Optimal Modules Deployment in Large-Scale Photovoltaic Plants

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Abstract –**Operation with using the feed-in tariffs of photovoltaic power plants, even with small improvements or optimizations may lead to considerable financial benefits. In this paper is presented a method for increasing a photovoltaic generator power availability by proper sorting of photovoltaic modules. For this, it is analysed generator's behaviour of photovoltaic modules that have variations in current-voltage characteristics. The sorting is done in order to minimize the mismatch losses. The total gain may increase the generated power of few percents.**

Keywords – **Photovoltaic systems, mismatch, photovoltaic module plan, photovoltaic plant optimization.**

I. INTRODUCTION

The governmental support, mainly through the feed-in tariffs, followed by a mass production of photovoltaic modules, resulted in building of a huge number of photovoltaic power plants with installed power above 100 kWp all over the world. The number of such systems has rapidly grown from year-to-year. By the end of 2012, the total installed capacity was estimated to about 100 GWp. This increasing trend is expected to continue [1].

Along to the installation expansion, the plant design and engineering approaches have been constantly developing. This resulted to various system concepts (centralized, decentralized etc.), improved component (i.e. inverter) efficiency, and better component adaptability [2].

The commercially available photovoltaic modules (i.e. with mono- and poly- crystalline solar cells) constantly decrease their price at the same time, slightly increase the efficiency. However, the production process still hasn't resolved the issues related to the variations of the I-V characteristics and the related parameters values. The module sorting according the output maximal power point measurements before the delivery is not sufficient for optimal system design. The modules are supplied by their peak power tolerance, which usually ranges ±3 %, or at some manufacturers, 0 – +3 %, or 0 –+5 %. These variations, when the modules are connected in parallel strings, lead to operational mismatch losses in the photovoltaic generators. The situation becomes worsen when current and the voltage values additionally vary [2].

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In some cases, the mismatch losses may approach to more than 5 %, which would lead to a considerable financial loss, usually omitted during the plant design. In this paper, the issues connected to mismatch effects, and proposed a method for sorting the photovoltaic modules, is elaborated. It is proposed a method for module classification (sorting) and estimated benefits from it.

II. MISMATCH LOSSES IN PHOTOVOLTAIC GENERATORS

Photovoltaic generators are consisted of number of strings. Each string contains a number of photovoltaic modules connected in series (Fig. 1). In this regard, the total voltage in a string is a sum of the voltages of each module, while the current in all modules has a same value. In this regard, it is clear that all the modules should have nearly identical shape of the I-V characteristic. However, even slight I-V characteristics variations, may result in considerable decreasing of the total expected power, as well as in appearance of heat losses in modules with weaker characteristics. This will be explained with two indicative examples [3].

First we will consider a string that is consisted of two photovoltaic modules, having apparently different I-V characteristics (Fig. 2). It may be noted that the aggregate characteristic turn to be defected. When, in parallel to the modules diodes are connected, the power characteristic consequently will contain two local maximums, no one equal to the sum of the two separate maximal power point values. For a range of load values, the second module will dissipate power. This effect is regularly avoided by placing bypass diodes the module [2]. In such case when only one cell is not capable to generate enough current, the whole group of bypassed cells will not participate to the total string voltage.

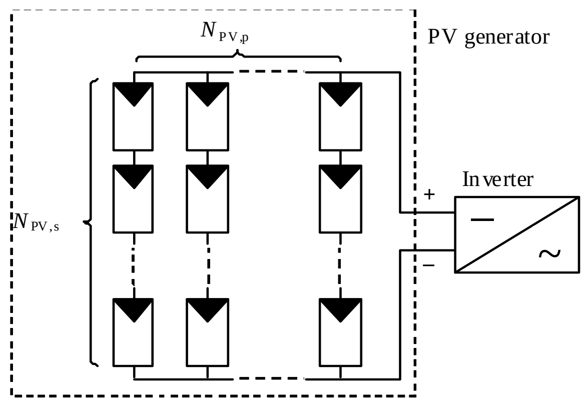

Fig. 1. PV generator with parallel strings

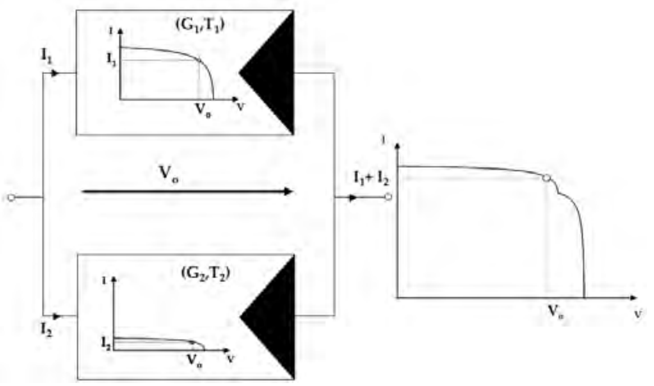

Fig. 2. Mismatch of parallel connection

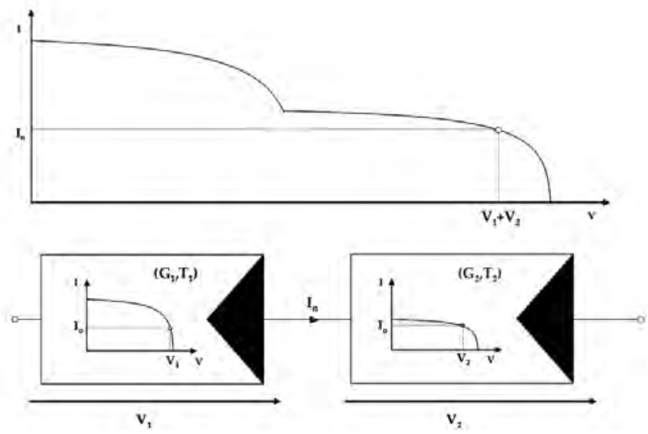

Fig. 3. Mismatch of series connection

Similarly, when two photovoltaic modules are connected in parallel, the total current is a sum of the currents of the separate modules. However, the module voltage is equal to booth modules. Fig. 3 shows that, when the I-V characteristic varies, the collective characteristic is deformed and the aggregated power has lower value than the sum of the power values at the maximum point. Depending on the load, the module with the lower voltage my dissipate power. This may be avoided by placing blocking diodes [2].

When the generator is consisted of strings with more photovoltaic modules, the total I-V characteristics might show high deviation. On Fig 4 the I-V characteristic of a photovoltaic generator consisted of 4 strings with 20 modules per string is shown. It is obtained for modules having ±5 % value variation of the shortcut circuit current I_{sc} and open voltage circuit voltage V_{oc}.

III. Estimation of the Photovoltaic Generator Output

There are several analytical models for describing the I-V characteristics for photovoltaic modules [2]. The more precise ones show a transcendental relation between the current and the voltage and it is hard to work with. The complexity

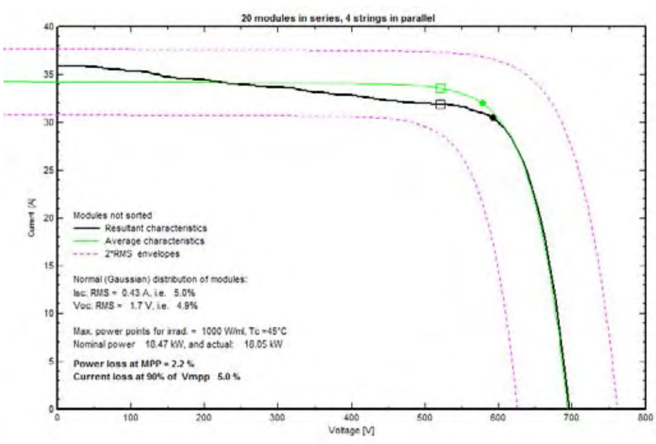

Fig. 4. Aggregate I-V characteristic of photovoltaic generator

becomes greater in case of multi-module photovoltaic generators consisted of non-identical characteristics [4]. In such cases the currents in the strings are limited to the current value at the maximal power point of the module with the lowest MPP current value. The total voltage of the generator corresponds to the minimal value of all voltages from all parallel strings. These principles are descriptively given in Fig 5. The consequence of the mismatched modules result only by non-generated power and the losses for the power dissipation are omitted. It is acceptable since the power dissipation is not significant for modules with small difference of I-V characteristics.

Manufactures sort the modules according to their maximal point power which is declared for a range of (few) percents. However, in order to provide the optimal power usage, in pre-installation phase, when making a module deployment plan for large-scale photovoltaic plants, to minimize the unused available power, the modules should be deployed according to their current values. For this, the module manufacturer should perform module testing, and provide the data to the consumers. The sorting has been performed according to the maximal point power values of the modules' current.

The optimal module deployment, for large-scale photovoltaic plants may be a time-consuming job and engage additional human labor during installation phase. However, the benefit from the optimal deployment usually justify these extra activities. In this paper is examined the benefits from the module sorting.

The example system is consisted of 8 Siemens PVM20 inverters and 640 photovoltaic modules Risen Energy SYP250M photovoltaic modules. The modules measured data is declared as sample, and provided by the modules' manufacturer. The modules are declared for power of 250 Wp, with power tolerance of 3 %. The total number of modules is 672, however 32 modules have not been installed. In each inverter there are connected 4 strings consisted of 20 photovoltaic modules. Each inverter has one MPP tracker.

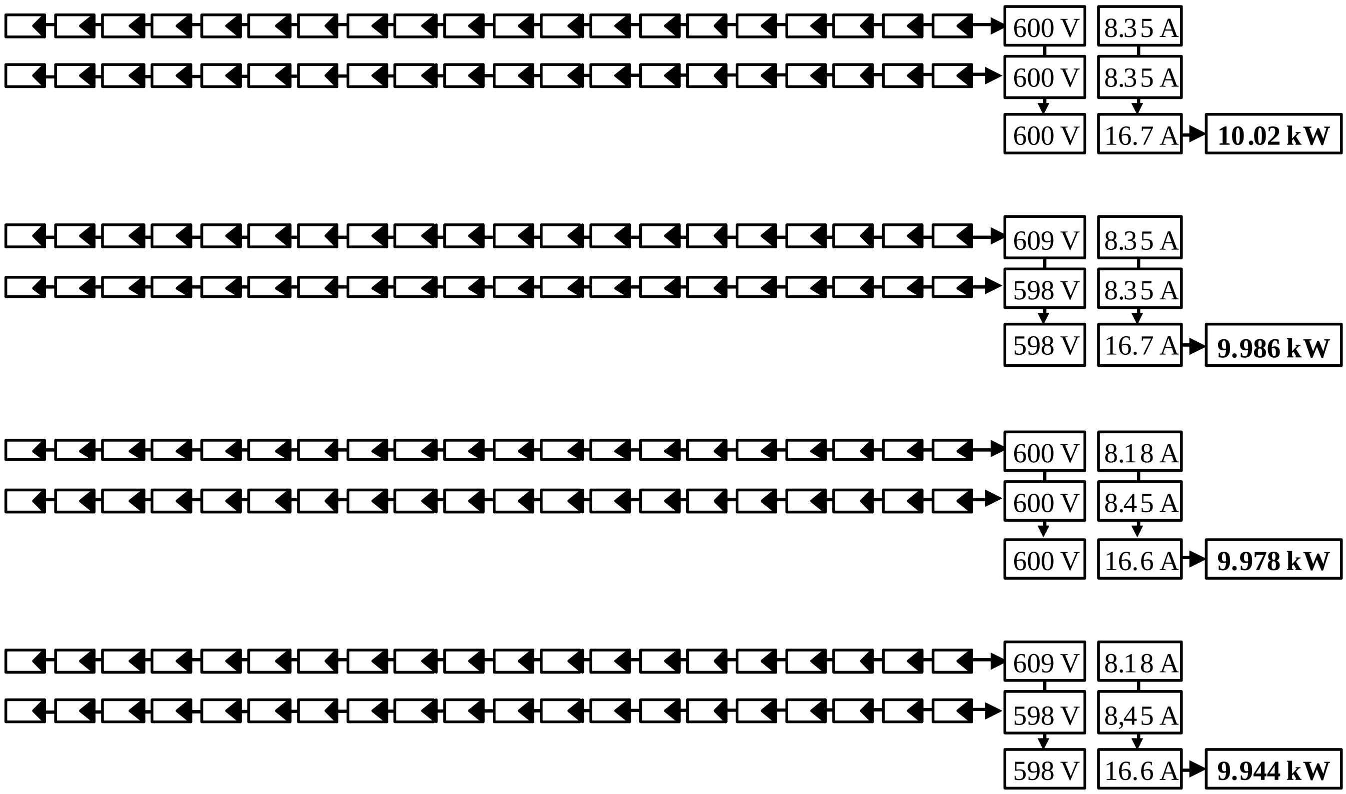

Fig. 5. Principles for estimation of string current and voltage

On Tab. I are shown string data in cases when photovoltaic modules are unsorted and sorted. There are given currents of the photovoltaic modules with minimal current values in each string. Total string voltages and total power values are also given. There are also given the maximal difference of the maximal power point currents between the modules in each string. All the values are at modules' maximal power point.

On Tab. II are given parameters of inverters: the total voltage, the available power, the measured power and the difference between the available and the measured power. At the end, the total power difference has been given.

As can be seen from the results given in the Tables, the total available power of the unsorted modules is 158.771 kWp, while the total measured MPP power is 161.003 kWp, and the difference is 2.232 kWp. Consequently, by sorting, the total power difference 314 Wp.

Despite the difference in the given example are rather small, it shows a guideline for module sorting. However, the considered modules are with the rated power of 250 Wp, which belongs at higher values in the range of modules with the same size. Modules, from the same type and manufacturer, and the same size with lower rated power (ex. 220 Wp), due to lower efficiency regularly have lower price per Wp, and the practice show that the measured power difference between modules is higher. This means that the module deployment with previous sorting may lead to increased power availability.

IV. Conclusion

In this paper is presented a simple sorting method for increasing the power availability of photovoltaic generator in the large-scale plants.

The benefit from the module deployment plan is generally few percents. Having in mind the high feed-in tariffs, the invested efforts for module deployment plan can certainly be cost-effective.

More significant results can be obtained by using modules belonging to lower rated power values at the product range and photovoltaic plants with higher installed capacity.

The optimal module deployment plan is applicable to photovoltaic system topologies with decentralized (string) inverters, but also in systems with centralized inverters.

References

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TABLE I
STRING PARAMETERS FOR UNSORTED AND SORTED PHOTOVOLTAIC MODULES

UNSORTED					SORTED				
String	Min. current [A]	Max. current difference [A]	Total voltage [V]	Power [W]	String	Min. current [A]	Max. current difference [A]	Total voltage [V]	Power [W]
1.1	8.34	0.06	599.1	4996.1	1.1	8.18	0.07	610.0	4989.4
1.2	8.37	0.08	598.2	5007.3	1.2	8.25	0.02	608.1	5016.9
1.3	8.23	0.14	599.9	4937.3	1.3	8.27	0.01	607.2	5021.8
1.4	8.32	0.08	600.1	4992.9	1.4	8.28	0.02	605.9	5016.5
2.1	8.29	0.12	600.0	4974.0	2.1	8.30	0.01	605.3	5023.7
2.2	8.26	0.14	599.9	4955.3	2.2	8.31	0.02	603.9	5018.6
2.3	8.34	0.06	599.3	4998.2	2.3	8.33	0.00	603.9	5030.3
2.4	8.25	0.16	601.4	4961.2	2.4	8.33	0.01	603.3	5025.7
3.1	8.30	0.04	600.5	4984.5	3.1	8.34	0.01	603.0	5029.1
3.2	8.24	0.08	602.0	4960.7	3.2	8.35	0.00	601.7	5023.9
3.3	8.33	0.08	599.9	4996.8	3.3	8.35	0.01	602.6	5031.4
3.4	8.31	0.14	599.3	4980.3	3.4	8.36	0.00	600.8	5022.8
4.1	8.30	0.07	599.8	4978.3	4.1	8.36	0.01	601.6	5029.4
4.2	8.33	0.01	600.1	4998.5	4.2	8.37	0.00	599.6	5018.7
4.3	8.33	0.06	598.8	4988.0	4.3	8.37	0.00	600.7	5028.1
4.4	8.23	0.08	599.5	4934.0	4.4	8.37	0.01	600.6	5026.7
5.1	8.24	0.15	598.8	4933.8	5.1	8.38	0.00	599.9	5026.8
5.2	8.27	0.02	601.5	4974.0	5.2	8.38	0.01	600.4	5031.7
5.3	8.27	0.00	600.8	4968.2	5.3	8.39	0.00	599.5	5029.5
5.4	8.34	0.12	598.5	4991.3	5.4	8.39	0.00	599.6	5030.2
6.1	8.26	0.10	598.6	4944.5	6.1	8.39	0.01	600.0	5034.3
6.2	8.28	0.12	602.4	4987.9	6.2	8.40	0.00	599.5	5035.4
6.3	8.26	0.11	602.2	4973.9	6.3	8.40	0.00	599.3	5034.0
6.4	8.26	0.02	600.9	4963.6	6.4	8.40	0.01	598.8	5029.6
7.1	8.25	0.13	601.8	4964.7\	7.1	8.41	0.00	599.0	5037.3
7.2	8.27	0.14	599.3	4956.3	7.2	8.41	0.01	598.3	5032.0
7.3	8.31	0.03	600.3	4988.6	7.3	8.42	0.00	598.0	5035.4
7.4	8.22	0.20	604.6	4969.4	7.4	8.42	0.00	597.5	5031.0
8.1	8.27	0.01	601.8	4976.5	8.1	8.42	0.01	597.9	5034.1
8.2	8.18	0.03	609.2	4983.3	8.2	8.43	0.00	598.2	5042.7
8.3	8.24	0.13	604.5	4981.4	8.3	8.43	0.01	598.3	5043.2
8.4	8.27	0.14	602.3	4981.2	8.4	8.44	0.01	597.3	5041.3

TABLE II
INVERTER PARAMETERS WITH UNSORTED AND SORTED PHOTOVOLTAIC MODULES

UNSORTED					SORTED				
Inv.	Voltage [V]	Power [W]	MPP Power [Wp]	Power Diff. [W]	Inv.	Voltage [V]	Power [W]	MPP Power [Wp]	Power diff. [W]
1	598.2	19897.5	20138.7	241.2	1	605.9	19981.3	20088.4	107.1
2	599.3	19861.1	20136.3	275.2	2	603.3	20072.8	20109.5	36.7
3	599.3	19885.1	20140.0	254.9	3	600.8	20067.1	20110.7	43.7
4	598.8	19874.2	20097.4	223.2	4	599.6	20068.6	20107.3	38.7
5	598.5	19821.7	20107.3	285.7	5	599.5	20105.9	20119.7	13.8
6	598.6	19790.0	20114.2	324.2	6	598.8	20112.3	20140.7	28.4
7	599.3	19807.2	20129.0	321.8	7	597.5	20111.9	20136.3	24.5
8	602.3	19834.4	20140.4	306.0	8	597.3	20159.2	20180.8	21.6
Total power difference				**2232.1**	**Total power difference**				**314.5**