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NEW APPROACH TO SIMULATION OF EXTRA-POWER SOLAR PLANT WITH POWER EVACUATION BY NETWORKS OF THE CHERNOBYL NPP

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This paper deals with the system study for the development and connection of 1200 MWp Chernobyl photovoltaic (PV) plant to the transmission grid of interconnected power system of Ukraine. The aim of this study is to develop the planetary models of solar power plant, to perform quasi-dynamic simulation and to check network steady-state operating conditions at peak production of the PV plant, including identification of the element loadings in the transmission and distribution networks, bus voltages in the area, fulfillment of the grid code requirements. References 5, figures 5.
Key words: extra-power solar plant, Chernobyl nuclear power plant (NPP), power evacuation, quasi-dynamic simulation, solar irradiation, voltage, equipment loading.

Introduction. This paper is dedicated to the system studies for the connection of extra-power solar plant (1200 MWp PV plant) to the transmission grid of interconnected power system (IPS) of Ukraine. In order to integrate such an extra-power solar plant, powerful network facilities are needed. After decommissioning the Chernobyl nuclear power plant (NPP), the transmission network of this power plant is not used. Thus, the *main goal* of this work is to develop the new simulation approach for extra-power solar plant and integration of such plant to IPS of Ukraine using the existing electrical networks, in particular, the evacuation scheme of Chernobyl NPP.One of the approaches used in this study is performing a Quasi-Dynamic Simulation of the whole IPS of Ukraine operation.

Nowadays the Quasi-Dynamic Simulation is widely used in international practice to analyze the impact of intermittent generation on the grid. The application of the comprehensive model of the PV system allows considering time-series data of the real irradiation level measured for each hour of the year for the latitude and longitude of the PV plant location in order to simulate active power output of the system for every hour. As a result, this results in a more realistic estimation of PV plant generation considering the period of interest (day, week, month, season, year etc.). The application of Quasi-dynamic simulation allows considering the system load curve and operation of other renewables in the area as well. However, in comparison with the simple dataset for the traditional deterministic approach, Quasi-Dynamic Simulation requires much more data and more complex models.

The software models of collector and evacuation schemes of the Chernobyl PV plant have been developed and integrated into the IPS of Ukraine calculation model which was updated for the planning horizon. All system study is performed in DIgSILENT PowerFactory software. In general, the study methodology combines two approaches: a classical deterministic approach (which is out of the scope of this paper) and Quasi-Dynamic Simulation. This methodology considers the particularities of the renewable intermittent generation and allows performing the grid calculation in a way that is more realistic. However, Quasi-Dynamic Simulation requires many input data and more complex models based on hourly time-series measurements of solar irradiation, temperature, etc. for a quite long period of time. Additionally, Quasi-Dynamic Simulation allows calculating the load flow for each hour of a year considering the realistic intermittent generation of Chernobyl PV plant and load demand curves in the IPS of Ukraine as well. This allows determining not only the critical values of network elements overloading but also the appearance frequency of these overloads. In order to perform Quasi-Dynamic Simulation, the active power values of each model of PV System have been calculated, the data of the solar panel type, the arrangement of the solar array, the local time and date, and irradiance data have been also considered.

Methodology. Taking into account the aims of the PV plant study and a state of the art of the renewables simulation technologies, a special methodology has been developed in this study. It should be noted that medium to long-term analysis must be carried out mainly using Quasi-Dynamic Simulation due to the consideration of the solar irradiance based on GPS coordinates, PV panel models, different mounting op-

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tions, including single/dual axis of the maximum power point (MPP) trackers, various steady-state voltage/reactive power control options coordinated with other units, etc.

A Quasi-Dynamic Simulation allows considering the data, which may be represented by hourly dependences. In particular, these data include load curves, a maintenance schedule of the grid elements, conventional generation dispatch and intermittent generation forecast/recorded time series data, etc. In this study daily load curves of IPS of Ukraine, generation dispatch of the most powerful Ukrainian pump storage power plant and Chernobyl PV plant active power generation profile have been simulated. The operation of the power system can be studied considering voltage limitations (over- and under-voltage), loading violations, reverse power flow in distribution networks, primary/secondary frequency control as well as similar analysis in microgrids including diesel generators and battery systems, etc. In the frame of this paper, the long-time series calculations (including 8760 hours, 1hour equals to 1 calculation) are performed.

Solar plant models. In order to perform a Quasi-dynamic simulation, the computer models of collector and evacuation schemes of the Chernobyl PV plant have been developed. In general, extra-power solar power plant consists of 8 blocks. Each block contains the 68 solar inverter stations with a capacity of 2250 kVA. The two solar invertors are combined into one PV unit (as shown in Fig. 1). The each solar inverter stations consist from the array of 6720 photovoltaic modules (the nominal power of each module is 335 W), connected to the grid through a single inverter of 2200 kVA. Considering the above mentioned, the total capacity of the Chernobyl PV plant is 1224000kVA.

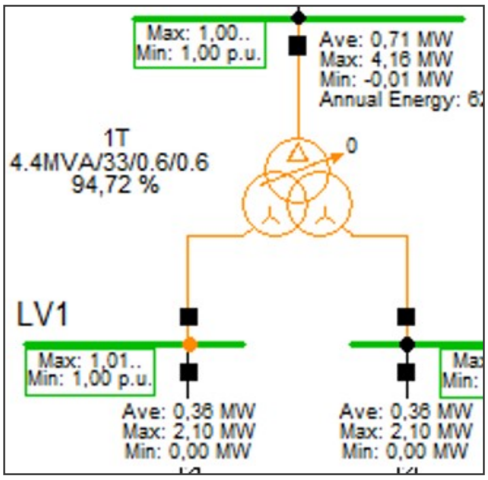


Fig. 1

In order to evacuate the PV generation power, a new substation model has been developed. It is equipped with eight 33kV switchgears, eight 150 MVA 330/33 kV step-up transformers, 330 kV breaker-and-a-half scheme and two short parallel overhead lines connecting the substation with the existing 330 kV switchgear of Chernobyl NPP (this is the point of common coupling). This configuration is the most appropriate case to connect the PV plant to the grid. The advantage of this approach is the reconnection of the existing 330 kV overhead lines in this area from switchgear 330 kV Chernobyl NPP to this new substation in the future, taking into account prospective plans of decommissioning of 750, 330 and 110 kV switchgears of Chernobyl NPP.

The PV system provides an option of automatic estimation of the active power setpoint based on the geographical location, date and time. The active power value can be directly defined and usually used for the deterministic approach, otherwise, it can be calculated considering data of the solar panel type, the arrangement of the solar array, the local time and date, and optionally irradiance data.

Solar radiance and insolation. The solar radiance is an instantaneous power density in units of kW/m^2 and it varies throughout the day from 0 at night to a maximum of about 1 kW/m^2. This value is strongly dependent on location and local weather. Solar radiance data are measured periodically throughout the day [1]. While solar irradiance is most commonly measured, the solar insolation is a more common form of radiation data used in system design.

The solar insolation is the total amount of solar energy received at a particular location during a specified time period, often in units of kW h/m^2 per day. Solar insolation data are commonly used for simple PV system design while solar radiance is used in more complicated PV system performance considering the values at each point of the day [1].

Traditionally, the PV electrical characteristics are measured at a reference incident radiation of 1000 W/m^2 and at an ambient temperature of 25ºC (these parameters are used in the deterministic approach). In practical applications, the solar cells do not operate under standard conditions. The operating temperature of a PV module is determined by the energy balance. The nominal operating cell temperature is defined as the temperature of the cell or module when the cells are mounted in their normal way at the solar radiation of 800 W/m^2, the wind speed of 1 m/s, the ambient temperature of 20 ºC, and no-load operation [2].

Solar irradiation in the area of the Chernobyl plant. The maximum and average values of the global irradiation on the horizontal plane at ground level (GHI) at the Chernobyl area during the last ten years were analyzed. The annual global in-plane irradiation is 1325 kWh/m^2 [3]. These data correlate with the average data for the past 10 years, i.e. with 133 W/m^2. However, the GHI exceeding 900 W/m^2 appears during the year for a few hours only.

The data on solar irradiance for the site have been taken from [4] and entered into the model. The Copernicus Atmosphere Monitoring Service (CAMS) radiation service provides time series of Global, Direct, and Diffuse Irradiations on a horizontal surface, and Direct Irradiation on a normal plane (DNI) for the actual weather conditions as well as for clear-sky conditions (Fig. 2). The geographical coverage is the field-of-view of the Meteosat, namely: Europe, Africa, Atlantic Ocean, Middle East (–66° to 66° in both latitudes and longitudes). Data are available with a time step ranging from 1 min to 1 month. For purposes of the study, irradiance data have been simulated on an hourly basis. Additional data on monthly average temperature and ground albedo from Atmospheric Science Data Center [5] have been considered in the model. Besides, the monthly air temperature during the last 22 years has been considered as well.

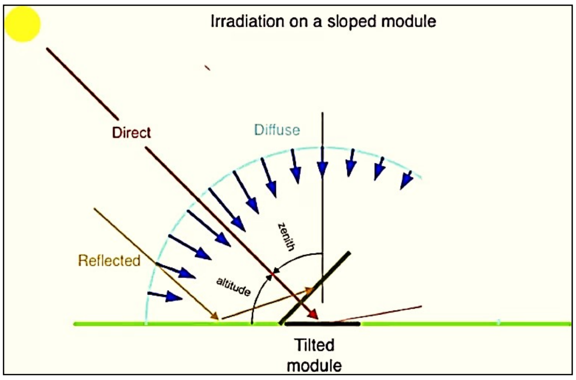


Fig. 2

Operating transmission system in the area of the Chernobyl PV plant. Initially, the 750/330/110 kV substation and grid connection scheme of Chernobyl NPP has been designed to evacuate 4000 MW generated by four nuclear units (the capacity of each generating unit is 1000 MW). However, due to the NPP decommissioning, the connection scheme and grid infrastructure of this area have been significantly changed. Nowadays, one of two 750 kV overhead lines is already decommissioned. The entire 750 kV switchgear may be decommissioned in the coming years due to the different reasons (absent of necessity to transfer such power and high radiation level at 750 kV switchyard, as it is situated near the fourth nuclear unit exploded in 1986). The decommissioning is foreseen by the Ten-Year Network Development Plan of IPS of Ukraine. The most powerful connection is in the 330 kV networks. The evacuation scheme at 330 kV level includes three overhead lines to IPS of Ukraine. The fourth line (Chernobyl NPP – Mozyr) is a tie line connected with the Belarus power system. This line will be disconnected in the future, in case of the operation of the Ukrainian power system in parallel with ENTSO-e and disconnection from IPS/UPS. The 110 kV switchgear is connected to 330 kV busbar systems by two autotransformers with a capacity of 125 MVA each. At the present, a few 110 kV overhead lines are connected to the main grid of IPS of Ukraine through 110 kV distribution network of the Kyiv area.

Simulation results. In this study, a Quasi-Dynamic Simulation has been performed for different time intervals including day, week, summer and year with a time resolution of 1 hour. Therefore, 24 load flow cases have been calculated to identify different possible overloadings and/or voltage deviations in the electrical network occurring during the whole day, 168 load flow cases – for a week, 2208 cases for the summer season and finally 8760 cases for a whole year.

Based on the proposed model of PV system and model of electrical collector/evacuation schemes, active power generation of Chernobyl PV plant has been calculated by using time series on GHI, DNI, Ambient Temperature and Ground Albedo with hourly resolution data. The Quasi-Dynamic simulation results for annual power generation of the single PV unit based on historical meteorological data are shown in Fig. 3.

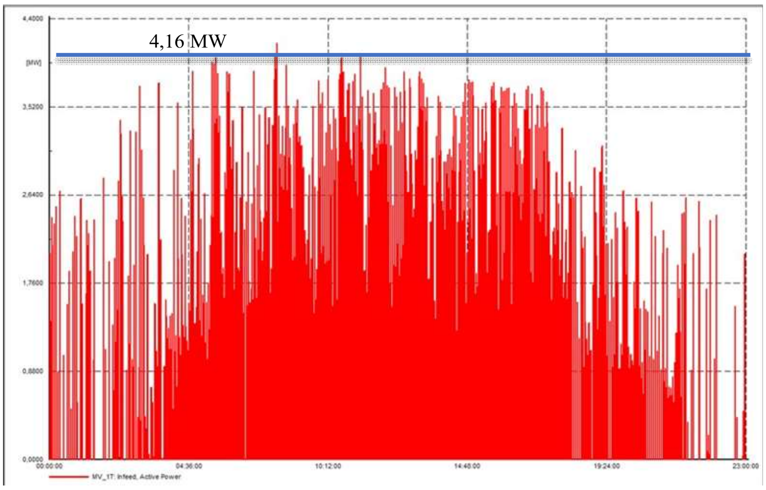
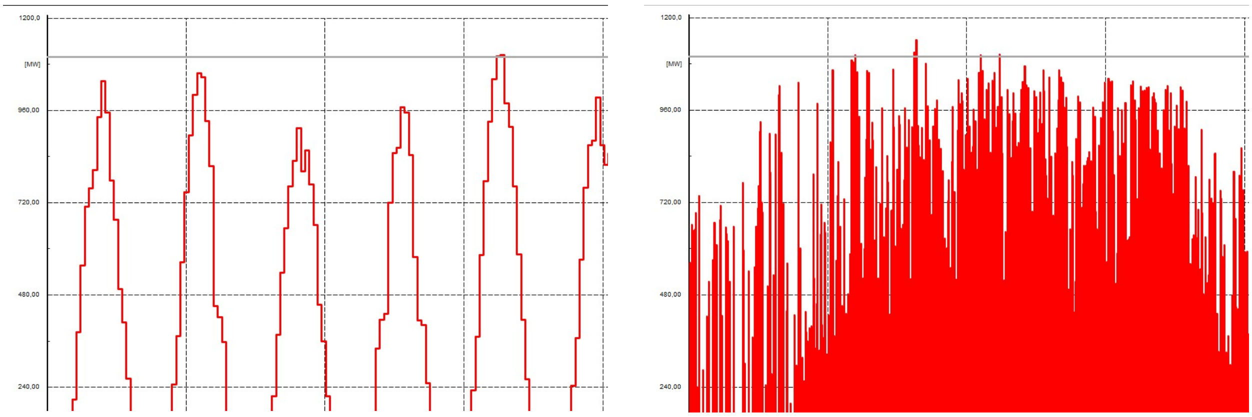


Fig. 3

As seen, the maximum active power of a single PV unit with installed capacity 4502 kVA is about 4,16 MWp only (considering real irradiation data). And this maximum active power generation will appear extremely seldom. Whole Chernobyl PV plant generation profiles for summer working week with maximum irradiation and the whole year are presented in Fig. 4, *a* and 4, *b*, respectively.

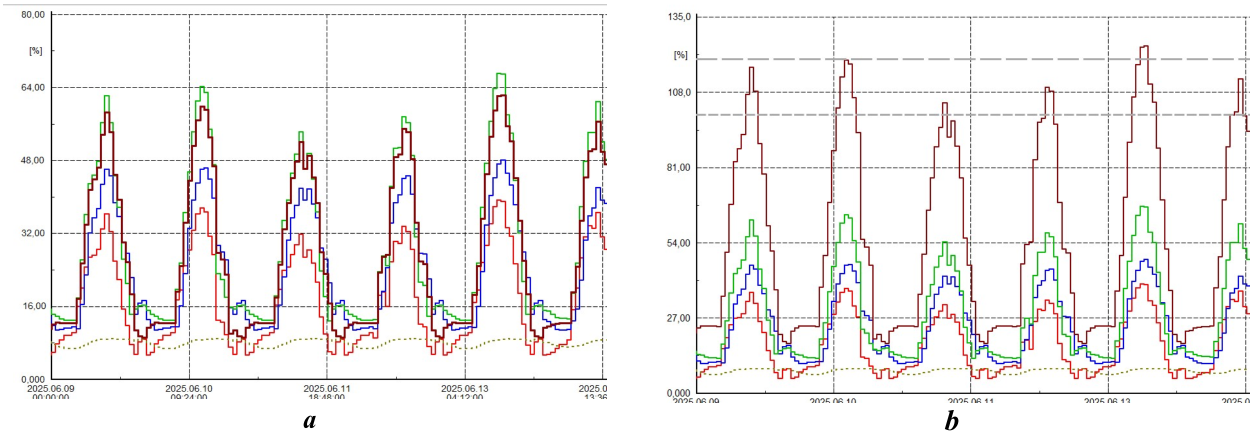


a ***b***

Fig. 4

Besides, under a normal grid configuration (all overhead lines of the area are in operation), the connection of the Chernobyl PV plant does not lead to the overloads of the network elements. The Quasi–dynamic simulation has been performed for different cases of single disconnections of overhead lines, which are connected to the point of common coupling. As expected, no voltage violations have been defined. The loading (in %) of the 330 kV overhead lines in the area of Chernobyl NPP during the different time intervals (summer working day, summer week, summer and year) is depicted in Fig. 5, *a* and 5, *b*. Fig. 5, *a* illustrates the loading of the overhead lines for the summer week (these are days with maximum irradiation) for normal system conditions. The obtained results for the same period but considering "N-1" cases are shown in Fig. 5, *b*. It should be noted that the rated line currents have been decreased in the assumption of 40˚C of ambient temperature for the summer period that allows defining the real loadings of the network elements.

In case of the disconnection of one of two parallel 330 kV overhead lines Chernobyl NPP – Chernobyl PV plant connecting the switchgear of Chernobyl NPP with Chernobyl PV plant, may lead to the overloading of another 330 kV overhead line up to 125% for two hours in the summer. It should be noted that the duration of such overloading is too short (1–2 hours).



a ***b***

Fig. 4

Conclusions. The new approach proposed for calculation of extra-power solar plants allowed more accurately simulating the extra-power solar plant integrated in IPS of Ukraine and obtaining the more realistic data concerning PV station. In fact, the maximum output of the Chernobyl PV plant does not exceed 1100 MW during the year. The conditions with the higher output of the PV plant are extremely short-term cases and may be estimated as a few hours per year (1170 MW is assumed as a maximum output by deterministic worst-case scenario). The maximum loading of the overhead lines in the surrounding area of the Chernobyl PV plant in the normal scheme does not exceed 70% during the maximum generation of this PV plant.

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НОВИЙ ПІДХІД ДО МОДЕЛЮВАННЯ НАДПОТУЖНОЇ СОНЯЧНОЇ ЕЛЕКТРОСТАНЦІЇ З ВИДАЧЕЮ ПОТУЖНОСТІ ЧЕРЕЗ ЗВ'ЯЗКИ ЧОРНОБИЛЬСЬКОЇ АЕС

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Наведено результати системних досліджень розвитку та підключення Чорнобильської сонячної електростанції (СЕС) потужністю 1200 МВт до магістральних мереж ОЕС України. Метою дослідження є розробка та налаштування планетарних моделей СЕС, виконання квазідинамічного моделювання та перевірка режимних умов роботи мережі з урахуванням максимальної потужності генерації сонячної станції, а також з урахуванням положень принципу надійності «N-1» відповідно до мережевих кодексів. Бібл. 5, рис. 5.

Ключові слова: сонячна електростанція, Чорнобильська АЕС, видача потужності, квазідинамічне моделювання, сонячна іррадіація, напруга, завантаженість обладнання.

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НОВЫЙ ПОДХОД В МОДЕЛИРОВАНИИ СВЕРХМОЩНОЙ СОЛНЕЧНОЙ ЭЛЕКТРОСТАНЦИИ С ВЫДАЧЕЙ МОЩНОСТИ ЧЕРЕЗ СВЯЗИ ЧЕРНОБЫЛЬСКОЙ АЭС

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Приведены результаты системных исследований развития и подключения Чернобыльской солнечной электростанции (СЭС) мощностью 1200 МВт к магистральным сетям ОЭС Украины. Целью настоящего исследования является разработка и настройка планетарных моделей СЭС, выполнение квазидинамичного моделирования и проверка режимных условий работы сети с учетом максимальной мощности генерации солнечной станции, а также с учетом положений принципа надежности «N-1» в соответствии с сетевыми кодексами.
Библ. 5, рис. 5.

Ключевые слова: солнечная электростанция, Чернобыльская АЭС, выдача мощности, квазидинамическое моделирование, солнечная иррадиация, напряжение, загруженность оборудования.

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