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Using of functional capability of RTDS hardware and software complex in the educational process of electrotechnical cpeciality master's training in ecomony global digitalization conditions

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Abstract. This article deals with problem of renewable enery resource studying during laboratory works of Power Engeneering students (bachelors and masters levels). Hardware and sofware RTDS complex is considered as a base of lab works. Solar panel (PV module) is considered as an example of renewable source. Plan of lab work, which is connectd with practical using, is offered.

Introduction

The renewable energy sources implantation is one of the priority tasks in power supply systems. Many countries gradually refuse of conventional power sources in favor of renewable ones. For example, it is planned to completely abandon of coal-fired power plants in France by 2021 [1], while Britain can cover up to 29% of country's needs in hours of strong winds [2]. Attitudes towards renewable energy sources (RES) are also change in USA (new houses in Miami now will be built with solar panels [3[). According to Finnish scientist's calculations, a complete transition to wind power stations by 2050 is possible [4].

In connection with this, the requirements for electrotechnical students in terms of professional competencies in renewable energy and industry 4.0 are growing. In addition to theoretical course studying, a course of practical and laboratory works, which aimed a practical consolidation of knowledge, are needed.

As a material and technical base for laboratory works carrying out either real stands that simulates power stations work or software (or software and hardware) complexes can be chose. In this paper using of RTDS (Real Time Digital Simulation, RTDS Technologies, Canada) hardware and software complex is proposed. This complex consists of software part – RSCAD software, in which model buildings are done, and hardware part – the cabinet, in which calculations and modeling are done. Software part contains of huge library, which also includes RES.

The structural diagram of laboratory stand is shown on Fig.1.

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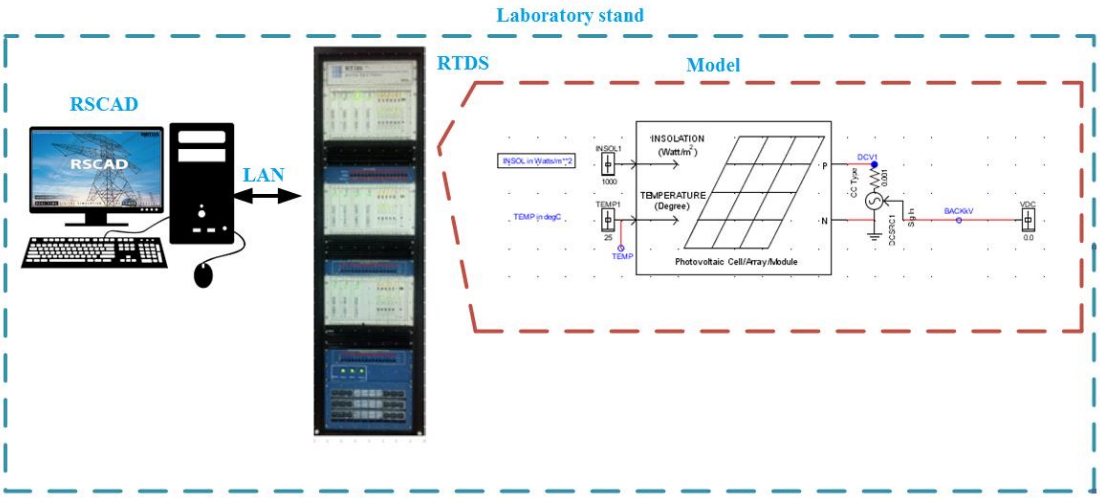

Fig.1. The structural diagram of laboratory stand.

The study of a renewable energy complex based on a solar panel is considered as an example, but it is possible to study wind power stations, energy storage complexes and simulate the work of other power plants in the same way.

Solar panel

The solar panel is a current source with diode connected in parallel and resistors connected in series and in parallel. The model can be constructed in two ways: as a four-parameters model and as a five-parameter model. The difference between them is in a shunt resistance (R_{sh}) (Fig. 2)

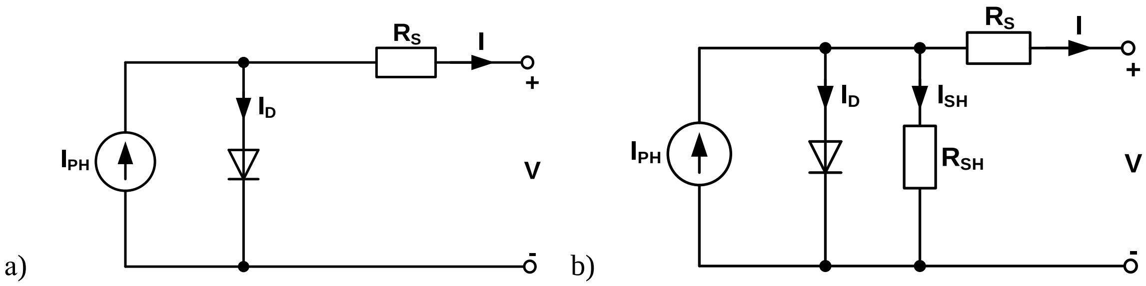

Fig. 2. Four-parameters scheme (a) and five-parameters scheme (b). [5]

The circuit with shunt resistance is more precise, but it requires more complex calculations. To study the basics of solar panel working principles, a simplified four-parameter scheme is quite suitable.

For a such scheme, the equation for current-voltage dependence will be as follows [5]:

$$I = I_{PH} - I_0(\exp(\frac{V + R_S I}{N_C a V_T}) - 1), \quad (1)$$

where I_{PH}- photocurrent generated by a single solar cell, A;

I_0–diode inverse saturation current, A;

N_c- the number of solar cells, connected in series in a solar module,

α – diode ideality factor,

V_t– diode thermal voltage, V.

$$I_{PH} = \frac{G}{G_{ref}}(I_{PHref} + k_i(T - T_{ref})), \quad (2)$$

$$I_0 = I_{0ref} \left(\frac{T}{T_{ref}}\right)^3 \exp\left(\frac{E_g}{\alpha V_t}\left(1-\frac{T_{ref}}{T}\right)\right), \quad (3)$$

$$\alpha = \alpha_{ref} \left(\frac{T}{T_{ref}}\right), \quad (4)$$

$$V_t = \frac{kT}{q}, \quad (5)$$

where
G solar insolation, W/m^2;
k_i– temperature coefficient at short-circuit current, %/^{0};
T - temperature, K;
E_g– photovoltaic element energy gap, eV;
α_{ref}, I_{PHref} – calculated value;
G_{ref} and T_{ref} - insulation and temperature parameters at which solar module parameters were measured (typically T_{ref} = 25^{0}C, G_{ref} = 1000 W/m^3);
q –electron charge, 1,602·10^{-19} C;
k – Boltzmann's constant, 1,38·10^{-23} J/K.
The passport parameters of solar panels are:
V_{oc}– open-circuit voltage, V;
V_m- voltage at maximum power, V;
I_{sc}– short-circuit current, A;
I_m - current at maximum power, A;
k_i– temperature coefficient at short-circuit current, %/^{0}C;
k_v– temperature coefficient at open-circuit voltage, %/^{0}C.
Based on this data, it is possible to calculate the following parameters:

$$I_{PHref} = I_{sc}, \quad (6)$$

$$\alpha_{ref} = \frac{q(2V_m - V_{oc})}{N_c k T_{ref}\left[\frac{I_{sc}}{I_{sc}-I_m} + \ln\left(1-\frac{I_m}{I_{sc}}\right)\right]}, \quad (7)$$

$$I_{0ref} = \frac{I_{sc}}{\exp\left(\frac{V_{OC}}{N_c \alpha_{ref} V_t}\right) - 1}, \quad (8)$$

$$R_s = \frac{N_c \alpha_{ref} V_t \ln\left(1-\frac{I_m}{I_{sc}}\right) + (V_{oc} - V_m)}{I_m}, \quad (9)$$

The model of solar panel is contained in the RSCAD library. The appearance of the solar panel model is shown on Fig. 3.

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Input data for this model are solar insolation value (*Insolation*) and temperature (*Temperature*), and outputs are positive and negative DC voltage contacts (*P* and *N*).

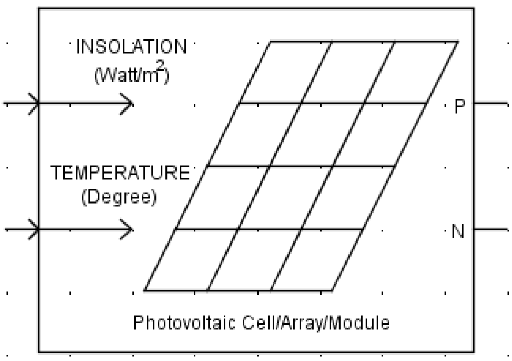
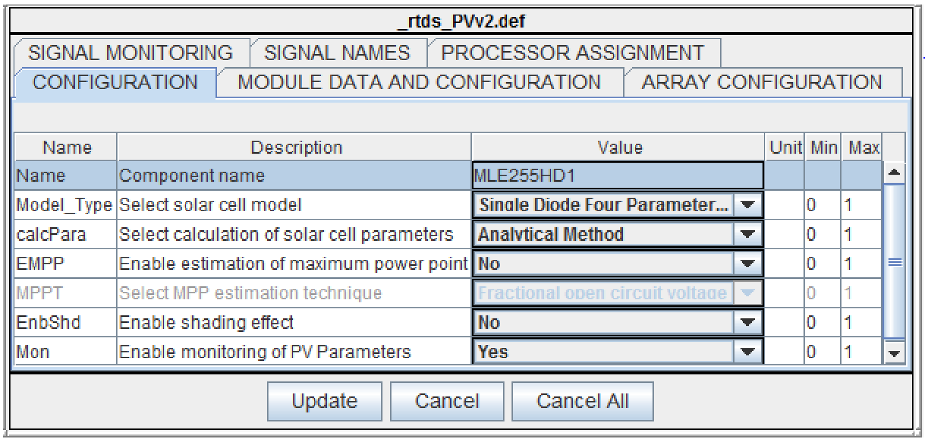
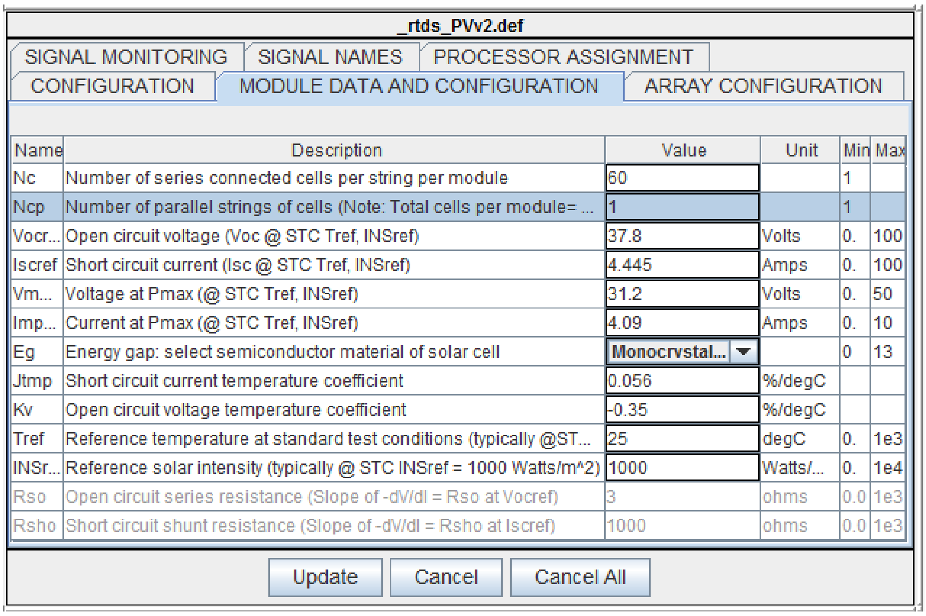


Fig. 3. Solar panel model in RSCAD

Menu of parameters that are needed for modeling is shown on Fig. 4.

a) 

Name	Description	Value	Unit	Min	Max
Name	Component name	MLE255HD1			
Model_Type	Select solar cell model	Single Diode Four Parameter...		0	1
calcPara	Select calculation of solar cell parameters	Analytical Method		0	1
EMPP	Enable estimation of maximum power point	No		0	1
MPPT	Select MPP estimation technique	Fractional open circuit voltage		0	1
EnbShd	Enable shading effect	No		0	1
Mon	Enable monitoring of PV Parameters	Yes		0	1

b) 

Name	Description	Value	Unit	Min	Max
Nc	Number of series connected cells per string per module	60		1	
Ncp	Number of parallel strings of cells (Note: Total cells per module= ...	1		1	
Vocr...	Open circuit voltage (Voc @ STC Tref, INSref)	37.8	Volts	0.	100
Iscref	Short circuit current (Isc @ STC Tref, INSref)	4.445	Amps	0.	100
Vm...	Voltage at Pmax (@ STC Tref, INSref)	31.2	Volts	0.	50
Imp...	Current at Pmax (@ STC Tref, INSref)	4.09	Amps	0.	10
Eg	Energy gap: select semiconductor material of solar cell	Monocrystal...		0	13
Jtmp	Short circuit current temperature coefficient	0.056	%/degC		
Kv	Open circuit voltage temperature coefficient	-0.35	%/degC		
Tref	Reference temperature at standard test conditions (typically @ST...	25	degC	0.	1e3
INSr...	Reference solar intensity (typically @ STC INSref = 1000 Watts/m^2)	1000	Watts/...	0.	1e4
Rso	Open circuit series resistance (Slope of -dV/dI = Rso at Vocref)	3	ohms	0.0	1e3
Rsho	Short circuit shunt resistance (Slope of -dV/dI = Rsho at Iscref)	1000	ohms	0.0	1e3

Fig.4. Solar panel configuration menu (a) and module parameters menu (b)

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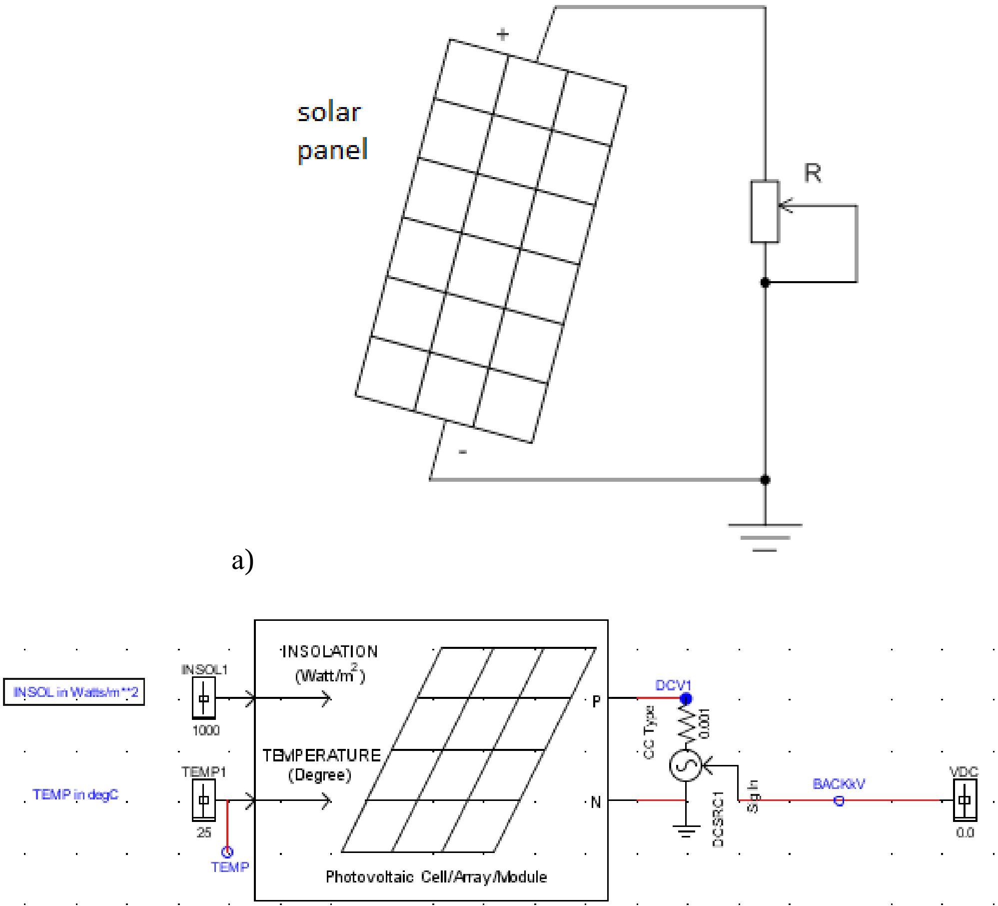
The passport data of solar panel should be used as a menu parameters. For example, parameters of Mitsubishi PV-MLE255HD solar panel are used:
Nc = 60 – number of solar cells connected in series;
N_{cp} = 1 – number of strings with solar cells connected in parallel;
V_{ocref} = 37,8 – open-circuit voltage, V;
I_{scref} = 4,445- short-circuit current, A;
V_{mpref} = 31,2- voltage at maximum power, V;
I_{mpref} = 4,09 – current at maximum power, A;
Material – minocrystalline silicone;
J_{tmp} = 0,056 – temperature coefficient of short-circuit current, $\%/^0$C;
k_v = -0,35 – temperature coefficient at open-circuit voltage, $\%/^0$C;
T_{ref} = 25 – temperature of parameters measurement, °C;
INS_{ref} = 1000 – insolation, at which parameters were measured, W/m^2.
The main experiments at laboratory works with renewable energy sources are short-circuit and open-circuit experiments, as well as VI characteristics measurements and series and parallel connection of solar panels. Short-circuit and open-circuit experiments can be done more clearly and effectively on a real stands; during the simulation, parameters of open-circuit voltage and short-circuit current are already set.
The experiment of VI-curve drawing of solar panel is easy to implement (Fig. 5). In this case, value of connected resistance can be changing during the simulation.



a)

b)

Fig. 5. VI-curve drawing: a) schematic diagram of experiment, b) realization in RSCAD software.

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In the framework of laboratory work on the solar panel studying, students need to calculate VI-characteristic points based on above equations as well as simulate this case on RTDS. Next step is to compare results obtained in the calculations and modeling.

As a result of calculations, the following curve is obtained (Fig. 6):

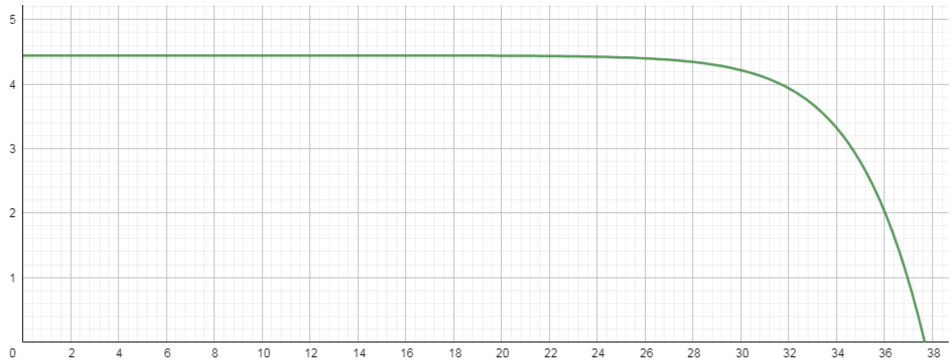

Fig. 6. Solar panel VI-curve, obtained by calculations.

Based on Fig. 5, VI-curve drawing is obtained on RTDS complex. Modeling result is shown on Fig. 7.

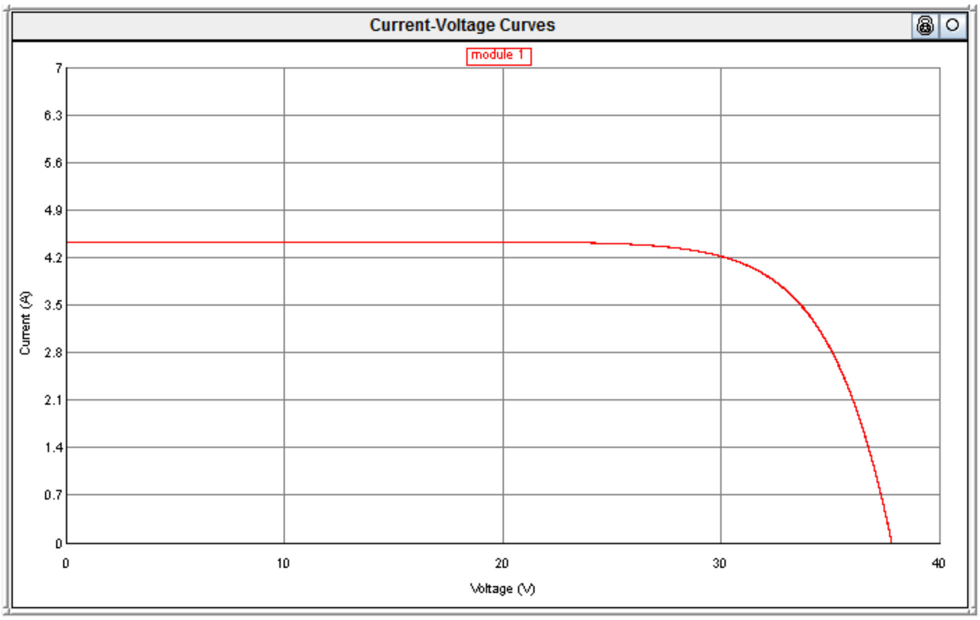

Fig. 7. Solar panel VI-curve, obtained in RSACAD complex.

Un case of solar panel modeling, it is possible to chose parameters of shading conditions of a part of the module, specifying certain parameters (Fig. 8). In the shading parameters menu it is possible to choose will the circuit has a return or/and blocking diode, specify the number of shaded modules and cells, type of shading (constant or varying) and level of isolation on shaded parts.

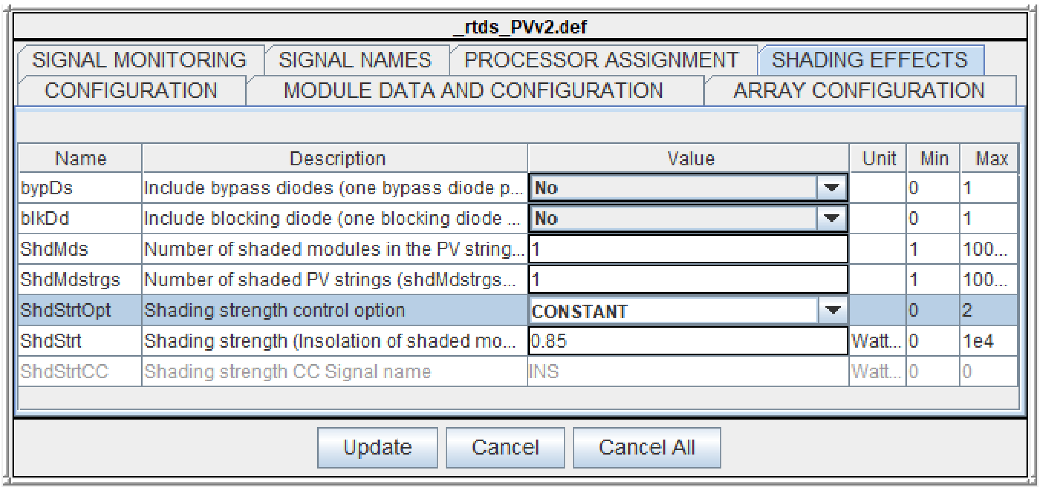

Fig. 8. Shading of the module part parameters.

A typical silicon solar cell generates a voltage about 0.7 V. To achieve the necessary voltage and current levels solar cells are usually connected in parallel and/or in series and creates a solar modules, which generates higher voltage about 16-36 V. For larger voltages (kV) and currents (kA) for practical applications modules can be connected in series and in parallel for create photovoltaic arrays (Fig. 9).

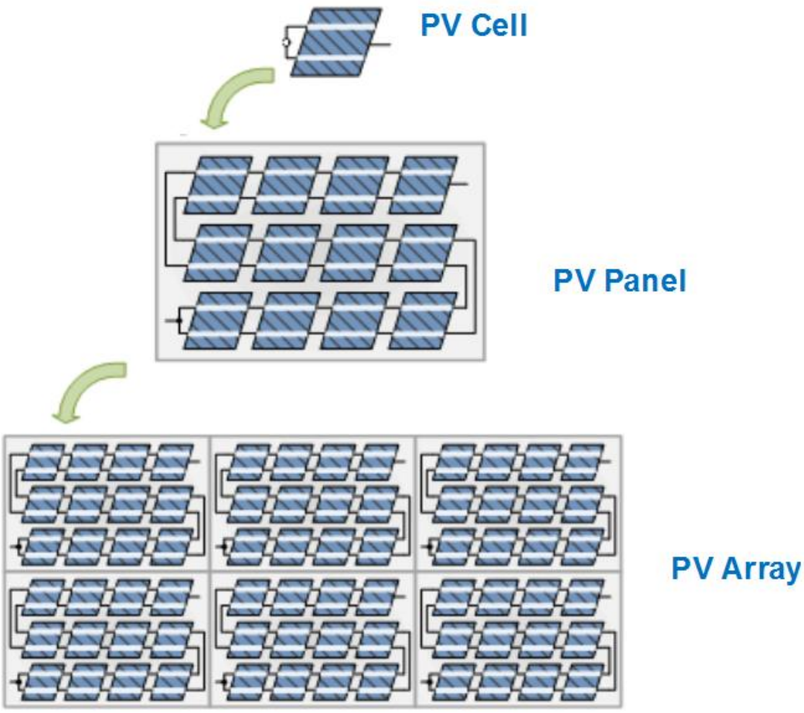

Fig. 9. Photovoltaic arrays.

It is quite easy to implement experiments on series and parallel connection of solar modules: for this case it is enough to set the numbers of connected modules(N_s – number of modules connected in series, N_p – number of modules connected in parallel) in Array Configuration menu (Fig. 10).

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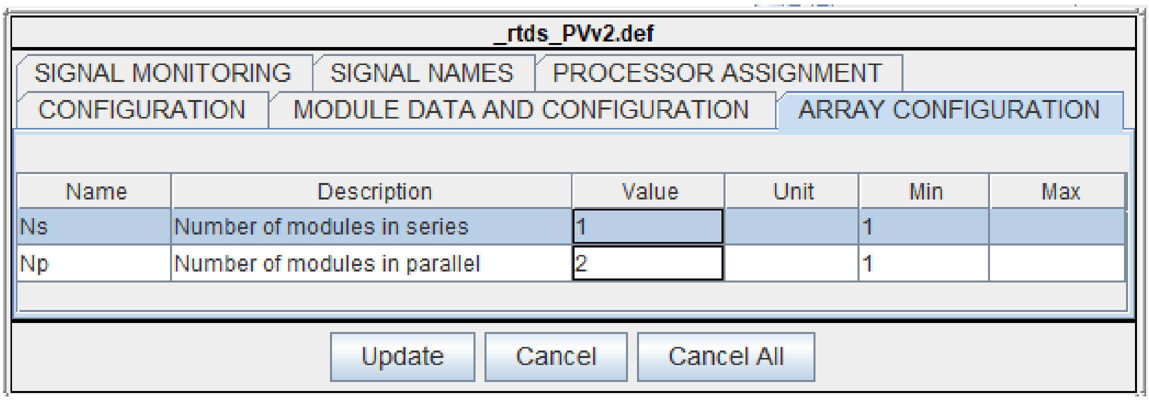

Fig. 10. Array Configuration menu

As a result, it is possible to compare the VI-characteristics of arrays with different number of modules. Four cases are shown in Fig. 11.

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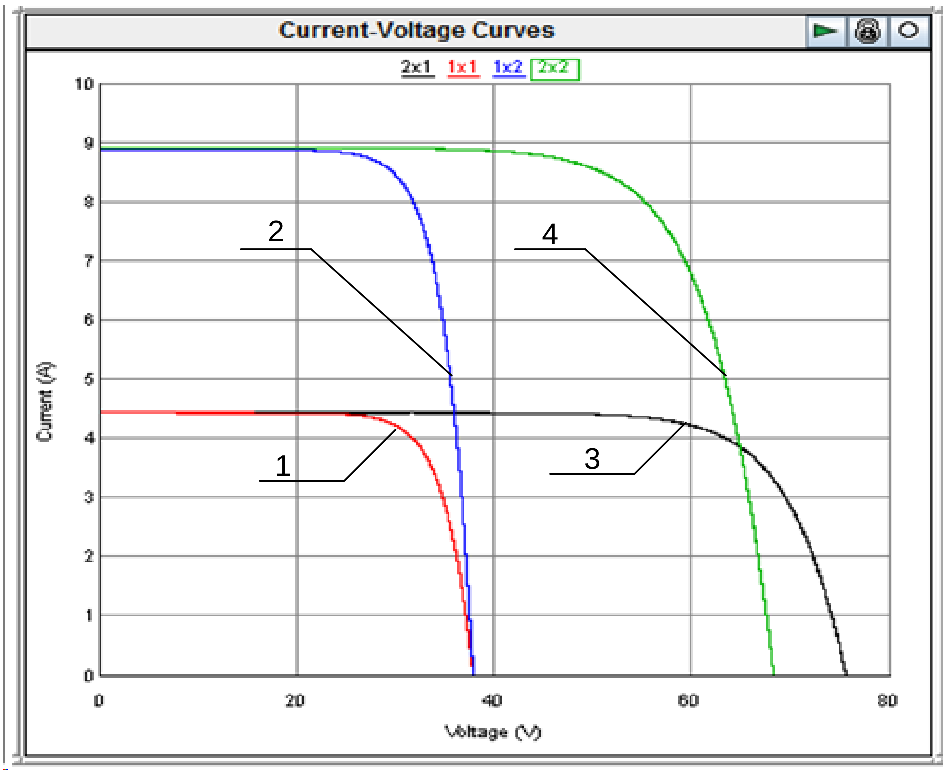

Fig. 11. Series and parallel connection of solar modules: 1- single module; 2 - two modules connected in parallel; 3 – two modules connected in series; 4 - array consisted of two connected in parallel and two connected in series modules.

Such experiments can show work of PV-array modules and will perfectly fit into the studying process of power energy students in bachelor’s level. For master level such experiments are too easy.

Proposed laboratory stand

To improve the studying quality of solar panels working principles, the following laboratory experiment’s items can be added:

- automatic change of parameters during the day (insolation and temperature) according with statistic data for a specific region;
- modeling of secondary equipment (inverter, battery, battery control system, etc);
-setting the schedule of the load in district, enterprise or household load.

Thus, this laboratory works will allow the following studies:

1. Select or set load schedule in the enterprise, shop or household load;
2. Select a schedule of solar insolation change for a specific area. Such data can be found in free access in the Internet (for example, on weather forecast website);
3. Calculate the parameters of solar array (power, dimensions, number of modules, connection scheme, etc.). In this case geoparameters are also can be teken into account (for example, if it is possible to use only 100 m^2 of area for solar panels);
4. Choose the real model, suitable for calculated parameters;
5. Calculate and choose the secondary equipment (inverters, batteries, etc.);
6. Create model in RSCAD software and test the system's operation. In case if the power generated by renewable energy system is not enough, it is possible to consider the joint operation of the solar system and centralized power source;
7. Perform a feasibility study of the payback period of the project, make conclusions about the economic possibilities of solar panel installation for power supply system.

Additional interest of students can be stimulated by connection of calculations with real objects. Most of students have a job, so they can use parameters from the enterprise, organization, etc. as an input data for calculations.

In the future, it is possible to add one or more other renewable energy sources. Thus, this laboratory work can be a good base for master thesis.

Conclusion

Using of RTDS hardware and software complex is a good basis for a renewable energy sources studying. The advantage of modeling is a combination of theoretical knowledge about RES's main characteristics with practical application.

Despite the fact that solar panel was considered as an example is this article, the principle for studying other renewable sources remains the same: the study of the source under conditions of variable load, variable input parameters, study and connection of additional equipment, such as invertors, batteries, controllers, etc.

This approach will increase the student's interest in the learning process that will lead to calculations and modeling for real power supply facilities and will became a good basis for bachelor's and master's theses.

Also, researches in the field of renewable sources will speed up the process of introducing of this sources in power supply facilities, and will also lead to the possibility of creation electric power systems based on MicroGrid concept.

It is planned to introduce the described laboratory works for *Kazan National Research Technical University n.a. A. N. Tupolev– KAI* Master's student for specialty 13.04.02 on the profiles "Electrical equipment and electric economy of organizations, enterprises and institutions" and the joint program of German-Russian Institute of Advanced Technologies (GRIAT) "Electrical Engineering and Informational Technologies".

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