EVALUATING THE IMPACT OF GRID CONNECTED PHOTOVOLTAIC SYSTEM ON BIHOR COUNTY POWER SYSTEM

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Abstract – The influences of distributed electrical energy sources based on renewable energy resources over the electricity transmission and distribution systems are varied. The possible effects are more pronounced in the case of electricity generated using solar and wind resources, given the specificity and intermittency of the power produced from these resources. Photovoltaic systems (PVS) are one of the most promising renewable energy solutions. In case of the grid connected photovoltaic systems (GCPVS), these could provide many benefits to the network utilities.
This paper aims at assessing the impact of the presence of GCPVS upon the own technical power consumption level at 110 kV, from Bihor County Power System (BCPS) power transmission lines.

Keywords: photovoltaic sources, simulations, own technical power consumption, power system.

1. INTRODUCTION

Concerns about environmental problems due to the use of fossil energy resource (FES) and research to identifying new sources of sustainable energy, in the last decades have led to an increasing use of renewable energy resources (RER) [1][2][3]. Electrical renewable energy sources (E-RES) means electrical energy from RER, namely wind, solar, geothermal and hydrothermal, ocean energy, hydropower, biomass, landfill gas, sewage treatment plant, gas and biogases [6].

Nationally evolution of PVS

From these different types of E-RES based on RER, in the past decade, the electrical energy (EE) obtained from wind and solar resources basically have experienced exponential growth in Romania between 2010 and 2014. The EE from photovoltaic sources (PVS) has increased more than 1000 times.

In spite of the fact that in 2007, the total production of electricity was approximately 64,7 TWh, according to the statistical data published by Romanian Energy Regulatory Authority (ANRE), regarding the production of EE in terms of E-RES, Romania had only total production of 17,08 GWh from RER, compound 99.9% from hydro-electric power plants (HEPP) and 0.1% wind, according to ANRE. It can be noticed the fact that at the level of 2008 E-RES was practically produced exclusively within HEPP power plants and reached only 26,4 % from the amount of EE production, with mention that the HEPP amount is almost entirely represented by the large hydro power plants, who do not receive any subvention, with installed capacity over 10 MW. In conclusion, in 2008 the share from total EE production in Romania, in terms of E-RES [6] was basically inexistent.

During the last five-year period 2008–2014, installed capacity of RER technologies grew very rapidly, with the fastest growth in the power sector, sustained by the several government decisions adopted and promotion scheme, such as the Green Certificates (GCs).

According to grid operator Transelectrica, Romanian renewable projects reached 4412 MW installed capacity by January 2014: the wind sector had 2704 MW, while the photovoltaic sector has grown to 1171 MW; the hydroelectricity sector had 536 MW, while biomass edged close to 100 MW [5].

In recent years, Romania has begun to re-establish itself as a major user of PV systems. The evolution of the installed PV capacity in Romania is presented bellow, in the Figure 1, according the data from [5].

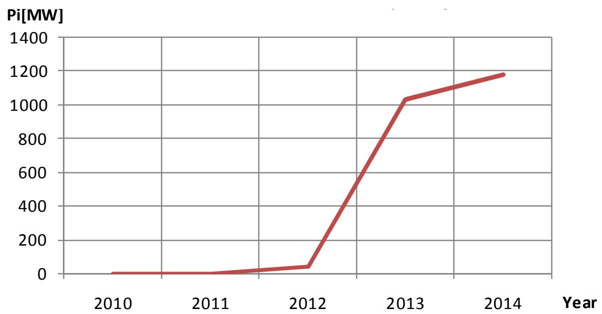

Fig. 1 - Evolution of the installed PV capacity

Romania is situated in the European's "B" sunlight zone, which gives the country a major solar potential waiting to be tapped. Romania is eligible for annual energy flow between 1000 and 1300 [kWh/m^2/year].

Evolution of PVS within BCPS

The BCPS is a part of the National Power System and works interconnected. Transmission and distribution activities are provided by the Local Branch of *S.C. F.D.E.E. Electrica Distributie Transilvania Nord S.A.*, the main distribution operator in the North-Western part of Romania, through high, medium and low voltage installations across the Bihor County.

Regarding the situation before spreading the PVS, in terms of the years 2010, the BCPS consists from:

- 31 – Electrical Substations (ESS) [110 kV];
- 68,2 [km], EHV power lines[400 kV];
- 803,52 [km], HV power lines and cables[110 kV];
- 2916,55 [km] Medium Voltage lines;
- 731,03 [km] LES Medium Voltage cables;
- 2264 transformers;
- 6 small hydro-power stations (SHPS).

In the next period, between 2011 and 2013 many renewable energy sources was installed in Bihor County, such as:

- Hydro power plants, at the end of 2013, 16 units, with 35 groups with a total installed capacity of 227,158 MW;
- 45,872 MW installed capacity in PVS, from 19 PVS connected to the grid, from the total of 126,312 MW installed in 47 PVS.

Regarding the geographic location of PVS within Bihon County, in the Figure 2, we have placed the most important PVS in terms of installed capacity.

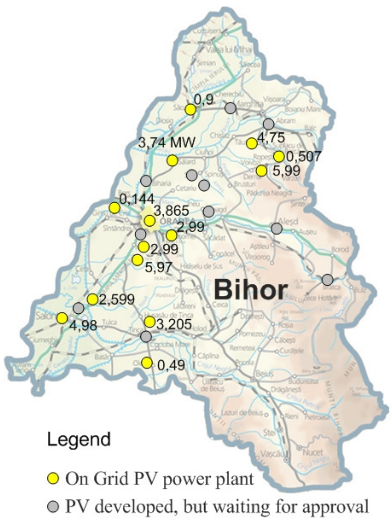

Fig. 2 - PVS localization in Bihor County

3. THE SIMULATION PROGRAM USED

To assess the impact of this distributed energy production, GCPVS in our case, at the transmission level (110 kV) of BCPS, the simulation software EDSA (Electrical Distribution System Analysis) was used from Research Centre of the Department of Energy Engineering,

The simulation program has several modules, in this case the advanced power flow analysis (EAPF) was used to calculate the permanent regime of the analyzed power system.

To evaluate the steady-state operation of a power system, the power flow analysis can be used to, having different load conditions, power and configuration. The objective of the algorithm used in the power flow is to determine the following parameters, knowing that all nodes connected loads are known:

- Power flow on each branch (lines and transformers)
- Power consumption at each generator node;
- The magnitude and the angle of each electric node;
- Loss of power in the system.

Once these data are known, corrective measures can be taken to ensure that every load is supplied with power and operating within acceptable limits. These actions may include adjusting the taps on transformers, reactive power compensation, etc.

The EAPF module [7] is one of the most powerful, fast and efficient modules of the EDSA, and can be used as permanent regime analysis tool with a graphical user interface (GUI). EAPF has advanced engine starting features of modeling and displaying. EAPF is based on advanced algorithms that incorporate the latest technical solutions applicable to complex systems. From the modeling capabilities of the program the following are mentioned:

- Voltage controls at generators;
- Using computational methods, as:
  - Fast Decoupled Newton - Raphson;
  - Advanced Gauss Seidel;
- Voltage control by changing the generated reactive power;
- The system types of nodes can be defined as follows:
  - out of service;
  - load;
  - generator;
  - swing bus;

3. MODELING THE NETWORK COMPONENTS

Generator modeling – in order to calculate the power flow, it is possible to create three different types of generator nodes, like:

- Fixed generation (PQ);
- Voltage control (PV);
- Balancing generators (equilibration nodes) (EN)[9][10].

For the PQ type, the active and reactive power generation is constant or known, but not the voltage, therefore voltage limits are defined.

For the PV type, the active power is known, and only the minimum and maximum reactive power output is know, not the value. In addition desired voltage is specified at the generator terminals or to another node.

For the EN type (balancing) the desired voltage and voltage angle is specified (normally set to zero) at the terminals of the generator. Basically it is a mathematical artifice to solve power flow.

Consumer modeling - loads, according to [7][9][10], may generally be modeled in three ways, namely with:

- Constant Power (kVA);
- Constant current (A);
- Constant Impedance (Ω).

Knowing the active and reactive power absorbed by each consumer in the system we opted for modeling loads as with constant power.

Modeling the photovoltaic sources - Photovoltaic plants within BCPS, mainly due to installed capacity, are exclusively connected to the distribution network, at medium voltage level (≤ 20 kV). In order to modeling the photovoltaic impact, inclusion in to the 110 kV BCPS network of the GCPVS, these was placed on their nearest ESS bus bars from the analyzed power system, as it is show in the next capture (Figure 3).

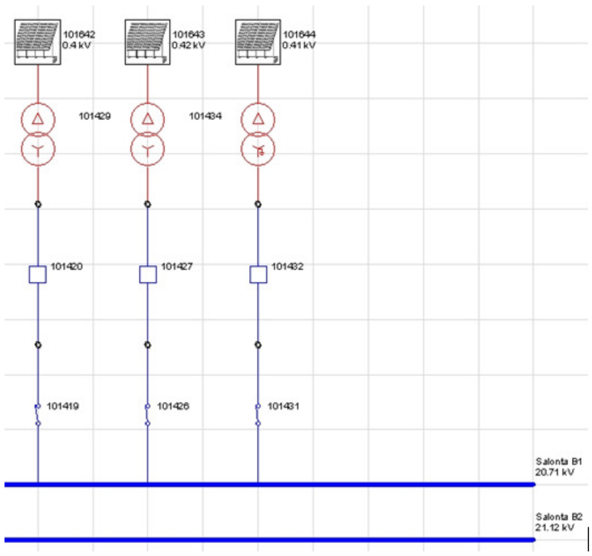

Fig. 3 PV placing at nearest ESS bus bar

4. BCPS OPERATING REGIME SIMULATIONS IN CASE OF DIFFERENT GCPVS STATES

Choosing the proper balancing node of a power system in order to perform the power flow analysis it has a particular importance, the correct choice depends on achieving convergence of power flow calculation. From the possible alternatives we opted for choice for balancing node, interconnection nodes with neighboring subsystems. These are: ESS Vaşcău, ESS Salonta, ESS Oradea – Sud. All chosen ESS's are located within BCPS.

The aim of the analysis is to calculate power flow in the BCPS, for each scenario considered, by highlighting the power loss amounts with reference to the presence of GCPVS, as the algorithm had the restriction to maintain the voltages of nodes in the acceptable limits.

At the 110 kV transmission level, the acceptable voltage limits are between 160 ÷ 121 kV, while the economic voltage level for the ESS within the BCPS, are between 118 ÷ 121 kV in case of ESS Vascau and 113 ÷ 118 kV in case of the other ESS's.

The calculation method used to determine the power flow in normal operation is fast decoupled method with restrictions on voltage specified above. The maximum number of iterations allowed is 1000, and the maximum allowable tolerance is 0,010 MVA.

Under these conditions simulation of the normal operation of the system was performed for the four different scenarios (cases), as it was presented in Table 1.

Table 1. - The node types and states for the simulated cases

Case	Generator node types					
	Oradea- Sud		Salonta		Vaşcău	
	EN	PQ	EN	PQ	EN	PQ
1	NOT	YES	YES	NOT	YES	NOT
2	YES	NOT	YES	NOT	NOT	YES
3	NOT	YES	YES	NOT	NOT	YES
4	YES	NOT	NOT	YES	NOT	YES

In the analyzed power system, regarding the presence of GCPVS, were simulated four different variants namely:

1. ESS Oradea – Sud is connected as a PQ node, GCPVS's are in operation (ESS Salonta and ESS Vaşcău are EN node types);
2. ESS Oradea – Sud is disconnected but GCPVS's are in operation (ESS Salonta is EN node type and ESS Vaşcău is PQ node type);
3. ESS Oradea – Sud is connected as a PQ node but GCPVS's are off (ESS Salonta is EN node type);
4. ESS Oradea – Sud is unconnected GCPVS's are in off (ESS Salonta PQ node type, ESS Vaşcău also PQ node type).

Using the EDSA simulations software, and run all the considered scenarios, were simulated the active powers, reactive powers, apparent powers and the power factors, depending on the balancing nodes and the GCPVS power plant states. The results obtained are presented for each considered case below.

Case 1 – The analysis refers to the scenario when ESS Oradea - South was considered connected when ESS Vaşcău and ESS Salonta are balancing nodes types. The values of active and reactive power losses in the analyzed system under the simulated operating conditions are summarized in Table 2.

Table 2. The amount of active and reactive power within the analyzed system in case 1

	Values of powers in / out within the system	
	Active power [MW]	Reactive power [MVAR]
EN Node Type	-39,983	38,985
Generators	169	44,063
GCPVS's	52,414	12,405
Load	177,446	66,875
Total losses	5,569	29,661

Value in percentage of total active power losses for this scenario is **2,19 %**.

Case 2 – In this case of the analyzed scenario we considered the ESS Oradea – Sud disconnected, ESS Salonta is EN type and Vaşcău is PQ type, under the consideration of GCPVS's are operational. The obtained values of active and reactive power losses in the analyzed system under the simulated operating conditions are summarized in Table 3.

Table 3. The amount of active and reactive power within the analyzed system in case 2

	Values of powers in / out within the system	
	Active power [MW]	Active power [MW]
EN Node Type	-26,38	81,53
Generators	160	2,341
GCPVS's	52,414	16,977
Load	177,446	66,875
Total losses	8,585	38,897

Value in percentage of total active power losses for this scenario is **4,61%**.

Case 3 - For the third analyzed scenario runs, we considered that ESS Oradea - Sud is operational and the GCPVS's disconnected. ESS Salonta is EN node type and ESS Vașcău PQ generator type. For this case, the obtained values of active and reactive power losses in the analyzed system under the simulated operating conditions are summarized in Table 4.

Table 4. The amount of active and reactive power within the analyzed system in case 3

	Values of powers in / out within the system	
	Active power [MW]	Active power [MW]
EN Node Type	-23,496	61,851
Generators	208	37,753
GCPVS's	0	0
Load	177,446	66,875
Total losses	7,059	35,389

Value in percentage of total active power losses for this scenario is **3,82%**.

Case 4 - The simulation results obtained for the last case, in which the ESS Oradea - Sud was considered disconnected and the GCPVS's are also off but ESS Salonta and ESS Vașcău are PQ generator types, are presented in the Table 5.

Table 5. The amount of active and reactive power within the analyzed system in case 4

	Values of powers in / out within the system	
	Active power [MW]	**Active power [MW]**
EN Node Type	48,334	55,518
Generators	138	45,949
GCPVS's	0	0
Load	177,446	66,875
Total losses	8,894	39,836

Value in percentage of total active power losses for the scenario 4, is **4,77 %**.

The voltage levels at bus bars (nodes) from the BCPS ESS's in case of each simulated scenario are shown in the Table 6.

Table 6. – The bus bar voltage levels under the simulated scenarios

Node	Voltage levels from the bus bars (kV)			
	Case 1	Case 2	Case 3	Case 4
Chisineu Cris	118	118	118	95,06
Huedin	118,03	110,82	112,22	99,13
Sarmasag	117,3	109,37	110,88	94,91
Simleu	117,3	109,37	110,88	94,91
Varfuri	118,16	108,82	111,31	105,22
Alesd 1	117,82	109,89	111,79	96,81
Alesd 2	117,82	109,89	111,79	96,81
Beius A	116,91	107,57	110,19	101
Beius B	116,91	107,58	110,2	101
CET 2-1A	117,9	108,98	111,92	95,21
CET 2-1B	117,92	108,98	111,93	95,21
CET 2-2B	117,9	108,98	111,92	95,21
Marghita A	116,92	109	110,2	93,71
Marghita B	116,92	109	110,2	93,71
Mecanica 1	117,14	109,32	111,52	94,07
Mecanica 2	117,22	109,39	111,57	94,22
Munteni	118,03	110,82	112,22	99,13
Oradea Sud 1	117,9	108,98	111,92	95,21
Oradea Sud 2	117,92	108,98	111,93	95,21
Oradea Vest 1	117,29	109,47	111,72	94,31
Oradea Vest 2	117,29	109,46	111,71	94,32
Remeti A	117,84	110,74	112,06	99,3
Remeti B	117,84	110,74	112,06	99,3
Sacuieni A	116,79	108,88	110,38	93,52
Sacuieni B	116,79	108,88	110,38	93,52
Salonta A	117,98	117,94	117,95	95,05
Salonta B	117,99	117,96	117,95	95,05
Sudrigiu 1	116,79	107,48	110,05	101,89
Sudrigiu 2	116,8	107,49	110,06	101,88
Suncuius A	117,71	110,23	111,8	97,95
Suncuius B	117,71	110,23	111,8	97,95
Suplac 1	117,3	109,37	110,88	94,91
Suplac 2	117,3	109,37	110,88	94,91
Vascau 1	117,21	107,86	110,31	104,16
Vascau 2	117,22	107,85	110,31	104,17
Voivozi	117,45	109,55	110,96	94,63

In Figure 7, are presented the total active power losses for the four simulation scenarios regarding the analysis the influences of the GCPVS's.

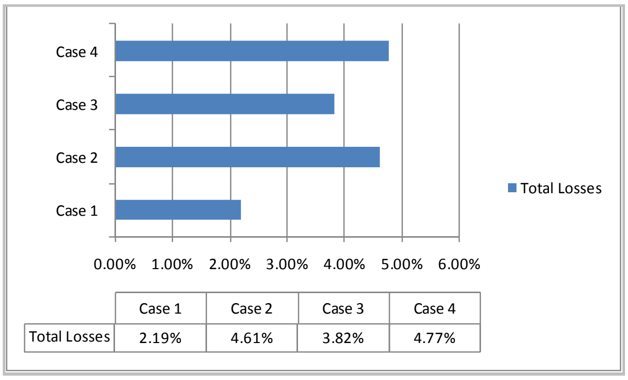

Fig. 4 Total active power losses obtained [%]

4. CONCLUSIONS

The analysis confirmed that EDSA can be a powerfully modeling tool in order to simulate any power system, regardless of the number of its nodes. The program, allows interactive real-time simulations the operational regime of the modeled power system, and also allow at any time introduction / removal operations of power system element and operating status changes of any existing element.

The simulation program has proven to be very useful if the analyzed power system is equipped distributed generators, like photovoltaic power plants in our case.

For all simulations in different operating conditions, the voltage levels from the system nodes were analyzed. The best values for nodes voltage levels were obtained for case 1 when ESS Oradea - South was considered connected, ESS Vașcău and ESS Salonta are balancing nodes types, and the GCPVS's are operational, in which case the total active power losses obtained, in percentage was 2,19 %.

In the case of case 3, namely when ESS Oradea - Sud is operational but the GCPVS's are disconnected. ESS Salonta is EN node type and ESS Vaşcău PQ generator type, the percentage of total active power losses obtained was 3,82 %.

In the other two cases simulated case 2, and the 4th case in which the ESS Oradea - Sud was considered disconnected, ESS Salonta is EN type and Vaşcău is PQ type, under the consideration of GCPVS's are operational the total active power losses was 3,82 %, respectively, the GCPVS's are also off but ESS Salonta and ESS Vaşcău are PQ generator types the total active power losses in percentage of was 4,77 %.

In terms of energy efficiency of the 4 analyzed cases, the scenario according to the case 1 is the most effective. As the presence of the GCPVS's is more pronounced, the power losses are smaller, meaning certainly a reduction of own technological consumption on the transmission lines, which means, significant financial savings and also reduce the negative effects of power losses in transmission lines.

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