

## MODELING ELEMENTS of A BASIC CLOUD SUBSTATION

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**Abstract.** In this paper, the main requirements were considered that will allow us to create a complete model of a cloud substation in the future. The mathematical models on the basis of which the basic elements of a cloud substation will be built in the future are described.

**Keywords:** calculation method, WLAN, breaker, remote protection.

### Introduction

In modern design practice, the decision to use digital substations for different voltage classes is becoming more widespread. "Digital Substation" (DSP) is a term applied to substations controlled by intelligent electronic devices (IEDs) linked by a communications network [1]. However, the development of cloud technologies, the emergence of new ways of manipulating the amount of information and increasing the speed of data transfer using the Internet opens up new opportunities for automating the management of electric power facilities.

The idea of a cloud substation (CPS) is based on two requirements. The first is the transfer of all logical processes to the central server, which, based on the data received in real time (on-time), forms a command and sends it to the operational bodies of the PS. The second is getting rid of the overall equipment of substations to reduce its size.

Therefore, the purpose of this work is to determine the work cycle of the OPS, study the features and properties, and determine the laws and models that will make it possible to compile a complete model of the OPS in the Matlab modeling environment.

### Initial conditions

To begin with, it is necessary to determine the stages of the work cycle of the OPS. The system interacting with information processing must be able to collect information about the state of the equipment (switch, cubicle door, grounding knives, surge arresters, etc.). An approximate interaction scheme is shown in Fig.1.

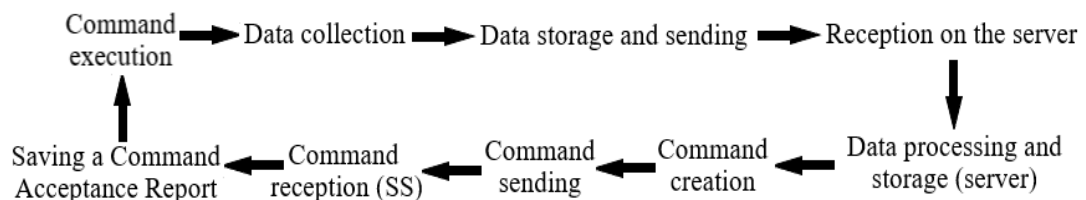


Figure 1. Scheme of the work cycle of the OPS

Intelligent automated processes always start with data collection. Thus, it is necessary, for starters, to determine what data is important for the operation of the OPS and which devices to ensure the collection of this data.

For the operation of the protection of the equipment of the substation, it is necessary to provide the following data: the value of the current and voltage in the phases (possibly the frequency in the system) and the state of the switches. This will allow the data processing program to decide whether to perform switches depending on situations.

To fix the system parameters (current, voltage), it is proposed to use optical current and voltage sensors. This decision was made on the basis that the main parameter in an on-time system is the speed of system responsiveness. Thus, the problem of classical and electronic current transformers is that the processes in them occur at a speed that is calculated by the formula below:

$$T_E = \frac{T_r}{\lambda_R}, \text{ where } \lambda_R = \frac{1}{\sqrt{1 + \frac{k_r^2 R_r}{R_s + R_d}}}$$

This is primarily due to the inertia of the coils and core used in classical current transformers, which under normal conditions are not a problem and do not create a significant delay, but in an on-time system it can significantly affect the speed of operation. The optical system is devoid of these disadvantages, however, it is worth considering the optimal wire length for it, since the length of the path can also affect the response speed of the system.

### Method of calculation

Basic elements such as transformer and switches will be provided in building blocks. An example of the simplest implementation is shown in Fig. 2. However, the transformer model will be supplemented with a block that simulates a temperature sensor, which will also send data in real time, since this parameter is also important in making decisions about the execution of operations in the system.

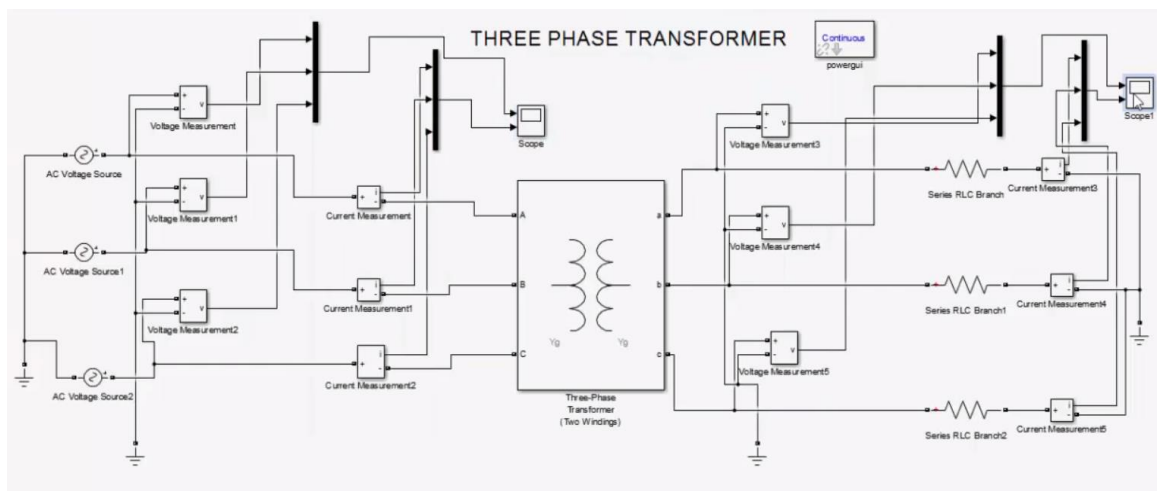


Figure 2. Implementation of the simplest source-transformer-line circuit in Matlab Simulink

As mentioned earlier, one of the means of collecting information in the system are optical current and voltage transformers. Their work is based on the Faraday effect. It consists in the rotation of the plane of polarization of electromagnetic radiation (for example, light) propagating in a substance along the lines of force of a constant magnetic field passing through this substance

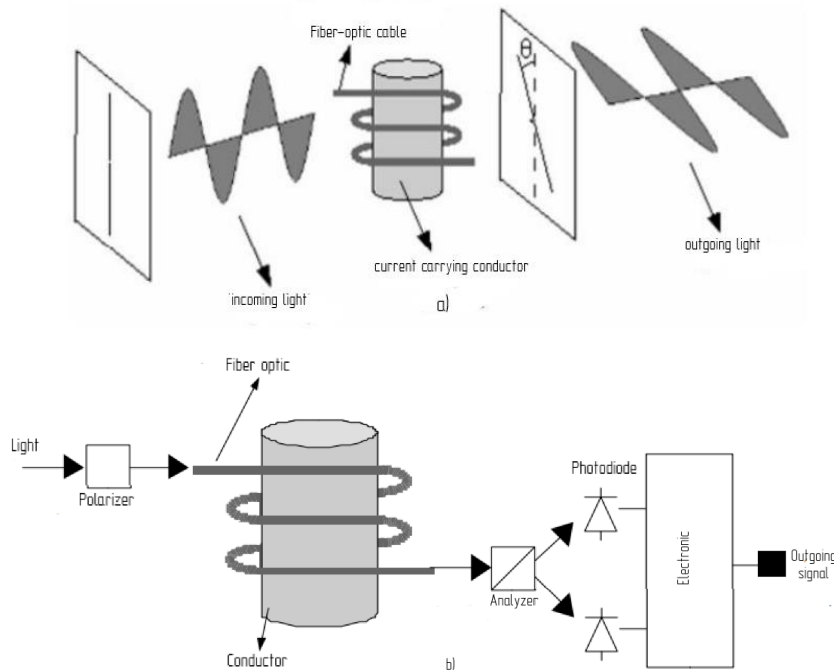
A magnetized substance in the general case can no longer be characterized by a single refractive index  $n$ . The refractive indices  $n_+$  and  $n_-$  for radiation of the right and left circular polarizations become different. Linearly polarized radiation passing through an isotropic medium can always be formally represented as a superposition of two waves polarized in the right and left circles with the opposite direction of rotation. The difference between  $n_+$  and  $n_-$  leads to the fact that the radiation components polarized in the right and left circles propagate in the medium with different

phase velocities, acquiring a path difference that linearly depends on the optical path length. As a result, the plane of polarization of monochromatic light with a wavelength depends linearly on the strength of the magnetic field  $H$ . In the general case, the relation is true:

$$\theta = V \oint \vec{H} d\vec{l} \quad (1)$$

where  $\theta$  – rotation angle of the polar plane;  $V$  - Verdet constant;  $\vec{H}$  - tension vector magnetic field through light direction;  $d\vec{l}$  - Short length vector faraday material through direction light propagation.

A schematic representation of the fiber optic sensor system and the principle of operation of the sensor itself are shown in Fig.3 a, b.



**Figure 3. Fiber optic sensor system**

However, according to Ampère's law, equation (1) can be reduced to the form

$$\theta = VNI$$

where  $N$  - the number of turns of fiber;  $I$  - current of the conductor.

A fiber optic sensor in *Matlab* is a complex model consisting of several block models, namely: a laser, a polarizer, a fiber optic sensor, an analyzer, a photodiode, and a computational module.

The laser block model acts as a light source in the system. It has a constant wavelength and is described by the following Ec.:

$$\frac{dN(t)}{dt} = \frac{i(t)}{qV_a} - g_0 \frac{[N(t)-N_0]S(t)}{1-\varepsilon S(t)} - \frac{N(t)}{\tau_n} \quad (2)$$

$$\frac{dS(t)}{dt} = Gg_0 \frac{[N(t)-N_0]S(t)}{1-\varepsilon S(t)} - \frac{S(t)}{\tau_p} + \frac{G\beta}{\tau_n} N(t) \quad (3)$$

$$\frac{d\phi(t)}{dt} = \frac{1}{2} \alpha_L \left[ Gg_0 [N(t) - N_0] - \frac{1}{\tau_p} \right] \quad (4)$$

where  $i(t)$  - laser current;  $S(t)$  – photon density;  $G$  – optical factor confinement;  $g_0$  – slope gain;  $N(t)$  – carrier density;  $N_0$  – carrier density at transparency;  $\varepsilon$  – saturation parameter;  $\tau_p$  – photon lifetime;  $\beta$  - spontaneous emission factor;  $\tau_n$  – carrier lifetime;  $V_a$  – volume of the active region;  $\alpha_L$  – line-width enhancement factor;  $q$  – electron charge;  $\phi(t)$  – phase of the laser electric field.

The output optical power of a laser diode is mathematically expressed as follows [2].

$$P(t) = \frac{V_a \eta h \nu}{2G\tau_p} \quad (5)$$

where  $P(t)$  – line-width enhancement factor;  $\eta$  – quantum efficiency;  $h$  – phase of the laser electric field;  $\nu$  – frequency of the laser.

Since laser light is an electromagnetic field, the output power of laser radiation can be expressed as like an electric field [-].

$$E_{laser}(t) = \sqrt{P(t)}e^{i\phi(t)} \quad (6)$$

In the polarizer model shown in Fig.6, the light from the laser is perfectly linearly polarized in the x and y directions. The mathematical expression for this is as follows [3].

$$E_{pol} = \frac{1}{\sqrt{2}} \begin{bmatrix} 1 \\ 1 \end{bmatrix} E_{laser} \quad (7)$$

If we neglect the linear birefringence of light inside the fiber, the Faraday effect can be mathematically written as an M-matrix similar to [4].

$$M = \begin{bmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{bmatrix} \quad (8)$$

The attenuation of the electric field in the fiber can be expressed as follows, analogue [-].

$$E_{alfa} = E_{pol} \sqrt{10^{-\frac{\alpha_L}{10}}} \quad (9)$$

Since Rayleigh scattering dominates at short wavelengths and IR absorption loss dominates at long wavelengths, the damping factor can be expressed as:

$$\alpha(\lambda) = 7.81 \cdot 10^{11} e^{-\left(\frac{48.48}{\lambda}\right)} + \frac{1}{\lambda^4} \quad (10)$$

The change in the electric field of light due to the Faraday effect is also expressed as follows

$$E_{fiber} = ME_{alfa} \quad (11)$$

The analyzer model ideally divides the electric field of the light coming out of the fiber optic cable into x and y components. The equation below represents the x and y components of the electric field of light:

$$E_{x,y} = E_{laser} \frac{1}{\sqrt{2}} \sqrt{10^{-\frac{\alpha_L}{10}}} (\cos\theta \pm \sin\theta) \quad (12)$$

The current passing through the photodiode conductor can be found as follows:

$$I = \frac{1}{2VN} \arcsin \left( \frac{I_y - I_x}{I_y + I_x} \right) \quad (13)$$

### Switch connection and wireless transmission model

Another important link is the switch. Own design experience allows us to accept the Easypact EXE 10 kV circuit breaker from Schneider Electric as a simulation, as it is quite reliable, its contact diagram is freely available, and it also uses a spring-motor drive, which has proven itself better than electromagnetic. Its contacts make it easy to connect the switch to the I/O module. Thus, using contacts OF1, PF and B1, you can get a reliable picture of the state of the circuit breaker, because they are responsible for the position of the switch, readiness for switching on and the position of the contact for turning on the spring winding motor, respectively Fig. 4.

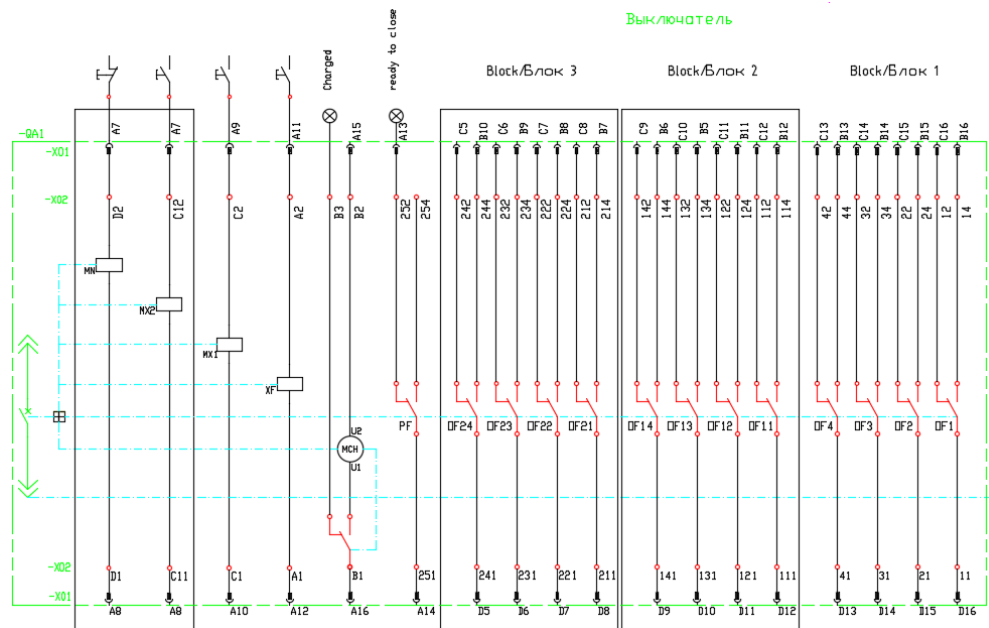


Figure 4. EasyPact EXE Wiring Diagram

In current design practice, for processing relay protection and automation (RPA) assembled from switches and terminals, a processor module is installed between the I/O module and the router, however, in our system there is no certainty that these functions need to be implemented in this way, since the device for converting discrete / analog signals and the formation of data packets for sending can be implemented in a much simpler and more compact design.

The standard functionality of the "switch" block will definitely not be enough, because even the basic model will require the implementation of relay protection in order to be able to manipulate the power switch. And since the idea of the OPS project is to transfer all logical processes to a remote server, it is necessary to model the process of information exchange between the executive bodies and the decision-making center. This requires a model of wireless data transmission.

One of the key questions that will be asked of this model will be the speed of data transfer, because it is necessary to ensure a sufficient speed of issuing commands. This will be achieved by optimizing the size of data packets and researching the fastest ways to transmit them. However, for the base model, it was decided to use the standard 4g network model, which, despite its familiarity, is an extremely difficult model to implement. However, the implementation algorithm is clear and its results are shown in Fig.5.

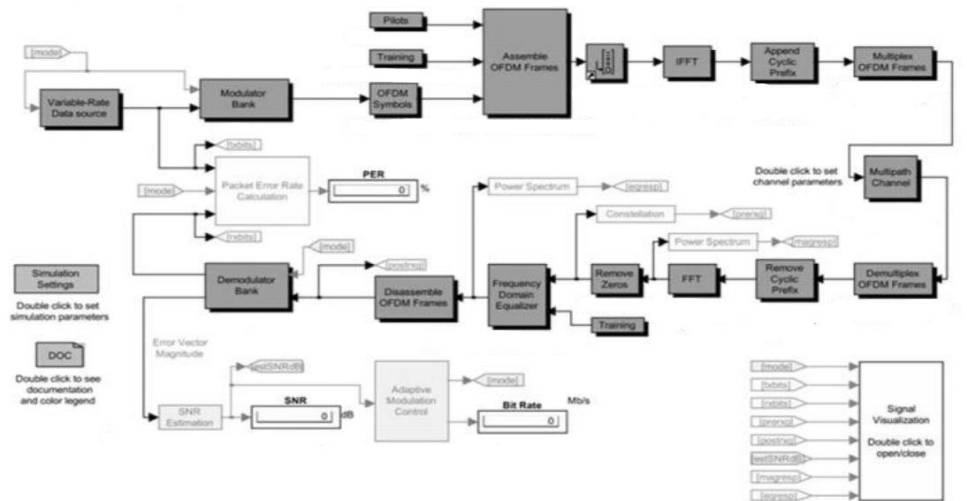


Figure 5. Results of the algorithm implementation

## Conclusions

In this paper, the basic for mathematical models of the elements of the basic cloud substation was considered. The basic requirements were determined, which formed the basis for the creation of models and the choice of equipment. The properties of some elements of a cloud substation are considered.

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