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COMBINED ELECTRIC POWER PLANT SIMULATION MODEL

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The article is dedicated to a simulation model of a wind/solar power plant. A variable speed diesel generator set is used as a backup energy source. A matrix frequency converter is used to control frequency of the generated voltage. The simulation model is implemented in the MATLAB Simulink environment. Oscillograms of currents and voltages are obtained when the model operates with an active inductive electrical load with the variable load value in the 1000–4000 VA range. During operation with a rated power load, the deviation of the line voltage parameters lies within the normal range (load voltage drop does not exceed 4% of the nominal value, total harmonic distortion does not exceed 2% in the 0–2000 Hz range). The constructed model can be used in the design of energy facilities, as well as in the development and testing of algorithms for control and monitoring systems.

Keywords: renewable energy sources, simulation modelling, matrix frequency converter.

Introduction

Nowadays the world electricity sector is boosting power of the units, using renewable energy sources. Crucial factors stimulating renewable power generation development in different countries are: continuously evolving technologies enhancing the units' environmental safety based on renewable energy sources, absence of pollutant and greenhouse gas emissions, energy independence from geopolitical environment affecting fossil fuels supply.

Among renewable energy sources, solar radiation and wind are most widely used. However, these energy sources are unstable which is a serious drawback hindering their widespread use and making it necessary to employ emergency auxiliary energy sources, such as petrol or diesel generators.

Today different generating units' structures have been proposed, using wind power, solar radiation and hydrocarbon fuel in various combinations [1–5]. Simulation models also have been described [6–9]. However, today the issue of creating an energy complex structure using renewable energy sources has no unique technical solution. This is explained by all the existing energy unit circuits having their own advantages and disadvantages as well as by continuous progress and sophistication of tool and mechanical engineering.

It is noteworthy that in a great number of diesel generator units the shaft speed remains constant regardless of electric load rate. Current research shows that constant shaft speed engine operation at a changing load rate leads to the power unit increased mechanical wear and higher fuel consumption, therefore variable speed diesel generator units are of interest for both researchers [10–14] and research and production enterprises (Fubag, Honda, Kipor, VNIIE, Sigma PLC (Kovrov), Zvezda PLC (St.Petersburg), VGUVT (N. Novgorod) etc.).

Frequency converter is necessary to keep constant frequency output voltage of a generator unit while adjusting the engine shaft speed. There are diesel generator unit circuits in which DC link frequency converters are used. However, converters of this topology have such downsides as loss of efficiency due to twofold energy conversion and loss in reliability due to DC link components' ageing and failure. These downsides are not characteristic of direct-coupled frequency converters, matrix topology converters representing perspectives for their development. They comprise nine bilateral switches allowing to connect each supply network phase to each load phase. This technical solution provides high electromagnetic compatibility while enhancing the converter's efficiency and reliability.

Research methods

When designing power units, a crucial task is to develop automatic control systems providing the complex's efficient and safe operation. Creating such control systems needs simulation models to develop and test algorithms, as well as to study processes taking place when the energy complex is operated in different modes including the emergency ones posing threats to the equipment and personnel. Therefore, simulation modelling was chosen as a research method in MATLAB Simulink environment. Fig. 1 shows the simulation model flow chart.

Simulation model comprises a solar energy converter, a wind energy converter, a diesel generator unit, a three-phase active-inductive electric load (nominal linear voltage RMS 380 V, 50 Hz). Energy converters are multiplexed by an AC bus. Solar energy converter comprises a photovoltaic panel simulator, a three-phase bridge voltage invertor with output LC filter and a step-up transformer. Photovoltaic panel simulator consists of controllable voltage source with controlled internal resistance allowing to simulate changing solar radiation density. Wind energy converter consists of a wind turbine simulator, synchronous generator and matrix frequency converter with output LC filter compensating voltage output frequency fluctuations at the wind speed change. Wind tur-

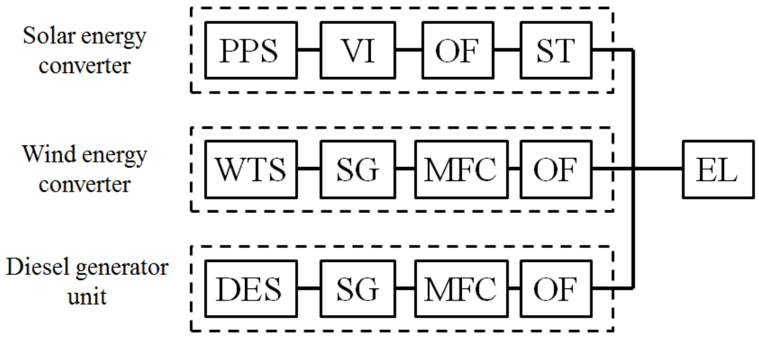

Fig. 1. The simulation model flow chart: PPS – photovoltaic panel simulator; VI – voltage invertor; OF – output filter; ST – step-up transformer; WTS –wind turbine simulator; SG – synchronous generator; MFC – matrix frequency converter; DES – diesel engine simulator; EL – electric load

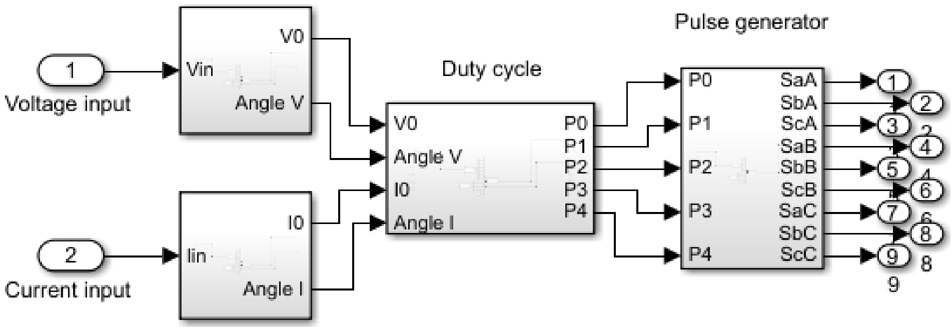

Fig. 2. Matrix frequency converter control system with space vector modulation

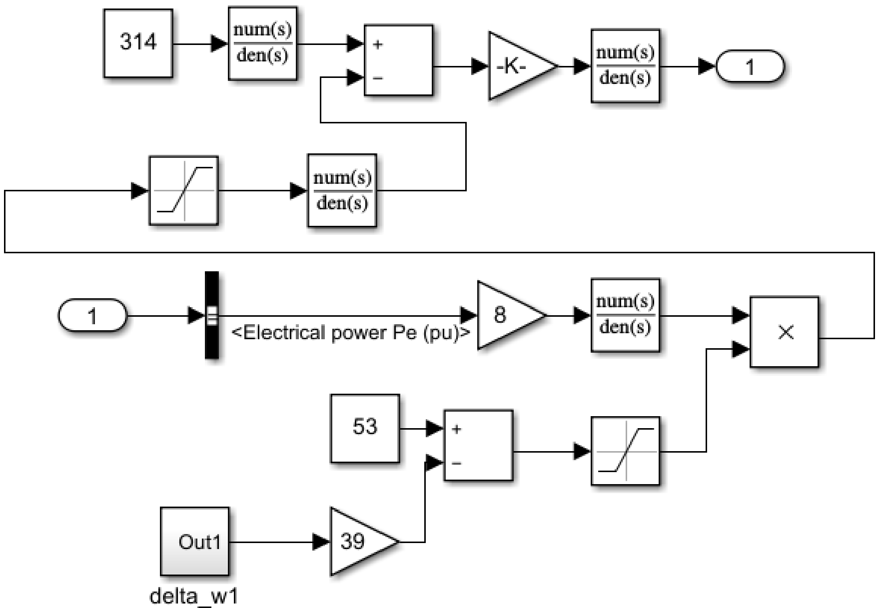

Fig. 3. Diesel engine simplified model

bine simulator produces a synchronous generator shaft speed signal according to the preset schedule of wind speed change. Matrix converter is realized according to a three phase-to-three-phase bridge circuit with space vector modulation under the principle of D. Casadei, G. Grandi, G. Serra, A. Tani [15]. The control system under this principle is shown in Fig. 2. Compared to the other well-known control technology by P.D. Ziogas, S.I. Khan, and M.H. Rashid [16, 17], this control technology has shown higher electromagnetic compatibility indices and voltage transfer ratio.

The system comprises s-function units, performing the following operations: input current and voltage parameter lock, detection and location of input current and voltage vectors relative position, calculation of the required on-state relative durations corresponding to matrix converter switch combination, producing control signals for matrix converter switches.

Diesel generator unit consists of a simplified model of diesel engine, a synchronous generator, matrix frequency converter with output LC filter. Diesel engine block model structure is shown in Fig. 3.

Diesel engine block model produces a synchronous generator shaft speed signal basing on electric power signal generated by synchronous generator and a fuel-control unit signal, set in relative units. To speed up the modelling process linear approximation of two diesel engine mechanical characteristics is used in the model – to provide generator operation at the nominal rated electric load and idle operation.

The model structure in MATLAB Simulink environment is shown in Fig. 4.

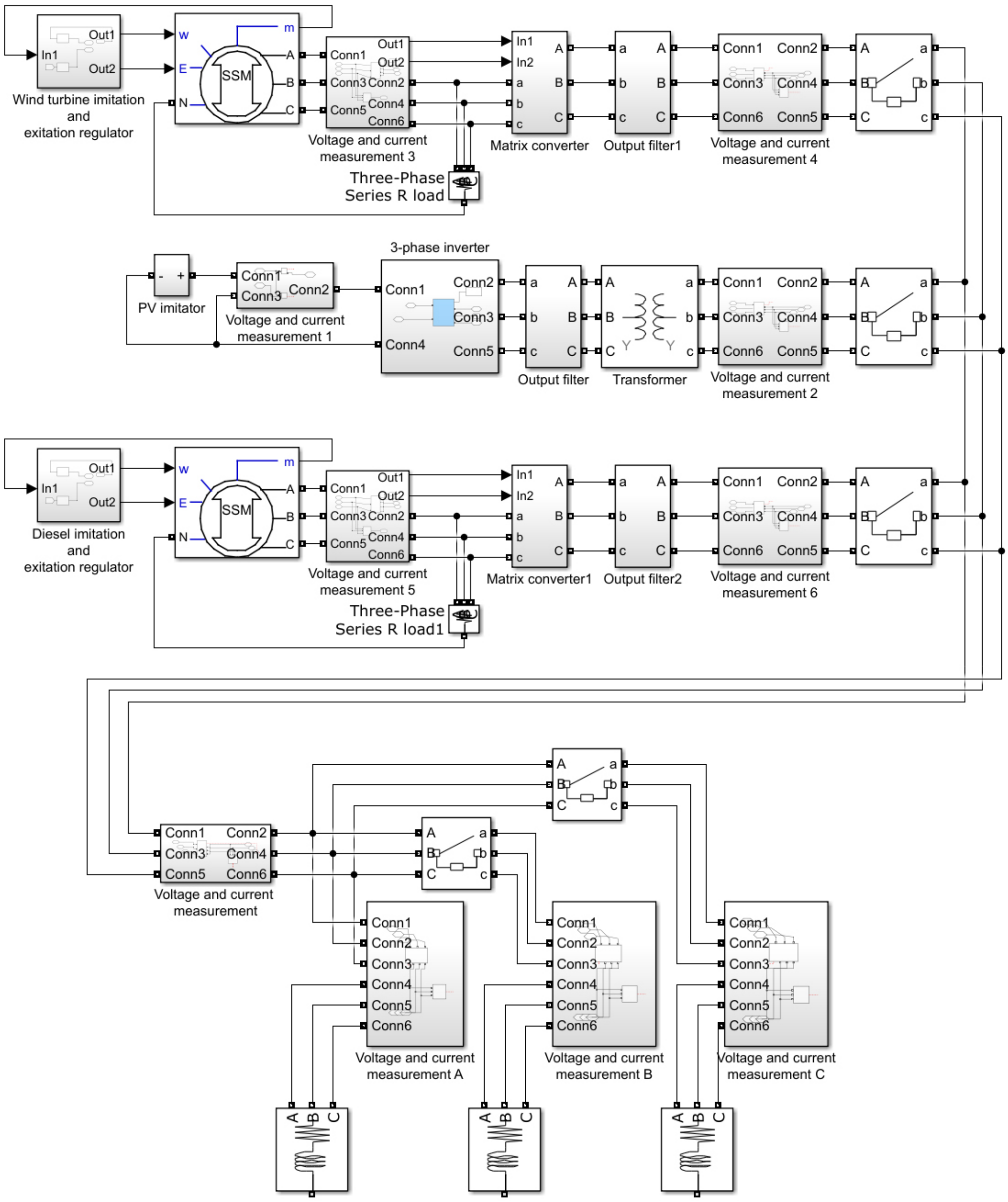

Fig. 4. Model structure in MATLAB Simulink environment

Research results

In the modelling process the unit operation with step-like electric power increase and sequential bringing into operation energy converters is considered.

Time sequence of the model state change during the modelling period:

– 0 s – start of modelling, wind energy converter in operation, load power 1000 VA, cosφ 0,95;

– 0,1 s – load power increase of up to 2000 VA, cosφ 0,95;

– 0,2 s – bringing into operation solar power converter;

– 0,3 s – load power increase of up to 4000 VA, cosφ 0,95; preparing to bring into operation diesel generator unit;

– 0,4 s – bringing into operation diesel generator unit.

Load current and load voltage oscillograms are shown in Fig. 5.

On the first time interval wind energy converter is employed. When connecting load with the power corresponding to wind energy converter 1000 VA nominal power, load voltage decrease does not exceed 4% of the nominal level 380 V RMS, while linear load voltage THD (Total harmonic distortion) does not exceed 2%. Herewith, it is possible to conclude that at the model preset parameters with electric load power not exceeding 1000 VA, it is possible to provide the electric power quality required parameters solely by one of renewable energy sources, the auxiliary energy source – diesel generator unit – being unnecessary.

On the second time interval at 0,1 s load power is increased up to 2000 VA, leading to 9% load voltage decrease of the nominal level. An extra energy source is necessary to restore the electric supply quality.

On the third time interval at 0,2 s solar energy converter is brought into operation simultaneously with wind energy converter. At this, load voltage amplitude is restored to its initial value.

On the fourth time interval load power is increased up to 4000 VA at 0,3 s, resulting in 10,3% load voltage decrease of the nominal level. In this

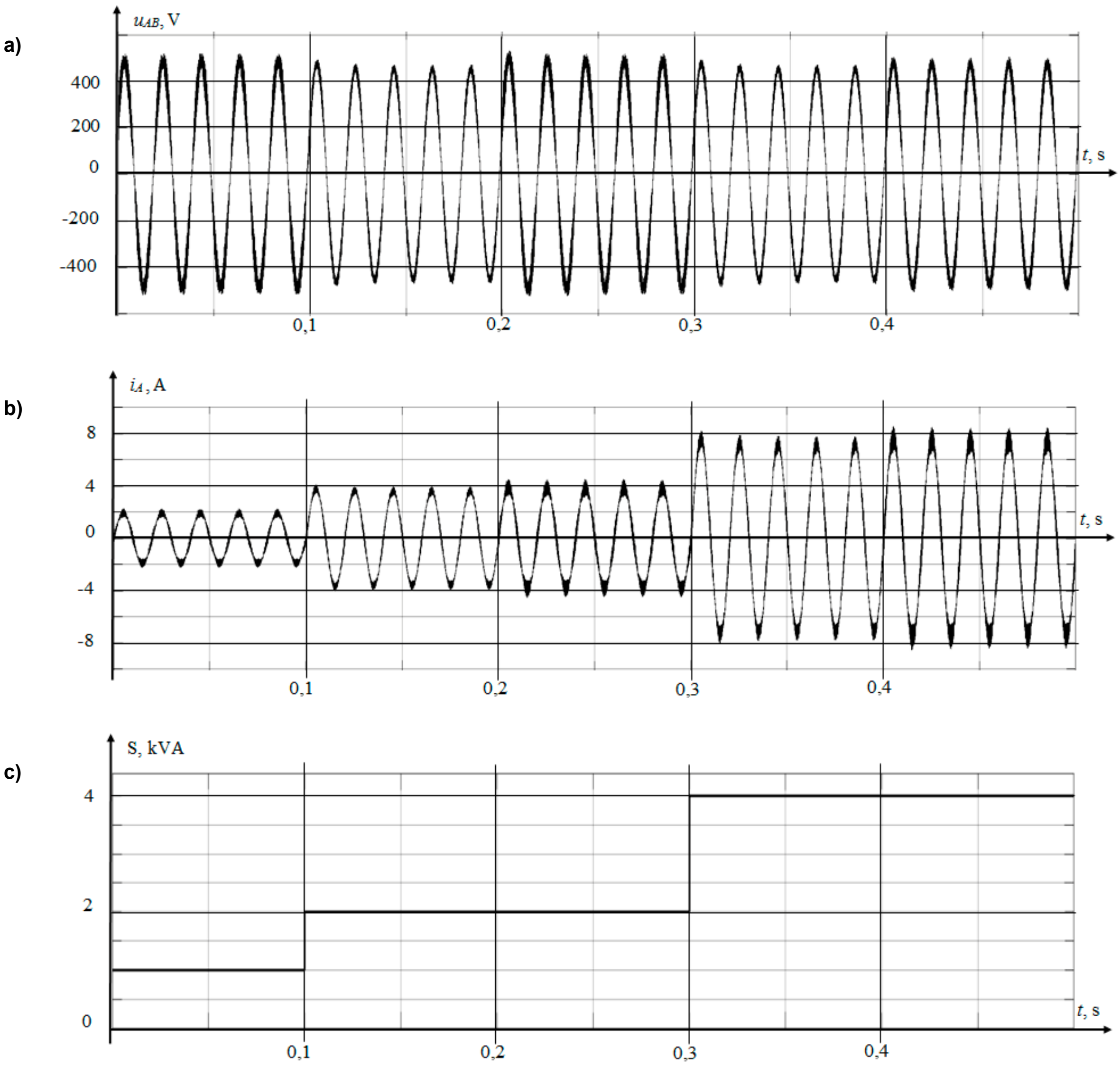

Fig. 5. Modelling-obtained oscillograms: a – linear load voltage; b – load phase current; c – electric load value

case, when the connected load power exceeds renewable energy sources nominal power, or in case of insufficient capacity of renewable energy sources it is necessary to employ an auxiliary energy source – diesel generator unit.

On the fifth time interval at 0,4 s diesel generator unit is simultaneously connected. At this, load voltage amplitude is restored to its initial value, deviation from the nominal level not exceeding 4%.

Conclusion

The article shows simulation modelling results of an electric power plant with combined wind-solar-diesel power generation. The modelling has been accomplished in MATLAB Simulink environment at the electric load power step change within the range of 1000–4000 VA, cosφ 0,95 and 50 Hz load voltage frequency. Current and voltage oscillograms have been obtained and load voltage THD has been determined. With the load value change in the given range, short-time voltage fall during the transition process does not exceed 10,3% of the nominal voltage value. In static operation mode load voltage parameters are maintained on the preset level. The simulation model allows to reproduce the processes taking place at the following parameter change: wind speed, solar radiation intensity, adjustment to the converters' output voltage frequency and amplitude, diesel engine shaft speed, electric load parameters. Matrix frequency converter with space vector control algorithm, which is employed in the model, allows to control diesel generator shaft speed at the electric load intensity change in order to select engine operation economy mode and to save fuel. However, despite the matrix topology having certain advantages, small value of voltage transfer ratio remains a serious drawback requiring further analysis of matrix frequency converter practicability in each case. The created simulation model can be used for designing renewable energy objects and testing control systems algorithms as well as researching energy complex static and dynamic operation modes.

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ИМИТАЦИОННАЯ МОДЕЛЬ КОМБИНИРОВАННОЙ ЭЛЕКТРОСТАНЦИИ

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В статье описывается имитационная модель ветро-солнечной электростанции с использованием в качестве резервного источника энергии дизель-генераторной установки с изменяемой частотой вращения вала. Для регулирования частоты генерируемого напряжения применяется матричный преобразователь частоты. Имитационная модель реализована в среде MATLAB Simulink. При работе имитационной модели с активно-индуктивной электрической нагрузкой с мощностью, изменяющейся в диапазоне 1000–4000 ВА, получены осциллограммы токов и напряжений. При работе с номинальной мощностью нагрузки отклонение параметров сетевого напряжения не превышает установленных норм (падение напряжения на нагрузке не превышает 4 % от номинального значения, суммарный коэффициент гармонических искажений не превышает 2 % в диапазоне 0–2000 Гц). Построенная модель может быть использована при проектировании объектов электроэнергетики, а также при разработке и тестировании алгоритмов систем управления и мониторинга.

Ключевые слова: возобновляемые источники энергии, имитационное моделирование, матричный преобразователь частоты.

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