through the use of soft starters. For the network connection case, a company can save 3 846 451 Rub and 54 442 339 for the diesel generator supply case. According to the results of sensitivity analysis, all these projects are highly sensitive to the discount rate and electricity and fuel price changes.

Finally, I can conclude that using the soft starters as additional electrical equipment is profitable. It will help to improve voltage level and will be good both in technical and economic aspects.

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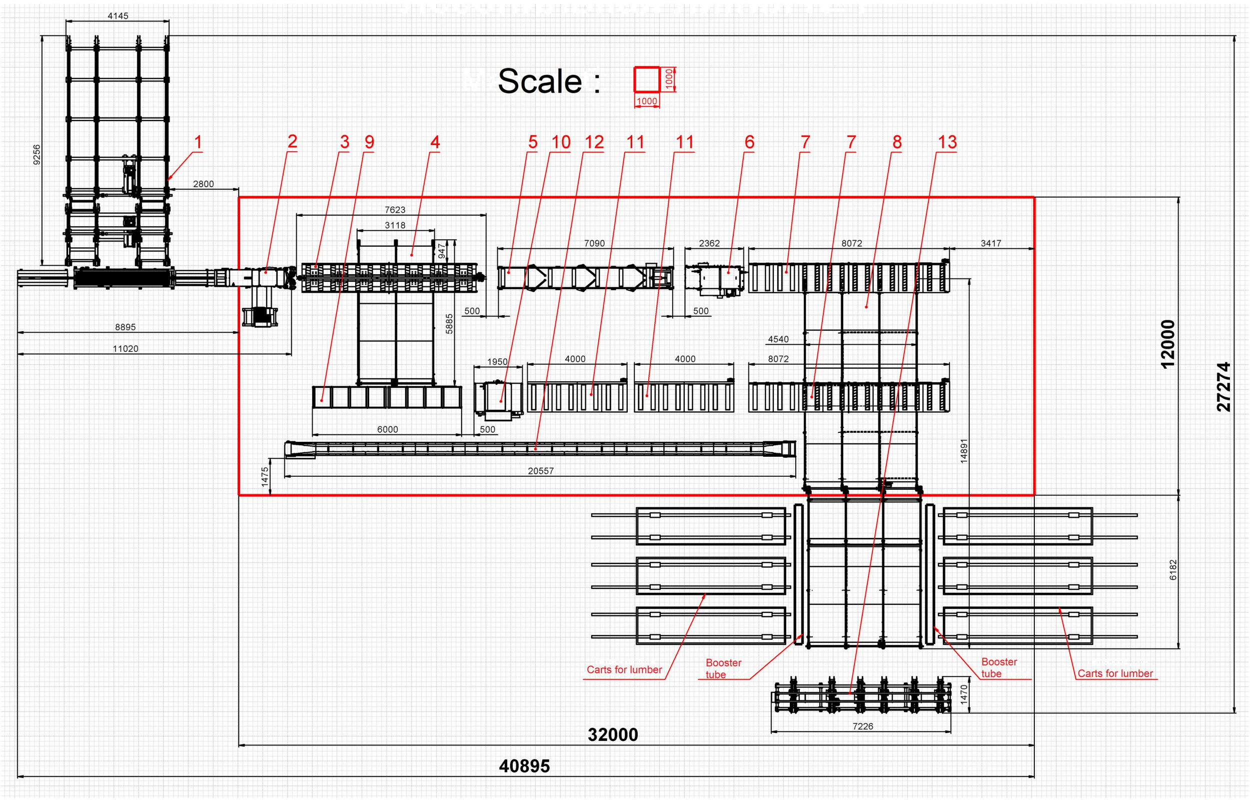
Appendices

Appendix A - Scheme of the Wood Processing Line No.1



Position	Name	Amount
1	Complex of piece delivery of logs	1
2	Twin-shaft multi-saw machine "Altai SBTs480" with a log tilter	1
3	Mechanical separator	1
4	Inclined transverse conveyor 6m	1
5	Log centering	1
6	Two-shaft multi-saw machine "Altai 2Ts16-350"	1
7	Dumping roller conveyor with spiral winding 8m	2
8	Conveyor for sorting timber 15m	1
9	Roller conveyor 3m	1
10	Multisaw edge-trimming machine "Altai KS1000"	1
11	Drive roller conveyor 4m	2
12	Belt conveyor for slab 20m	1
13	Crosscutting machine STP7000 type	1

Appendix B - Calculation of Workshop Load

Name of machine	Motor	P_{nom}, kW	I_{nom}, A	Power factor, cosj	tgj	K_u	η, %	LC, %	p_{100}, kW	q_{100}, kvar	U_{nom}, V	I_C, A	p_{shift}, kW	q_{shift}, kvar	p_{100}^2
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
The complex of piece delivery of logs	AOM-160MK	11	22,5	0,87	0,57	0,7	86,4	60	8,521	5,589	380	15,48	5,96	3,38	72,60
Twin-shaft multi-saw machine "Altai SBTs480" with a log tilter	1MJ7223-2CB	45	77	0,9	0,48	0,6	93,9	60	34,857	17,979	380	59,59	20,91	10,13	1215,0
	1MJ7223-2CB	45	77	0,9	0,48	0,6	93,9	60	34,857	17,979	380	59,59	20,91	10,13	1215,0
	AOM-100L	3	6,2	0,9	0,48	0,4	81	100	3,000	1,794	380	5,31	1,20	0,58	9,00
Mechanical separator	AOM-90LK	1,5	3,3	0,87	0,57	0,45	79	45	1,006	0,722	380	1,88	0,45	0,26	1,01
Inclined transverse conveyor 6m	AOM-90L	2,2	4,7	0,88	0,54	0,75	81	80	1,968	1,311	380	3,59	1,48	0,80	3,87
Log centering	AOM-100L	3	6,2	0,9	0,48	0,45	81	60	2,324	1,389	380	4,11	1,05	0,51	5,40
Two-shaft multi-saw machine "Altai 2Ts16-350"	AOM-200L	37	68	0,9	0,48	0,65	92,2	60	28,660	15,055	380	49,19	18,63	9,02	821,40
	AOM-200L	37	68	0,9	0,48	0,65	92,2	60	28,660	15,055	380	49,19	18,63	9,02	821,40
	AOM-100L	3	6,2	0,9	0,48	0,4	81	100	3,000	1,794	380	5,31	1,20	0,58	9,00
Dumping roller conveyor with spiral winding 8m	AOM-90LK	1,5	3,3	0,87	0,57	0,8	79	90	1,423	1,021	380	2,66	1,14	0,65	2,03
Dumping roller conveyor with spiral winding 8m	AOM-90LK	1,5	3,3	0,87	0,57	0,8	79	90	1,423	1,021	380	2,66	1,14	0,65	2,03
Conveyor for sorting timber 15m	AOM-132S	7,5	15,5	0,87	0,57	0,75	85	90	7,115	4,744	380	12,99	5,34	3,02	50,63
Roller conveyor 3m	AOM-80MK	0,75	1,8	0,83	0,67	0,8	75	90	0,712	0,638	380	1,45	0,57	0,38	0,51
Multisaw edge-trimming machine "Altai KS1000"	AOM-200L	37	68	0,9	0,48	0,35	92,2	50	26,163	13,743	380	44,90	9,16	4,43	684,50
	AOM-200L	37	68	0,9	0,48	0,35	92,2	50	26,163	13,743	380	44,90	9,16	4,43	684,50
	AOM-80M	1,1	2,5	0,87	0,57	0,3	78	100	1,100	0,799	380	2,07	0,33	0,19	1,21
Drive roller conveyor 4m	AOM-80MK	0,75	1,8	0,83	0,67	0,8	75	90	0,712	0,638	380	1,45	0,57	0,38	0,51
Drive roller conveyor 4m	AOM-80MK	0,75	1,8	0,83	0,67	0,8	75	90	0,712	0,638	380	1,45	0,57	0,38	0,51
Belt conveyor for slab 20m	AOM-132S	7,5	15,5	0,87	0,57	0,6	85	80	6,708	4,473	380	12,25	4,02	2,28	45,00

Name of machine	Motor	P_{nom}, kW	I_{nom}, A	Power factor, cosj	tgj	K_u	η, %	LC, %	p_{100}, kW	q_{100}, kvar	U_{nom}, V	I_C, A	p_{shift}, kW	q_{shift}, kvar	p_{100}^2
Crosscutting machine STP7000 type	AOM-132SK	5,5	11,5	0,87	0,57	0,5	83	70	4,602	3,142	380	8,47	2,30	1,30	21,18
	AOM-90LK	1,5	3,3	0,87	0,57	0,45	79	100	1,500	1,076	380	2,80	0,68	0,38	2,25
TOTAL									**225,18**				**125,39**	**62,89**	**5668,51**

Appendix C – Substitution of the transformer with TMG-1000-10/0.4

Year	0	1	2	3	4	5	6	7	8	9	10
Investment	4 473 816										
Total equip balance		*4 112 331*	*3 780 055*	*3 474 627*	*3 193 877*	*2 935 812*	*2 698 598*	*2 480 551*	*2 280 123*	*2 095 889*	*1 926 541*
Depreciation		361 484	332 276	305 428	280 750	258 065	237 214	218 047	200 429	184 234	169 348
Selling of equip											
Payment to distr comp	575 568										
Maintenance		89 476	89 476	89 476	89 476	89 476	89 476	89 476	89 476	89 476	89 476
Consumption of el en		19 008 641	19 578 900	20 166 267	20 771 255	21 394 393	22 036 225	22 697 312	23 378 231	24 079 578	24 801 965
EBT		-19 459 602	-20 000 653	-20 561 172	-21 141 482	-21 741 935	-22 362 915	-23 004 835	-23 668 136	-24 353 288	-25 060 789
Tax		-3 891 920	-4 000 131	-4 112 234	-4 228 296	-4 348 387	-4 472 583	-4 600 967	-4 733 627	-4 870 658	-5 012 158
EAT		-15 567 681	-16 000 522	-16 448 938	-16 913 185	-17 393 548	-17 890 332	-18 403 868	-18 934 509	-19 482 630	-20 048 631
CF	-5 049 384	-15 206 197	-15 668 246	-16 143 509	-16 632 435	-17 135 482	-17 653 118	-18 185 821	-18 734 080	-19 298 397	-19 879 284
DCF	-5 049 384	-13 285 163	-11 959 497	-10 765 562	-9 690 382	-8 722 232	-7 850 530	-7 065 725	-6 359 199	-5 723 182	-5 150 665

Year	11	12	13	14	15	16	17	18	19	20	21
Investment											
Total equip balance	*1 770 876*	*1 627 790*	*1 496 264*	*1 375 366*	*1 264 237*	*1 162 086*	*1 068 190*	*981 880*	*902 544*	*829 618*	*762 585*
Depreciation	155 665	143 087	131 525	120 898	111 130	102 150	93 897	86 310	79 336	72 926	67 033
Selling of equip											
Payment to distr comp											
Maintenance	89 476	89 476	89 476	89 476	89 476	89 476	89 476	89 476	89 476	89 476	89 476
Consumption of el en	25 546 024	26 312 405	27 101 777	27 914 830	28 752 275	29 614 843	30 503 289	31 418 387	32 360 939	33 331 767	34 331 720
EBT	-25 791 165	-26 544 968	-27 322 779	-28 125 205	-28 952 881	-29 806 470	-30 686 662	-31 594 173	-32 529 751	-33 494 169	-34 488 230
Tax	-5 158 233	-5 308 994	-5 464 556	-5 625 041	-5 790 576	-5 961 294	-6 137 332	-6 318 835	-6 505 950	-6 698 834	-6 897 646
EAT	-20 632 932	-21 235 974	-21 858 223	-22 500 164	-23 162 305	-23 845 176	-24 549 329	-25 275 339	-26 023 801	-26 795 335	-27 590 584
CF	-20 477 267	-21 092 888	-21 726 698	-22 379 266	-23 051 175	-23 743 026	-24 455 433	-25 189 029	-25 944 465	-26 722 410	-27 523 551
DCF	-4 635 332	-4 171 489	-3 754 007	-3 378 263	-3 040 094	-2 735 749	-2 461 851	-2 215 359	-1 993 534	-1 793 911	-1 614 269

Year	22	23	24	25	26	27	28	29	30
Investment									
Total equip balance	*700 968*	*644 330*	*592 268*	*544 413*	*500 424*	*459 990*	*422 823*	*388 659*	*0*
Depreciation	61 617	56 638	52 062	47 855	43 989	40 434	37 167	34 164	388 659
Selling of equip									0
Payment to distr comp									
Maintenance	89 476	89 476	89 476	89 476	89 476	89 476	89 476	89 476	89 476
Consumption of el en	35 361 672	36 422 522	37 515 198	38 640 654	39 799 873	40 993 869	42 223 686	43 490 396	44 795 108
EBT	-35 512 765	-36 568 637	-37 656 736	-38 777 985	-39 933 338	-41 123 780	-42 350 329	-43 614 036	-45 273 243
Tax	-7 102 553	-7 313 727	-7 531 347	-7 755 597	-7 986 668	-8 224 756	-8 470 066	-8 722 807	-9 054 649
EAT	-28 410 212	-29 254 909	-30 125 389	-31 022 388	-31 946 670	-32 899 024	-33 880 263	-34 891 229	-36 218 594
CF	-28 348 595	-29 198 271	-30 073 327	-30 974 533	-31 902 682	-32 858 590	-33 843 096	-34 857 065	-35 829 936
DCF	-1 452 611	-1 307 137	-1 176 228	-1 058 428	-952 423	-857 034	-771 197	-693 957	-623 209

NPV = -132 307 600 Rub

Appendix D – Setting of soft starters with TMG-630-10/0.4

Year	0	1	2	3	4	5	6	7	8	9	10
Investment	432 713								432 713		
Total eq balance		*311 553*	*224 318*	*161 509*	*116 287*	*83 726*	*60 283*	*43 404*	*0*	*311 553*	*224 318*
Depreciation		121 160	87 235	62 809	45 223	32 560	23 443	16 879	43 404	121 160	87 235
Investment (tr+cab)	2 379 642										
Total eq. balance (tr+cab)		*2 187 367*	*2 010 628*	*1 848 169*	*1 698 837*	*1 561 571*	*1 435 396*	*1 319 416*	*1 212 807*	*1 114 812*	*1 024 736*
Depreciation (tr+cab)		192 275	176 739	162 459	149 332	137 266	126 175	115 980	106 609	97 995	90 077
Scrap value											
Maintenance (tr+cab)		47 593	47 593	47 593	47 593	47 593	47 593	47 593	47 593	47 593	47 593
Cost of electrical energy		18 792 390	19 356 161	19 936 846	20 534 952	21 151 000	21 785 530	22 439 096	23 112 269	23 805 637	24 519 806
EBT		-19 153 417	-19 667 728	-20 209 707	-20 777 099	-21 368 419	-21 982 741	-22 619 548	-23 309 874	-24 072 384	-24 744 711
Tax		-3 830 683	-3 933 546	-4 041 941	-4 155 420	-4 273 684	-4 396 548	-4 523 910	-4 661 975	-4 814 477	-4 948 942
EAT		-15 322 734	-15 734 183	-16 167 766	-16 621 679	-17 094 735	-17 586 193	-18 095 639	-18 647 900	-19 257 907	-19 795 769
CF	-2 812 355	-15 009 299	-15 470 209	-15 942 498	-16 427 125	-16 924 909	-17 436 575	-17 962 779	-18 497 887	-19 038 753	-19 618 457
DCF	-2 812 355	-13 113 139	-11 808 336	-10 631 515	-9 570 764	-8 615 047	-7 754 231	-6 979 067	-6 279 025	-5 646 181	-5 083 086

Year	11	12	13	14	15	16	17	18	19	20	21
Investment						432 713					
Total eq balance	*161 509*	*116 287*	*83 726*	*60 283*	*43 404*	*0*	*311 553*	*224 318*	*161 509*	*116 287*	*83 726*
Depreciation	62 809	45 223	32 560	23 443	16 879	43 404	121 160	87 235	62 809	45 223	32 560
Investment (tr+cab)											
Total eq balance (tr+cab)	*941 937*	*865 828*	*795 869*	*731 563*	*672 453*	*618 119*	*568 175*	*522 266*	*480 067*	*441 278*	*405 622*
Depreciation (tr+cab)	82 799	76 109	69 959	64 306	59 110	54 334	49 944	45 909	42 199	38 789	35 655
Scrap value											
Maintenance (tr+cab)	47 593	47 593	47 593	47 593	47 593	47 593	47 593	47 593	47 593	47 593	47 593
Cost of electrical energy	25 255 400	26 013 062	26 793 454	27 597 258	28 425 176	29 277 931	30 156 269	31 060 957	31 992 786	32 952 569	33 941 146
EBT	-25 448 601	-26 181 986	-26 943 566	-27 732 600	-28 548 758	-29 423 262	-30 374 965	-31 241 693	-32 145 387	-33 084 174	-34 056 955
Tax	-5 089 720	-5 236 397	-5 388 713	-5 546 520	-5 709 752	-5 884 652	-6 074 993	-6 248 339	-6 429 077	-6 616 835	-6 811 391
EAT	-20 358 881	-20 945 589	-21 554 853	-22 186 080	-22 839 006	-23 538 609	-24 299 972	-24 993 355	-25 716 309	-26 467 339	-27 245 564
CF	-20 213 273	-20 824 258	-21 452 334	-22 098 331	-22 763 017	-23 440 871	-24 128 869	-24 860 211	-25 611 301	-26 383 327	-27 177 348
DCF	-4 575 573	-4 118 363	-3 706 602	-3 335 854	-3 002 090	-2 700 933	-2 428 977	-2 186 439	-1 967 934	-1 771 148	-1 593 964

Year	22	23	24	25	26	27	28	29	30
Investment			432 713						
Total eq balance	*60 283*	*43 404*	*0*	*311 553*	*224 318*	*161 509*	*116 287*	*83 726*	*0*
Depreciation	23 443	16 879	43 404	121 160	87 235	62 809	45 223	32 560	83 726
Investment (tr+cab)									
Total eq balance (tr+cab)	*372 848*	*342 722*	*315 030*	*289 576*	*266 178*	*244 671*	*224 901*	*206 729*	*0*
Depreciation (tr+cab)	32 774	30 126	27 692	25 454	23 398	21 507	19 769	18 172	206 729
Scrap value									0
Maintenance (tr+cab)	47 593	47 593	47 593	47 593	47 593	47 593	47 593	47 593	47 593
Cost of electrical energy	34 959 381	36 008 162	37 088 407	38 201 059	39 347 091	40 527 504	41 743 329	42 995 629	44 285 497
EBT	-35 063 191	-36 102 760	-37 207 095	-38 395 266	-39 505 316	-40 659 413	-41 855 914	-43 093 954	-44 623 546
Tax	-7 012 638	-7 220 552	-7 441 419	-7 679 053	-7 901 063	-8 131 883	-8 371 183	-8 618 791	-8 924 709
EAT	-28 050 553	-28 882 208	-29 765 676	-30 716 213	-31 604 253	-32 527 530	-33 484 731	-34 475 163	-35 698 837
CF	-27 994 335	-28 835 203	-29 694 581	-30 569 599	-31 493 620	-32 443 214	-33 419 739	-34 424 431	-35 408 381
DCF	-1 434 458	-1 290 883	-1 161 415	-1 044 591	-940 211	-846 200	-761 550	-685 343	-615 877

NPV= - 128 461 149

Appendix E – Using AD-1250WP

Year	0	1	2	3	4	5	6	7	8	9	10
Investments	9 778 527										
Total eq balance		*8 667 686*	*7 683 037*	*6 810 244*	*6 036 600*	*5 350 843*	*4 742 987*	*4 204 184*	*3 726 588*	*3 303 248*	*2 927 999*
Depreciation		1 110 841	984 649	872 793	773 644	685 758	607 856	538 803	477 595	423 340	375 249
Scrap value											
Overhaul						290 900					290 900
Maintenance		701 205	701 205	701 205	701 205	701 205	701 205	701 205	701 205	701 205	701 205
Fuel cost		49 399 143	51 869 100	54 462 555	57 185 683	60 044 967	63 047 215	66 199 576	69 509 555	72 985 032	76 634 284
EBT		-51 211 188	-53 554 954	-56 036 553	-58 660 531	-61 722 829	-64 356 276	-67 439 584	-70 688 355	-74 109 578	-78 001 638
Tax		-10 242 238	-10 710 991	-11 207 311	-11 732 106	-12 344 566	-12 871 255	-13 487 917	-14 137 671	-14 821 916	-15 600 328
EAT		-40 968 951	-42 843 963	-44 829 242	-46 928 425	-49 378 264	-51 485 021	-53 951 667	-56 550 684	-59 287 662	-62 401 310
CF	-9 778 527	-39 858 110	-41 859 314	-43 956 449	-46 154 781	-48 692 506	-50 877 165	-53 412 864	-56 073 089	-58 864 322	-62 026 061
DCF	-9 778 527	-34 822 742	-31 951 012	-29 313 075	-26 890 677	-24 785 256	-22 625 618	-20 752 464	-19 033 758	-17 456 954	-16 070 774

Year	11	12	13	14	15	16	17	18	19	20	21
Investments											
Total eq balance	*2 595 378*	*2 300 543*	*2 039 202*	*1 807 548*	*1 602 211*	*1 420 200*	*1 258 865*	*1 115 858*	*989 096*	*876 735*	*777 138*
Depreciation	332 621	294 835	261 342	231 653	205 337	182 011	161 335	143 007	126 761	112 361	99 597
Scrap value											
Overhaul					290 900					290 900	
Maintenance	701 205	701 205	701 205	701 205	701 205	701 205	701 205	701 205	701 205	701 205	701 205
Fuel cost	80 465 998	84 489 298	88 713 763	93 149 451	97 806 924	102 697 270	107 832 133	113 223 740	118 884 927	124 829 173	131 070 632
EBT	-81 499 824	-85 485 338	-89 676 310	-94 082 309	-99 004 366	-103 580 486	-108 694 673	-114 067 952	-119 712 893	-125 933 640	-139 102 506
Tax	-16 299 965	-17 097 068	-17 935 262	-18 816 462	-19 800 873	-20 716 097	-21 738 935	-22 813 590	-23 942 579	-25 186 728	-26 374 287
EAT	-65 199 859	-68 388 270	-71 741 048	-75 265 847	-79 203 493	-82 864 389	-86 955 738	-91 254 362	-95 770 315	-100 746 912	-105 497 147
CF	-64 867 238	-68 093 435	-71 479 706	-75 034 194	-78 998 155	-82 682 378	-86 794 404	-91 111 354	-95 643 553	-100 634 550	-105 397 550
DCF	-14 683 658	-13 466 674	-12 350 488	-11 326 790	-10 418 635	-9 526 933	-8 737 317	-8 013 185	-7 349 108	-6 755 730	-6 181 615

Year	23	24	25	26	27	28	29	30
Investments								
Total eq balance	*8 667 686*	*7 683 037*	*6 810 244*	*6 036 600*	*5 350 843*	*4 742 987*	*4 204 184*	*0*
Depreciation	1 110 841	984 649	872 793	773 644	685 758	607 856	538 803	4 204 184
Scrap value								0
Overhaul					290 900			
Maintenance	701 205	701 205	701 205	701 205	701 205	701 205	701 205	701 205
Fuel cost	144 505 372	151 730 640	159 317 172	167 283 031	175 647 182	184 429 541	193 651 019	203 333 569
EBT	-146 317 417	-153 416 494	-160 891 170	-168 757 880	-177 325 045	-185 738 602	-194 891 027	-208 238 958
Tax	-29 263 483	-30 683 299	-32 178 234	-33 751 576	-35 465 009	-37 147 720	-38 978 205	-41 647 792
EAT	-117 053 934	-122 733 196	-128 712 936	-135 006 304	-141 860 036	-148 590 882	-155 912 822	-166 591 166
CF	-115 943 093	-121 748 546	-127 840 143	-134 232 660	-141 174 278	-147 983 026	-155 374 018	-162 386 983
DCF	-5 190 496	-4 761 831	-4 368 413	-4 007 384	-3 682 176	-3 372 152	-3 093 285	-2 824 483

NPV = - 399 754 651 Rub

Appendix F – Using AD-600-T400 with soft starters

Year	0	1	2	3	4	5	6	7	8	9	10
Investment (Gen)	3 048 158										
Total eq balance (Gen)		*2 194 674*	*1 875 788*	*1 603 236*	*1 370 286*	*1 171 183*	*1 001 010*	*855 563*	*731 250*	*624 999*	*534 187*
Depreciation (Gen)		853 484	318 886	272 552	232 950	199 102	170 173	145 447	124 313	106 251	90 812
Investment (soft starter)	432 713								432 713		
Total eq balance (soft starter)		*311 553*	*224 318*	*161 509*	*116 287*	*83 726*	*60 283*	*43 404*	*0*	*311 553*	*224 318*
Depreciation (soft starter)		121 160	87 235	62 809	45 223	32 560	23 443	16 879	43 404	121 160	87 235
Overhaul					207 800				207 800		
Maintenance		804 525	804 525	804 525	804 525	804 525	804 525	804 525	804 525	804 525	804 525
Fuel cost		43 109 301	45 264 766	47 528 004	49 904 404	52 399 624	55 019 605	57 770 586	60 659 115	63 692 071	66 876 674
EBT		-44 888 469	-46 475 412	-48 667 890	-51 194 902	-53 435 812	-56 017 747	-58 737 437	-61 839 157	-64 724 006	-67 859 247
tax		-8 977 694	-9 295 082	-9 733 578	-10 238 980	-10 687 162	-11 203 549	-11 747 487	-12 367 831	-12 944 801	-13 571 849
EAT		-35 910 776	-37 180 329	-38 934 312	-40 955 921	-42 748 650	-44 814 197	-46 989 949	-49 471 326	-51 779 205	-54 287 397
CF	-3 480 871	-34 936 132	-36 774 208	-38 598 951	-40 677 749	-42 516 987	-44 620 581	-46 827 623	-49 736 321	-51 551 795	-54 109 350
DCF	-3 480 871	-30 522 568	-28 069 576	-25 740 340	-23 699 651	-21 641 820	-19 843 249	-18 193 905	-16 882 771	-15 288 332	-14 019 577

Year	11	12	13	14	15	16	17	18	19	20	21
Investment (Gen)						3 048 158					
Total eq balance (Gen)	*456 570*	*390 230*	*333 530*	*285 068*	*243 647*	*0*	*2 194 674*	*1 875 788*	*1 603 236*	*1 370 286*	*1 171 183*
Depreciation (Gen)	77 617	66 340	56 700	48 462	41 420	243 647	853 484	318 886	272 552	232 950	199 102
Investment (soft starter)						432 713					
Total eq balance (soft starter)	*161 509*	*116 287*	*83 726*	*60 283*	*43 404*	*0*	*311 553*	*224 318*	*161 509*	*116 287*	*83 726*
Depreciation (soft starter)	62 809	45 223	32 560	23 443	16 879	43 404	121 160	87 235	62 809	45 223	32 560
Overhaul		207 800								207 800	
Maintenance	804 525	804 525	804 525	804 525	804 525	804 525	804 525	804 525	804 525	804 525	804 525
Fuel cost	70 220 508	73 731 533	77 418 110	81 289 016	85 353 466	89 621 140	94 102 197	98 807 307	103 747 672	108 935 055	114 381 808
EBT	-71 165 460	-74 855 421	-78 311 896	-82 165 446	-86 216 291	-90 712 716	-95 881 366	-100 017 953	-104 887 558	-110 225 553	-115 417 996
tax	-14 233 092	-14 971 084	-15 662 379	-16 433 089	-17 243 258	-18 142 543	-19 176 273	-20 003 591	-20 977 512	-22 045 111	-23 083 599
EAT	-56 932 368	-59 884 336	-62 649 517	-65 732 357	-68 973 033	-72 570 173	-76 705 092	-80 014 362	-83 910 046	-88 180 443	-92 334 397
CF	-56 791 941	-59 772 774	-62 560 256	-65 660 451	-68 914 733	-75 763 992	-75 730 449	-79 608 241	-83 574 685	-87 902 270	-92 102 734
DCF	-12 855 695	-11 821 117	-10 809 357	-9 911 776	-9 088 788	-8 729 774	-7 623 544	-7 001 493	-6 421 754	-5 900 995	-5 401 868

Year	22	23	24	25	26	27	28	29	30
Investment (Gen)									
Total eq balance (Gen)	*1 001 010*	*855 563*	*731 250*	*624 999*	*534 187*	*456 570*	*390 230*	*333 530*	*0*
Depreciation (Gen)	170 173	145 447	124 313	106 251	90 812	77 617	66 340	56 700	333 530
Investment (soft starter)			432 713						
Total eq balance (soft starter)	*60 283*	*43 404*	*0*	*311 553*	*224 318*	*161 509*	*116 287*	*83 726*	*0*
Depreciation (soft starter)	23 443	16 879	43 404	121 160	87 235	62 809	45 223	32 560	83 726
Overhaul			207 800				207 800		
Maintenance	804 525	804 525	804 525	804 525	804 525	804 525	804 525	804 525	804 525
Fuel cost	120 100 899	126 105 944	132 411 241	139 031 803	145 983 393	153 282 563	160 946 691	168 994 025	177 443 727
EBT	-121 099 040	-127 072 795	-133 591 283	-140 063 738	-146 965 965	-154 227 514	-162 070 578	-169 887 811	-178 665 508
tax	-24 219 808	-25 414 559	-26 718 257	-28 012 748	-29 393 193	-30 845 503	-32 414 116	-33 977 562	-35 733 102
EAT	-96 879 232	-101 658 236	-106 873 026	-112 050 990	-117 572 772	-123 382 011	-129 656 462	-135 910 249	-142 932 406
CF	-96 685 616	-101 495 910	-107 138 022	-111 823 580	-117 394 725	-123 241 585	-129 544 900	-135 820 988	-142 515 150
DCF	-4 954 269	-4 543 730	-4 190 384	-3 821 113	-3 504 704	-3 214 447	-2 951 995	-2 704 011	-2 478 842

NPV = -345 312 312 Rub