Technical Conditions for PV Plants Connection on the MV Distribution Grids in the Republic of Macedonia

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Abstract – **In this paper the technical conditions, which have to be fulfilled for connection of a Photovoltaic Power Plant (PV plant) on distribution MV grid in the Power System (PS) of the Republic of Macedonia, are given. As the base, the technical conditions from the aspect for obtaining a permission from the distribution system operator for connection of a PV plant, the following conditions are described: nodes voltages changing, flickers appearances, increasing of higher-harmonics currents, increasing of short currents intensity in the grid, changing of feeder load segment distribution and location of energy-meter. The approach and results for checking the technical conditions which have to be fulfilled for a real case 1 MW PV plant connection to a 10 kV distribution grid are presented.**

Keywords – **Renewable energy sources, Photovoltaic system, Photovoltaic plant connection, Dispersed generation.**

I. Introduction

According to the Base Study on Renewable Energy Resources in the Republic of Macedonia [1] and Strategy for power plants development in the period 2008-2020 in the Republic of Macedonia [2], it is planning to construct 10 – 30 MW PV Power plants till 2020, with total electricity production of 16 – 60 GWh/year. There are two categories of PV plants: 1. with installed power ≤50 kW and feed-in tariff 30 €c/kWh and 2. with installed power between 50 kW and 1 MW and feed-in tariff 26 €c/kWh. At the moment, the total allowed capacities which the Government would support by feed-in tariffs are: 2 MW for the first and 8 MW for second category. Recently, the Energy regulatory commission of the Republic of Macedonia issued a register of connected PV plants [6]. Till now, six PV plants from the first (total capacity of 220.765 kW) and two from the second (total capacity of 1246.7 kW) category have been put into operation.

According to the technical recommendation [3], [4] and Distribution grid code [5], there are several technical conditions which have to be fulfilled in order to connect a PV plant on distribution grid. In the following sections the technical conditions which have to be fulfilled by the PV plant, necessary for obtaining permission for connection to the MV grid of the distribution company EVN, are explained.

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II. Conditions for the Allowed PV Plant Instaled Power

The installed power of the PV plant has impact to the voltages in the distribution grid during the plant switching-on or switching-off transient period. This voltage impact should not exceed value of $\Delta u_m = 2\%$ at the plant connection point to the distribution grid. The small PV plant may connect to the distribution grid according to the criterion of allowed installed power, only if the condition given by Eq. 1 is satisfied:

$$S_{nPV} \leq \frac{S_{3pc}}{50 \cdot k} \tag{1}$$

where:

− S_{nPV} is rated installed apparent power of the plant in MVA,

− S_{3pc} is three phase short-circuit power in MVA and

− k is coefficient, which has value 1 for inverters DC/AC.

In the MV distribution grids in the power system of the Republic of Macedonia, there are three standard values for maximal permitted three phase short-circuit currents (powers):

− for 10 kV grid, current of 14.5 kA and power of 250 MVA,

− for 20 kV grid, current of 14.5 kA and power of 500 MVA,

− for 35 kV grid, current of 12 kA and power of 750 MVA.

It is worth to mention, that no matter how big is installed power of the PV plant, the maximum voltage deviation in the connection point in steady-state conditions, should not exceed the interval $\Delta u_m = \pm 5\%$ from the MV grid rated voltage [3].

III. Condition for Flickers Generating

The flicker criteria can be assessed by the disturbance factor A_{fd} for the PV plants with flicker duration more than two hours. This factor can be calculated with Eq. 2:

$$A_{fd} = \left(c_f \cdot \frac{S_{nPV}}{S_{3pc}} \right)^3 \tag{2}$$

where:

− c_f is flicker coefficient (S_{nPV} , S_{3pc} are defined in section II).

With this coefficient is assigned the ability of the PV plant to produce flickers. After PV plant connection to the distribution grid, the flicker coefficient should be measured in real operating steady-state conditions. The value of this coefficient usually is $c_f > 20$, but it can reach a value up to 40. For every PV plant there should be issued certificate that condition for long time duration flickers is fulfilled. Calculated value of the disturbance factor with Eq. 2, should be $A_{fd} \leq 0.1$ as a proof that the PV plant would not generate flickers [3].

IV. CONDITION FOR HIGHER-HARMONICS CURRENTS

The criterion of permitted content of higher-harmonics currents can be checked by applying Eq. 3 [3]:

$$I_{hhp} = I_{hhr} \cdot S_{3pc} \qquad (3)$$

where:

- I_{hhp} is the permitted value of the higher-harmonic current on the generator voltage level, in A,
- I_{hhr} is the value of the higher-harmonic current in A/MVA (reduced on the S_{3pc} in the connection point on the grid).

The values of maximum permitted content of higher-harmonics currents reduced on the three phase short-circuit power in the PV plant connection point on the grid, are given in Table 1.

TABLE I
MAXIMUM PERMITED HIGHER-HARMONICS CURRENTS

harmonic ν	5	7	11	13	17	19	23	25
I_{hhr} A/MVA	0.7	0.6	0.5	0.3	0.3	0.2	0.2	0.2

If the current of any higher-harmonic ν exceeds the permitted value, the voltage for the ν-th harmonic $U_{h\nu}$ should be calculated. If the voltage of the 5-th higher-harmonic is $U_{h5} \leq 0.2\% \cdot U_n$ and for the rest higher-harmonics from Table 1 $U_{h\nu} \leq 0.1\% \cdot U_n$ (where U_n is rated voltage of the grid), than the criterion of permitted higher-harmonics currents is fulfilled. On the contrary the owner of the PV plant should undertake measures to eliminate higher-harmonics currents [3].

Another way to check the condition for higher-harmonic currents is to compare total harmonic distortion factor *THD* allowed by the distribution company, with the certified *THD* factor of the DC/AC inverter [8].

V. CONDITION FOR SHORT-CIRCUIT POWER

If the connection of the PV plant causes increasing of the three phase short-circuit power (current) over the allowed values for the equipment, the following measures should be undertaken:

- to limit the short-circuit currents in the PV plant,
- to replace the switching and other equipment which not meet requirements for short-circuit currents,
- to connect the PV plant in other place of the grid.

Because the PV plants with installed power less or equal to 1 MVA don't influence significantly on short-circuit power (current) increasing, it is not necessary to check this criterion for PV plants constructed in the Republic of Macedonia.

The relay protection of the MV feeder will trip the feeder circuit-breaker in cases of short-circuit faults in the feeder. In these cases is not allowed island operation of the PV plant (or PV plants if more then one are connected on the same feeder).

The relay protection of the PV plant should switch of the plant from the grid immediately.

The automation installed in the PV plant will allow switching on the plant to the grid when all three phases in the grid have normal operating voltages. The conditions for synchronized connection are voltage difference $\Delta U_{PV} < \pm 0.1 U_n$, $\Delta f_{PV} < \pm 0.5$Hz and phase angle difference $\Delta\varphi < \pm 10\%$ [3], [4].

VI. CONDITION FOR ELECTRICITY MEASURING

Despite that in the Grid Code [5] is not clarified, the distribution company obliges the dispersed producers, the measuring of produced and consumed electrical energy should be performed on one indirectly measuring place on 10 (20) kV side, with measuring transformers placed in separate measuring cabinet [8].

The current transformers (CT) in each phase, should have two cores X/5/5 A, 50Hz, 10/25 VA, class 0.5/5P10 (F_s<5 for the first core and F_s>10 for the second core). The voltage transformers (VT) in each phase should have the following characteristics: 10000/$\sqrt{3}$ (20000/$\sqrt{3}$)/100/$\sqrt{3}$/100/$\sqrt{3}$ V/V, 50 Hz, 25/25 VA, class 0.5/3P.

Electricity meter have to be with two-way measuring system of produced and consumed electrical energy. The type of this meter must be 5(6) A, 3x(100/$\sqrt{3}$)/100 V, class 1/2 (A/R) with optical port, internal connecting clock, CS/RS communication and connected with modem to the system of distance reading in the company EVN Macedonia. No other additional equipment is allowed to be connected on the secondary windings of the measuring transformers.

The measuring transformers and the electric energy meter are provided by the distribution operator - company EVN Macedonia and stay in their property.

VII. CASE STUDY: 1 MW PV PLANT CONNECTION

In this paper a case study for connection of 1 MW PV plant on 10 kV distribution feeder named "Egri", from substation TS 35/10 kV/kV Bukri, is analyzed. The schematic diagram of the PV plant main components is shown on the Fig. 1.

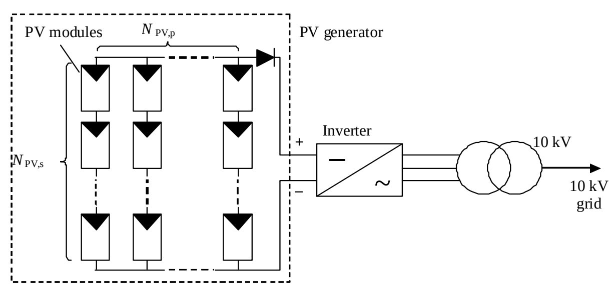

Fig. 1. Schematic diagram of the PV plant main components.

Total number of the modules will be 4320 each per 230 Wp. The nominal power of the DC generator of the PV plant will be 993.6 kWp. Because the power factor for this type of plants is $\cos\varphi \approx 1.0$ and modules power is with positive tolerance in the following calculations can be taken that $S_{nPV} \approx 1$ MVA.

The DC/AC inverter which is planed to be used is Sunny Central HE 1000MV for direct medium-voltage feed-in, because the MV/LV transformer is build in the same house.

Distribution feeder named “Egri” with all its elements as a part from 10 kV grid is shown on Fig. 2.

All data for the elements connected in and between the nodes are given on the same Fig. 2. A new PV plant will be connected in the node J4.

B. Check for the flickers generating

As it was mentioned in section III., the flicker coefficient c_f should be measured in real operating steady-state conditions. However, if the maximum possible value of this coefficient c_f =40 is taken into Eq. 2 and S_{3pc} =250 MVA, S_{nPV} =1MVA, the calculated value of disturbance factor A_{fd} =0.0041.

In this case A_{fd} <<0.1, so it can be concluded that the new PV plant will not generate flickers with duration more than two hours. After construction of the PV plant the certificate for measured c_f should be issued.

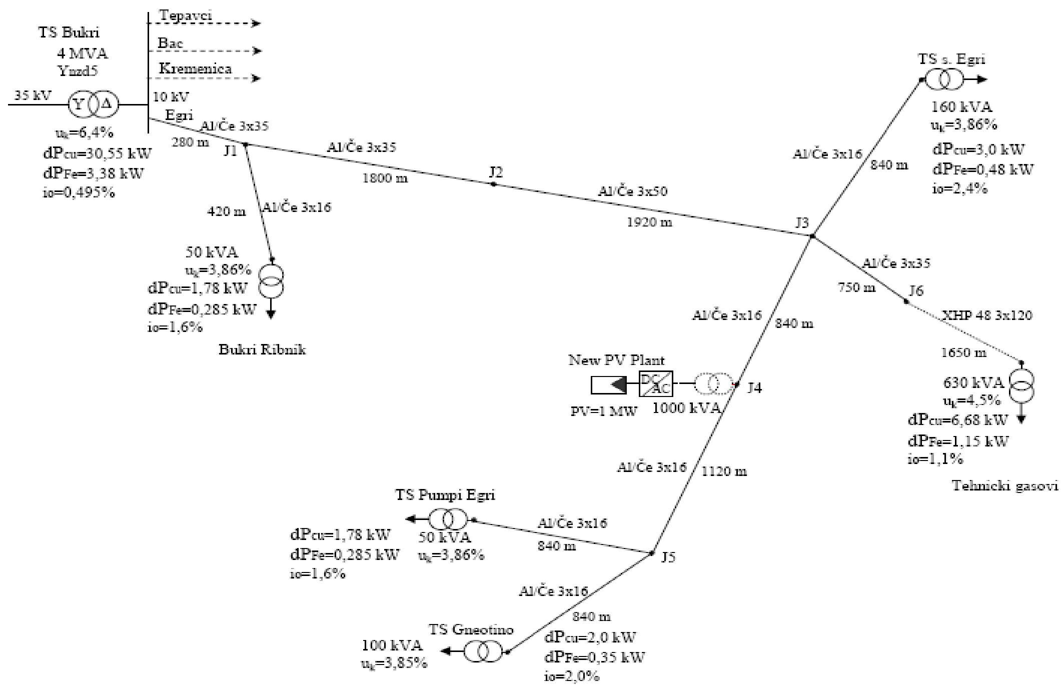

Fig. 2. 10 kV feeder named “Egri” with data for the connected elements and connection point of 1 MW PV plant.

A Load-flow and short-circuit analysis for the 10 kV feeder shown on Fig. 2 are performed with Neplan 5.0 software [9]. Two cases are analyzed. In the first case the new PV plant is not connected and in the second case this plant is connected in node J4. Also the calculations for checking the technical conditions which have to be fulfilled to connect this PV Plant of 1 MW, are done.

A. Check for the allowed PV plant installed power

According to Eq. 1 and taking into account the values for three phase short-circuit power (250 MVA for 10 kV grid) and k =1, the maximal allowed installed power for the PV plant connected in node J4 can be $S_{nPV} \leq 5$ MVA. Because the installed power of new PV plant is 1 MVA (actually 1 MW because PV plants work with $\cos\varphi$=1.0) it is obvious that condition for maximal allowed installed power is fulfilled.

The load-flow analysis confirmed that PV plant connection wouldn’t change the node voltages and line currents over permitted values. In this case, the voltage drops and energy losses in the lines are smaller than in the first case. Also the power losses in the entire grid are reduced [7].

D. Check for the higher-harmonics currents

Under the normal operating conditions the total harmonic distortion factor *THD* allowed by distribution company EVN Macedonia is 8% [8]. According to the inverter manufacturer data, this factor has value *THD*<3%. Taking into account these data, it is obvious that this condition is fulfilled and the generated higher-harmonic currents have acceptable values.

E. Check for the short circuit power (current)

The DC generator of the PV plant works as constant current source. For the planned PV modules with power of 230 Wp maximum power point current is I_{MPP} =7.8 A and maximum short circuit current is I_{sc} =8.3 A. Increasing of the short circuit current is only 6.4% over the I_{MPP}. Because of the presence of the PV plant in the MV grid, the total increasing of the three phase short circuit current and power at the point of connection will be also 6.4%. This is not significant increase which can take negative influence on the electrical equipment.

VIII. Conclusion

In the last few years, the construction and connection of the PV plants in MV grids in the PS of the Republic of Macedonia are occurred. The technical regulations for PV plants were very poor and lot of these documents were directly accepted from the foreign regulations which sometimes do not coincide with the PS situation and the present legislation. Distribution operator EVN Macedonia introduced additional regulations in this domain.

This paper deals with necessary technical conditions which have to be fulfilled for PV plant connection on the MV grid. The conditions as: the allowed PV plant installed power, the flickers generating, the increasing of the higher-harmonics currents, the increasing of the short circuit currents (power) intensity in the grid, the location and the type of energy-meter are described. These technical conditions are checked for a real PV plant of 1 MW which is planned to be connected in the 10 kV distribution grid in the middle of 2012. All necessary and proper parameters are calculated and compared with allowed values given by the grid code.

From the calculations and values of obtained results, it can be concluded that connection of PV plants with power equal or less than 1 MW will not have negative influence to the normal operation conditions of the MV distribution grid and the appertaining electrical equipment.

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