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DG integration limits in distribution networks.

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Abstract. This paper presents the results of a study to establish the limits of operation in underground distribution networks with distributed generation (DG). It has been made simulations with cables of different sections and different type of electric loads/generarators. It has been studied the influence of the cable parameters (length and section) and the load in each case in order to show the values of these parameters that exceed the limits of current and voltage drop in the cable.

This information is useful to know the integration limits of several types of DG in distribution networks and the set points to operate these networks.

Key words

Distribution network, integration of GD, limits of cables, types of loads.

1. Introduction

The distribution networks are suffering important changes produced mainly by:

- The increase of energy demand.
- The integration of DG.
- The environment conditions and applied to the new installations.

As consequence, the distribution lines are being overloaded and the new installations are being oversized and require new services [1]-[3]. In addition, the underground lines are installed more frequently. As an example, the underground lines of wind-parks are large relatively and have installed generation of several megawatts. These characteristics were not required for a distribution line and now are demanded and are usual [4], [5].

This paper presents the results of the study in order to know the maximum limits of distribution lines. It is focused in underground cables of 20kV, which are the more usual lines in distribution networks. It has been simulated several scenarios taking into account the limits imposes by the maximum current in the cable and the voltage drop in the load. It is possible to know the set points of operation with this information and know how they depend of the type of load and generator. By way of example, the set points of operation of the load or the maximum numbers of generator that can be connected to the network.

2. Models of line and loads

These simulations have been taken into account the model of line and the model of load.

A. Models of line.

It has been checked the results of three different models of line: the distributed parameters model, the concentrated parameters (Π model) model of and the constant impedance model [6]. The study is in steady-state so it is not necessary to analyse more complex models.

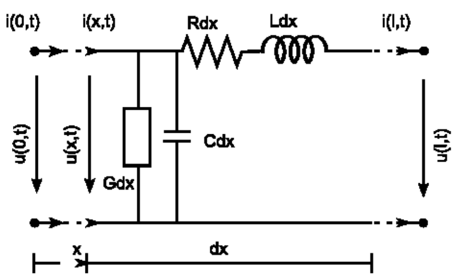

Fig. 1. Distributed parameters model.

The model of constant impedance does not consider the capacitance so it has got errors when the line is discharge. The differences of results between the distributed parameter model (Fig. 1) and the Π model are not very large.

TABLE I. – Electric parameters values of the cable HEPRZ1.

Sections	r	Xl	C	Imax
mm2	Ω/km	Ω/km	μF/km	A
50	0.564	0.154	0.150	172
120	0.235	0.126	0.242	290
240	0.118	0.111	0.310	429
400	0.071	0.103	0.380	557
500	0.056	0.099	0.422	637
630	0.045	0.095	0.478	730

Finally, it has been chosen the distributed parameters model because it is the most complete model. The parameters of the cable used in the simulations are shown in the table 1 and have been obtained of [7] y [8].

B. Models of loads/generators

It has have been used with three simple load models that represent most of the situations. The constant impedance models the behaviour of passive loads. The constant voltage and constant power models the active and passive loads as the generator, motors or capacitors banks in steady-state.

3. Influence on the current

This section shows the characteristic values of the load that achieve the maximum value of current in the cable (I_{max}). The graphics represent the curves obtained with the different loads. If there are not against other indication in the graphic, the length of the cable is 10km and the section is 240mm^2.

The limit value of maximum current matches the extremes of maximum current in the curves.

A. Constant impedance load.

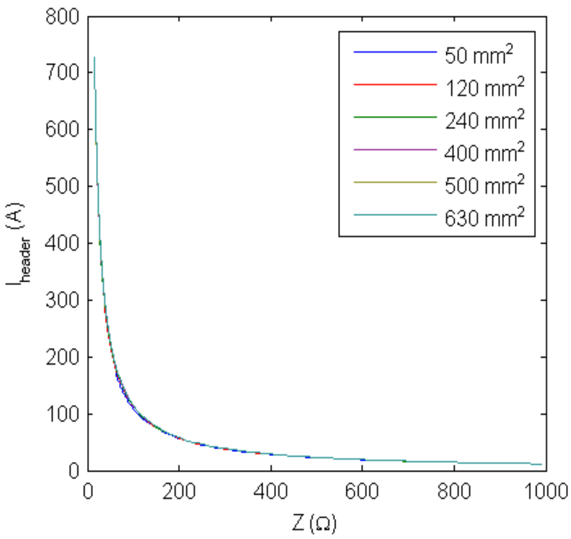

Fig. 2. Current when the impedance in the load increases at different sections of cable.

The fig. 2 shows the change of the current as a function of the impedance in the load and the section. The minimum values of impedance that do not exceed the maximum current in the cable and the maximum consumed power to each section, it is shown in the table II.

The Fig. 3 shows the curves for different lengths of the same cable. The influence of the length is not very important when the load is passive. The maximum load limit is about of 25Ω for large and short lengths.

TABLE II. – Constant impedance limits.

Section	Z	P_{max}
mm^2	Ω	MW
50	61.5	1.819
120	37.5	3.148
240	25.8	4.724
400	20.1	6.184
500	17.6	7.100
630	15.4	8.158

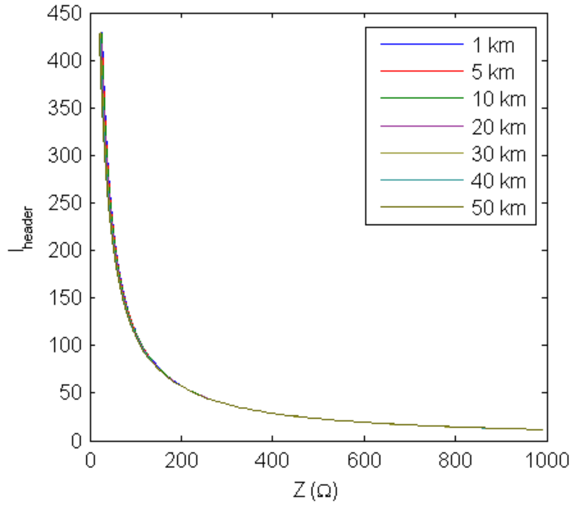

Fig. 3. Current when the impedance in the load increases to different lengths of cable.

B. Constant voltage load.

The voltage at the end of the line is fixed by the load. The phase-angle of the load is the same as the header. When the voltage in the load is 11.55 kV, that is equal to the nominal voltage (V_n) phase-ground, the current in the cable is only consumed by the own capacity of the cable. The ranges of the voltage magnitude that can operate the load without exceeding the current limit decrease with the section of the cable, as it is shown in Fig. 4.

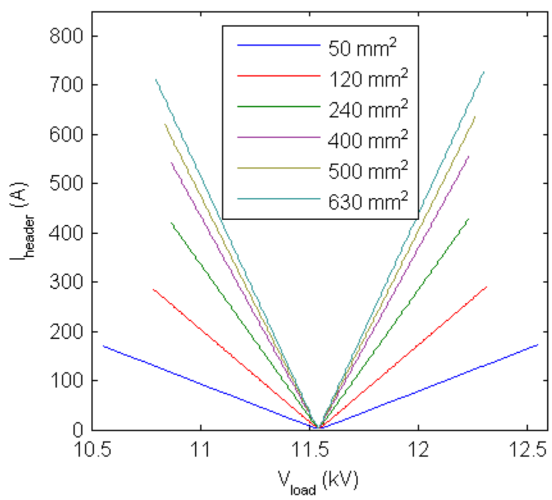

Fig. 4. Current when the voltage magnitude varies in the load to different sections of cable.

The Fig. 5 shows that if the section is fixed, the increasing in the length increases the range where the load can operate. The minimum of the curve goes up and right when the length increase. The cause is the increase of reactive power of the cable as a consequence of the increasing of the capacity, which is lineal with the length.

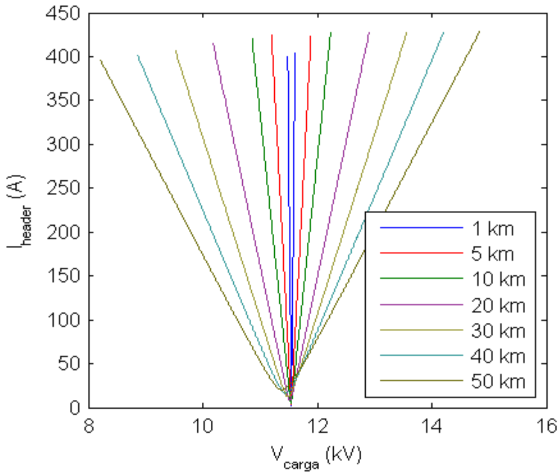

Fig. 5. Current depending on the length of cable when the voltage magnitude varies.

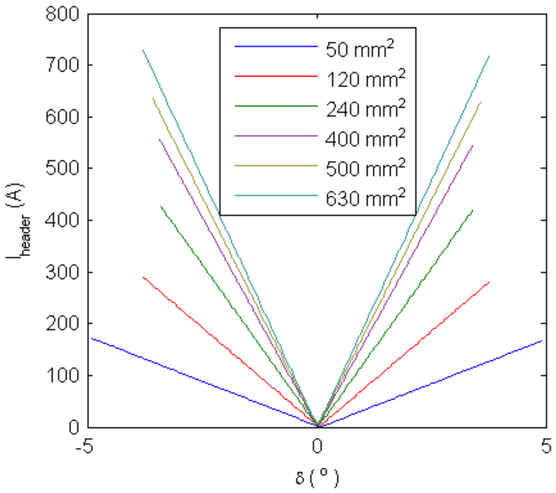

Fig. 6. Current depending on the phase-angle, at different sections of cables.

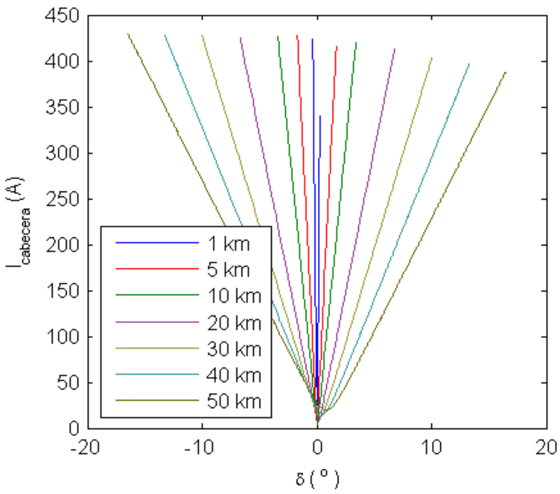

Fig. 7. Current depending on the phase-angle and lengths of cables.

The voltage in the load has been fixed to V_n and it has been varied the phase-angle of the voltage load in the Fig. 6 and 7.

The graphics depicted in Fig. 7 are very similar to those obtained when the voltage magnitude varies. The range in which the load is able to vary the phase-angle is more sensitive to changes in length than to changes in sections.

C. Constant power load.

The load consumes or generates active power with power factor (PF) equal to one in Fig. 8. The table III shows the active power limits that can be connected to the end of the cable without overload it

TABLE III. – Power constant limits and PF =1.

Sección	P_{gen}	P_{con}
mm^2	MW	MW
50	-2.1	1.8
120	-3.5	3.1
240	-5.1	4.7
400	-6.6	6.2
500	-7.5	7.1
630	-8.6	8.1

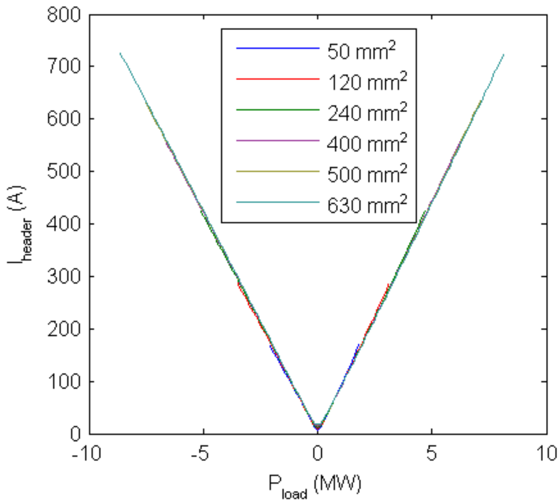

Fig. 8. Current depending on the power in the load for, at different sections of cables.

The Fig. 9 shows that the increasing of the length decreases the capacity of integration of passive loads and increases the capacity of integration of generation in the cable. The minimum of the curves is increased due to the generation of reactive power by the cable.

The Fig. 10 shows how the PF affect to the current and it has been drawn the curves for different lengths of cable. The PF near the unity allows the integration of more loads. The capacity of integration is increased when the load has inductive character.

The Fig. 11 shows the behaviour of a load of a 2MW when is connected to cables of different lengths. When the absolute value of PF is lower, the current that goes through the cable is bigger. In the point of view of energy looses, when the length is lager, the inductive PF are better, because the current decrease to compensate reactive power generated by the cable.

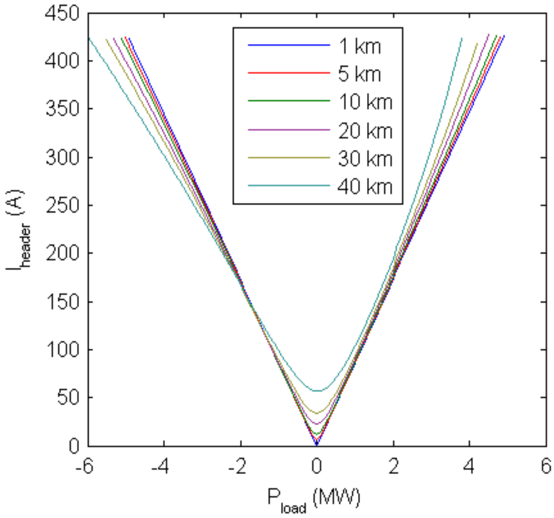

Fig. 9. Current depending on the power in the load and lengths of cables.

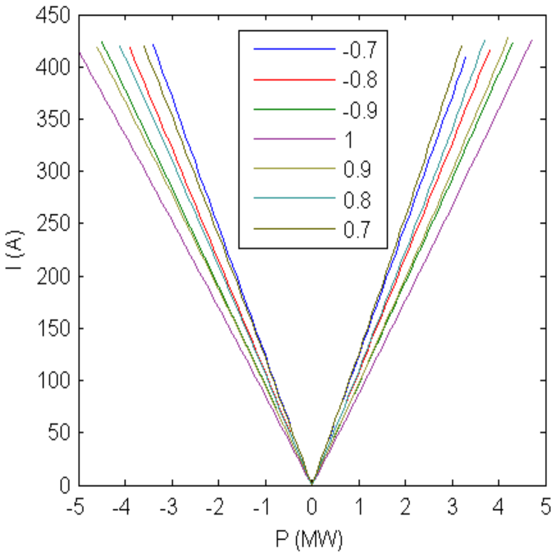

Fig. 10. Current depending on the PF of the load.

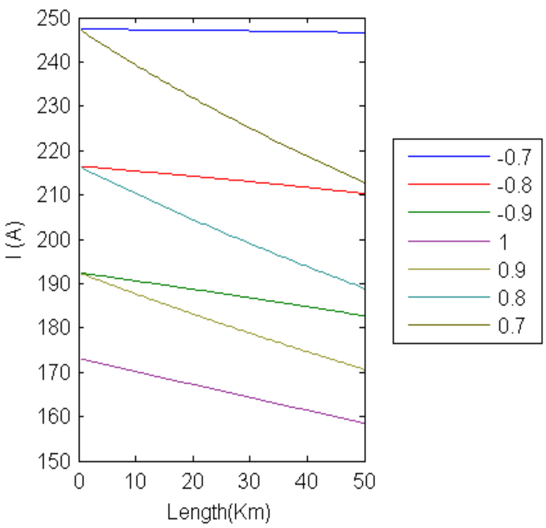

Fig. 11. Current depending on the length and the PF of the load.

4. Influence on the voltage

This section studies the parameters influence of the constant impedance model and constant power model on the load voltage.

A. Constant impedance load.

Fig. 12 shows that some values of impedance cause significant voltage drops when the impedance is lower than 100 Ω. The end of each curve show the point where it is exceeded the current limit in the cable. When the section is greater, the influence of the load on the voltage to the end of line of the cable is lower. It allows connecting lower values of impedance.

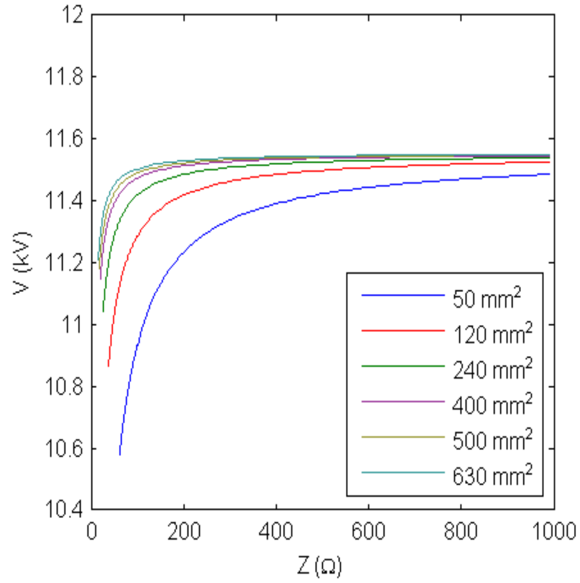

Fig. 12. Voltage on the load depending on the impedance of the load and the section of the cable.

The Fig. 13 shows how the voltage in the head (V_n) is exceeded from one value of impedance. This happens when the load is equal to the value of the characteristic impedance of the line. The increasing or decreasing of voltage is bigger when the length of the cable is larger.

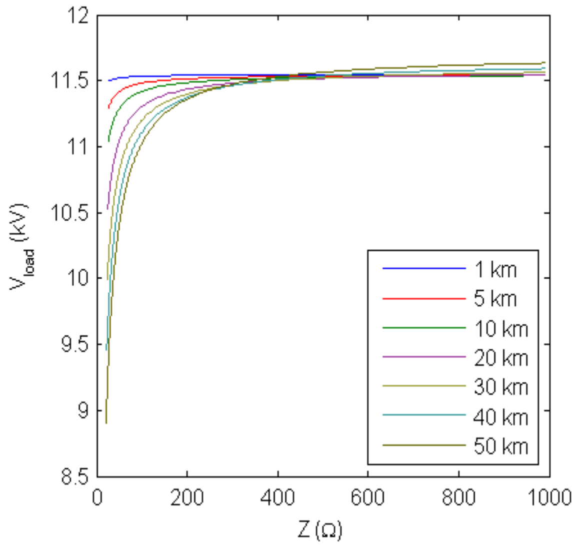

Fig. 13. Voltage on the load depending on the impedance of the load and the length of the cable.

B. Constant power load.

The Fig 14 shows that the influences of the constant power load increase when the section of the cable decreases. So the range that the load can operate is smaller. In every case the limit of operation is imposed by the I_{max} of the cable. The voltage drop in the extremes does not reach to 10 % V_n.

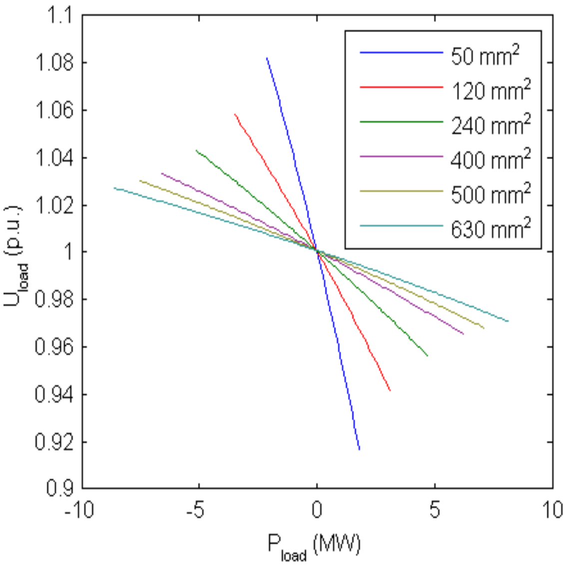

Fig. 14. Voltage in header of line depending on the power on the load and the section of the cable.

Fig 15. shows that an increasing of the length of the cable increases the influence of the load in the voltage of the connection point. If the load is a generator, the voltage increases. The more power is injected to the network the more voltage. When the load is passive the voltage decrease. It is possible to connect more generation than passive load without exceed the current limit of the cable. This trend is greater when the length of the cable is larger.

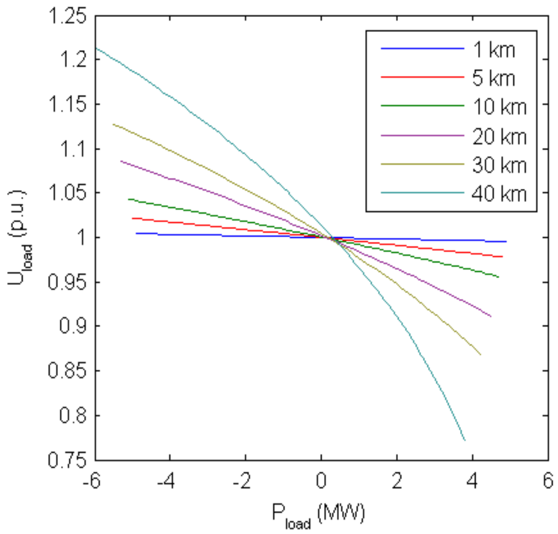

Fig. 15. Current in header depending on the power of the load and the length of the cable.

Fig. 16 shows the values of voltage load as a function of the PF. Capacitive PF values keep the voltage load near V_n. But the load has a more narrow rage without exceed the I_{max} of the cable. The greatest range is get for PF = 1.

voltage drop on the load (±10% V_n). The graphic shows that the voltage limit influences the integration limit of the load from a length of cable that it is function of the section. The P_{max} decreases when the length increases. An increasing in the section does not causes a substantial

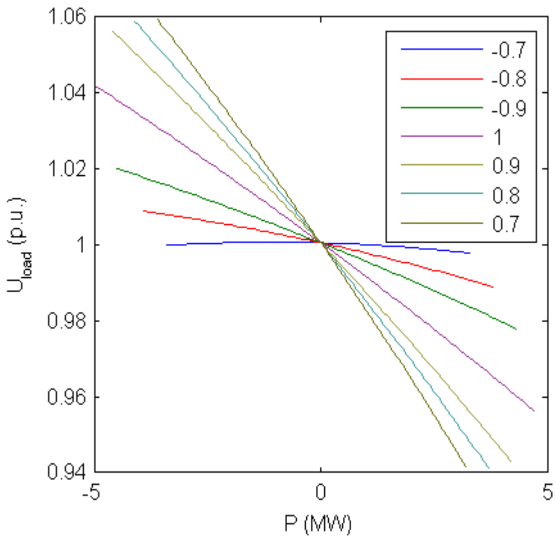

Fig. 16. Current depending on the power load and the PF.

increasing in the capacity of the cable to integrate generation.

Fig. 17 shows the maximum power injected by the generation depending on the section and the length of the cable. These curves show tow strokes. The first matches with the limit imposed by I_{max} of the cable. The second has an exponential wave and matches with the limit

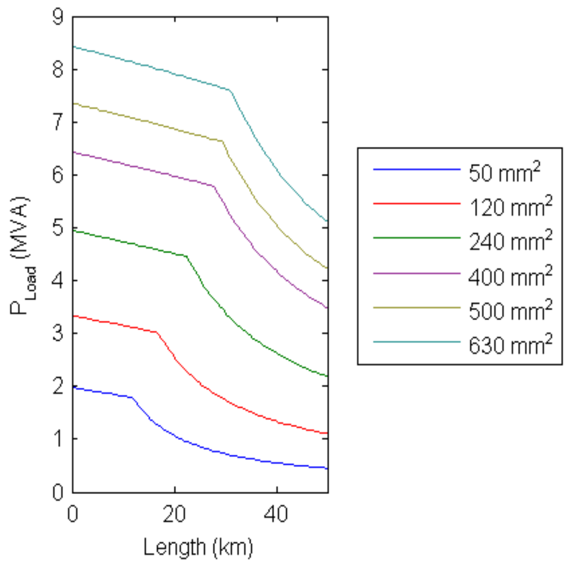

Fig. 17. Maximum power depending on the length of the cable and its section.

The Fig. 18 shows the maximum power of the generation when the PF varies to capacitive values. Similar graphics can be obtained to inductive values and passive loads. The graphic has three curves. The Imax current limit in the cable (red curve) and two voltage limits. Overvoltage (blue line) and voltage dips (green line). The area behind the three curves gives the values of power and the PF that the generation can operate when it is connected to cable of 50 km and a section of 240 mm2.

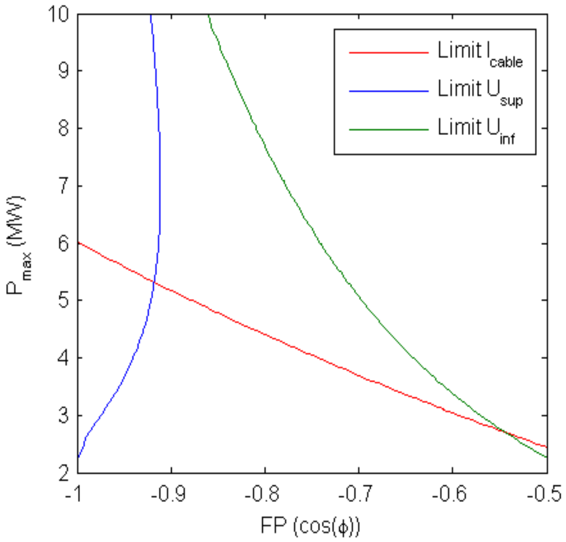

Fig. 18. Maximum power depending on the PF by a cable of 50 km and a section of 240 mm^2.

5. Conclusions

This paper has studied the integration limits of loads in MV cables in distribution networks. It has been included passive and active loads.

It has been depicted a group of graphics that are useful to know the behaviour of the currents and voltages when the parameters of the load varies. These parameters are the impedance, the voltage, the angle and the active power. This graphics also allows knowing the maximum values of operation of a DG connected to a distribution network.

It shows the set points of the DG in the cases of working as a voltage source or as a power source, that they do not must be exceeded in order to the DG causes problems in the distribution network.

Same procedure can be applied to get the behaviour of other underground lines with others characteristics and voltages of operation.

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