Engineering, 2014, 6, 34-41
Published Online January 2014 (http://www.scirp.org/journal/eng)
http://dx.doi.org/10.4236/eng.2014.61006

Scientific Research

Distributed Generation Effects on Large-Scale Distribution Networks*

Anastasia S. Safigianni#, George N. Koutroumpezis, Anastasios I. Spyridopoulos
Electrical and Computer Engineering Department, Democritus University of Thrace, Xanthi, Greece
Email: #asafig@ee.duth.gr

Received June 12, 2013; revised July 12, 2013; accepted July 19, 2013

ABSTRACT

This paper examines the results of the distributed generation penetration in large-scale medium-voltage power distribution networks. The network examined as a study case consists of twenty one lines fed by three power substations. The injected power comes mainly from photovoltaic units. Specifically, the influences of distributed generation on the network branch currents, losses and voltage profile as well as on the short-circuit level at the medium voltage busbars of the infeeding substations are examined according to international and national standards. The arising problems are explored and technical solutions are proposed. This paper is a pilot application as general conclusions concerning the extended distributed generation penetration in real power distribution networks are set out.

KEYWORDS

Distributed Generation Effects; Extended Penetration; Technical Constraints; Thermal Current; Losses; Short-Circuit Level; Voltage Profile

1. Introduction

In recent years, increasing amounts of distributed generation (DG) have been connected to distribution networks. Environmental, technical, and economic issues are playing an important role in the development of DG.

A general definition for DG was suggested in [1] and is now widely accepted: "Distributed generation is an electric power source connected directly to the distribution network or on the customer site of the meter". This definition does not determine the rating of the generation sources or the DG technologies used. Furthermore, it does not cover power delivery area, penetration, ownership, or treatment within the network operation.

As a result of DG penetration at distribution level, distribution systems are facing the challenge of evolving from passive networks with unidirectional power flow supplied by the transmission grid to active networks with bidirectional power flows. A number of steps should be followed concerning, on the one hand, best use of the existing distribution network by optimal allocation of the DG resources and, on the other hand, optimal planning of the development from passive to active, by taking account of all the relevant technical and commercial considerations. The technical issues include the adequacy of the network's and associated plant's thermal rating, fault levels, and sufficient voltage support to ensure both the security and quality of electricity supply [2-7]. The commercial issues include the cost of the DG, installation charges, operating costs, revenue expectations, and the value of reduced losses in the network [8-12].

The challenge is to identify suitable DG locations and ratings in distribution networks with respect to technical or economic constraints, which will enable a high DG penetration and avoid network sterilisation which results when capacity is allocated to bus/buses whose voltage and/or short-circuit levels (*SCLs*) are most sensitive to power injections. Thus, no more generation can be connected as the buses are constrained [4,7].

*This paper contains the final processed results concerning the examined subject. Relevant early results were presented in the 11th Euro PES 2012, June 25-27, Napoli, Italy.
#Corresponding author.

Although the optimal DG allocation on distribution networks is the most interesting research point, the most common practical question is whether DG resources of a particular type and rating can be connected at predetermined network positions without causing technical problems [6] and, if possible, without changing the network structure. This is determined by the specific requirements of independent producers.

In Greece, during the last years, a huge number of independent producer applications were submitted for approval, mainly concerning the connection of photovoltaic (PV) units to the Public Power Corporation (PPC) Medium Voltage (MV) distribution network. The Greek Government subsidises the production of these “green” kWhs in order to meet the environmental constraints established by the Kyoto Protocol and other government initiatives primarily concerning fuel saving. The aforementioned applications are very difficult to be examined in detail. So, there is a possibility that the existing MV networks will not be able to accommodate the new generation, operating in parallel, in a technically and economically acceptable manner.

In light of the above situation, this paper investigates the results of DG penetration in a large-scale MV distribution network as a pilot application. The network is fed by three power substations and it consists of twenty one MV lines. The DG resources to be connected are mainly PV units, with a total capacity of about 32 MW. Their locations are predetermined. Specifically, the influence of these units on the network branch currents, voltage profile, power flow, short-circuit level (*SCL*) at the MV busbars of the infeeding power substations, and losses are examined using a commercial-grade software package. The results arising from this real-world case study can be used as a pilot for the relevant analysis required for every relative network.

2. Network Description

The network examined in this paper is the rural MV network of the prefecture of Xanthi, Greece. This prefecture has an area of 1793 square kilometers and a population of 100,000 inhabitants.

The total MV network of the prefecture of Xanthi is illustrated in Figure 1. It is fed by the three power substations, 150/20 kV, of Xanthi, Magiko, and Iasmos. The substation of Xanthi has a rated capacity equal to 100 MVA (2 × 50 MVA) and a short-circuit level *SCLmax* = 138 MVA, the substation of Magiko has a rated capacity equal to 100 MVA (2 × 50 MVA) and a short-circuit level *SCLmax* = 129 MVA, and the substation of Iasmos has a rated capacity equal to 50 MVA (2 × 25 MVA) and a short-circuit level *SCLmax* = 230 MVA. The substation of Iasmos feeds, in part, Xanthi prefecture and, in another part (one line), the neighbouring Rodopi prefecture.

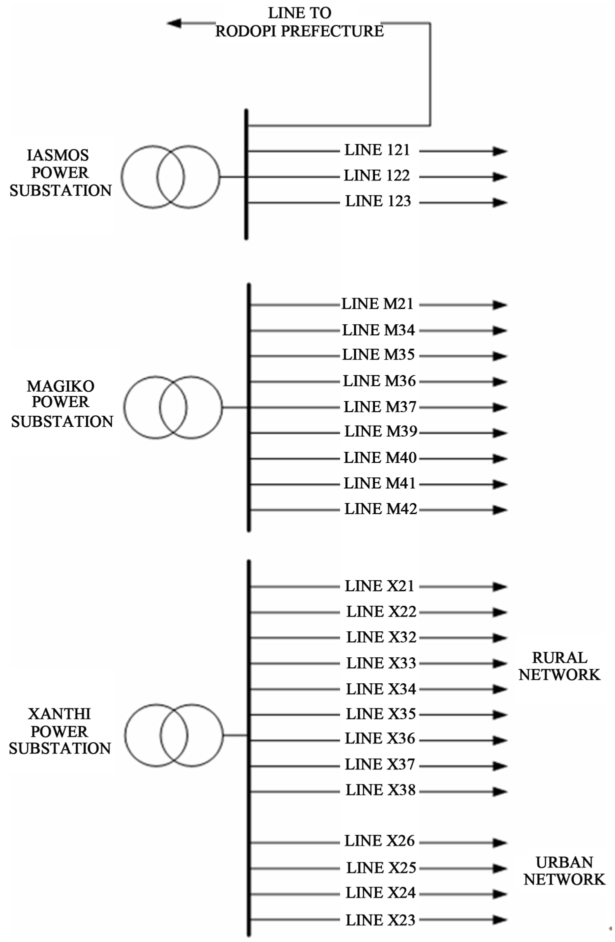

Figure 1. Sketch of the power substations and the MV lines of the examined network.

In this paper, only the lines belonging to the prefecture of Xanthi are examined. The substation of Xanthi feeds with four lines the town of Xanthi (urban network). These lines are not examined in this paper because they do not have DG units connected. So, the twenty one lines examined constitute the rural network of Xanthi, and their allocation to the three power substations is outlined in Figure 1 and Table 1. The types of conductors used in these lines are:

- ACSR 3 × 95 mm^2 and ACSR 3 × 50 mm^2 for the main feeders, and
- ACSR 3 × 35 mm^2 and ACSR 3 × 16 mm^2 for the secondary branches.

The total length per line is given in Table 1.

The nominal voltage of the MV buses is 20 kV, while their operating voltages are:

- For the maximum load: 21.4 kV
- For the daily minimum (evening) load: 21 kV
- For the absolutely minimum (night) load: 20.5 kV.

Given in Table 1 are the maximum recorded loads of the examined lines, for the examined year, measured by the PPC of Xanthi. The daily minimum (evening) load is

Table 1. Data of the rural MV network of the prefecture of Xanthi.

	Length per Line (km)	Maximum Recorded Load (A)	Overall Established Distribution Substation Capacity (kVA)	Overall Coincided Load (kVA)	Overall Scheduled DG Capacity (kW)	Already existing DG capacity (kW)	Existing Capacitors (kVAr)	
							Fixed	Switched
				Substation of Xanthi-rated power 100 MVA				
X21	29	145	21,395	5346	1272	140	-	-
X22	257	130	20,100	4820	2455	50	1500	-
X32	13	135	18,290	4991	200	100	-	-
X33	48	113	14,410	4077	3270	100	1500	-
X34	36	150	8275	5525	2261	100	-	-
X35	6	15	695	501	-	-	-	-
X36	60	100	17,905	3707	2628	-	1200	-
X37	33	80	9345	2965	367	-	1800	-
X38	50	85	12,980	3150	1098	100	2100	-
Total			21,395		13,551	590		
				Substation of Magiko-rated power 100 MVA				
M33	16	70	4070	2595	20	20	-	-
M34	11	80	6340	2965	200	200	-	-
M35	3	5	350	181.3	100	100	-	-
M36	96	212	18,935	5930	4960	20	1500	900
M37	79	166	12,740	3822	4240	20	-	-
M39	13	63	6460	2328	1700	-	-	-
M40	10	185	9210	6857	99	-	600	-
M41	4	215	10,720	7968	200	-	-	-
M42	19	150	8700	5550	270	-	-	-
Total			4070		11,789	360		
				Substation of Iasmos-rated power 50 MVA				
I21	33	93	8350	2296	2639	-	-	-
I22	33	105	8435	3892	3410	-	-	-
I23	50	105	8170	3890	300	100	600	-
Total			8350		6349	100		

taken as equal to 70% of the maximum load, while the absolutely minimum (night) load is taken as equal to 20% of the maximum load, following relevant PPC suggestions.

Table 1 also shows the overall installed distribution substation capacity per line. This capacity concerns both the PPC distribution substations and the distribution substations of the individuals. Since annual peak load measurements per PPC distribution substation are not available, the rated power of each substation is coincided with the maximum recorded load per line, following relevant suggestions and based on PPC data. Specifically, for each line, the maximum load of the individuals recorded was subtracted from its maximum load, and a coincidence factor for the PPC distribution substations installed in the line was then determined by dividing the remaining line load by the cumulative rated power of these substations. The product of the coincidence factor and the rated power of each substation gives the contribution of the substation to the maximum load of the line. The total coincided load per line is also given in **Table 1**. All the loads are considered to operate with a common inductive power factor equal to 0.9 with the exception of the loads of line M36 which, according to PPC suggestions, is considered to operate with a common inductive power factor equal to 0.89.

The total DG power per line (existing or scheduled to be connected) is also shown in **Table 1**. This power comes mainly from PV units, which operate with a capacitive power factor equal to 0.99, except for the line X22, where two small hydroelectric plants are connected, having a rated power equal to 2.36 MW and operating with a power factor equal to unit. The already existing DG power per line is shown in a separate column of **Table 1**. This power is taken into account in the computations for the existing situation.

Fixed and switched capacitors connected to the lines are also given in **Table 1**.

The network was captured and examined using the NEPLAN software package [13].

3. Technical Constraints

The following technical constraints are taken into account throughout the investigation of the DG penetration in the examined network:

1) *SCL* Constraint: a basic requirement for permitting the interconnection of DG is to ensure that the resulting *SCL* remains below the network design value (SCL_{rated}). The *SCL* is highest at the MV busbars of the infeeding substation (SCL_{max}). The following relation describes the constraint:

$$SCL_{\max} < SCL_{rated} \tag{1}$$

2) Transformer Capacity: the amount of generation connected minus the minimum load must not exceed the rating of the transformer at the higher voltage.

3) Thermal Constraint: the rated current of the lines, I_{irated}, must not be exceeded:

$$I_i < I_{irated} \tag{2}$$

where I_i is the current flowing at each network branch.

4) Voltage Variation Constraint: A critical consideration concerning the interconnection of DG sources to the grid is their effect on the slow voltage variations. Therefore the utility operators should impose certain limits within which the voltage variations should lie during normal network operation. The statistical nature of voltage variations is now recognised and relevant norms have been issued, such as the European Norm EN 50160 [14], which impose statistical limits, where a small probability of exceeding them is acceptable. However, checking the conformity against statistical limits at the planning stage requires elaborate procedures, such as probabilistic load flow techniques. Such an approach is relatively difficult to apply because it requires data usually unavailable in practice, which completely defeats the objective of simplicity and efficiency in the evaluation. For this reason, utility directives for the connection of DG adopt simpler and more straightforward procedures while also differentiating their requirements from those imposed by EN 50160 [15].

According to [14], and for the public MV networks, the 10-minute mean rms voltage values are between 90% and 110% of the nominal voltage UN during 95% of a period of one week.

As mentioned above, while EN 50160 gives general limits for public supply networks, various European countries have additional rules governing supply conditions. So, in Greece and for the PPC MV networks, the following requirements are set for the steady-state node voltages, according to [15,16]:

- The median voltage of any node *i* should lie within ±5% of the nominal voltage UN, a requirement dictated by the off-load tap changer of the MV/LV distribution transformers (±5% regulation, in steps of 2.5%):

$$0.95U_N \le \frac{1}{2}\left(U_{\max i} + U_{\min i}\right) \le 1.05U_N \tag{3}$$

where $U_{\max i}$ and $U_{\min i}$ are the maximum and minimum voltage values in the node *i*, determined by solving the load flow for all combinations of max/min load/generation (usually, minimum load/maximum generation yields maximum voltage values and maximum load/minimum generation yields minimum voltage values).

- The variation of the voltage around its median value should not exceed ±3% of the nominal, so that the LV network voltage deviations remain within ±8% (planning limit), after the median deviation is corrected by the fixed taps:

$$\frac{U_{\max i} - U_{\min i}}{2} \le 0.03U_N \tag{4}$$

4. Network Study

According to the data of **Table 1**, the total DG rated power in the lines stemmed from Xanthi substation is 13.55 MW, in the lines stemmed from Iasmos substation is 6.4 MW, and in the lines stemmed from Magiko substation is 11.8 MW.

For the *SCL* computation, the IEC60909 [17] was used. In particular, the computation of the contribution of the PV units to *SCL* was made using the following equation given in [18]:

$$I_k^{"} = kI_{rG} = ct \text{ over interval } \Delta t \tag{5}$$

where:

$I_k^{"}$ the initial symmetrical short-circuit current

k = 1.5 - 2.0 and Δt is the duration of the contribution

I_{rG} the rated current of the PV unit.

The value of *k* selected for this paper was equal to 2.

The fault current contribution of all the PV units is simply added algebraically to the total fault level of all other sources, which provides a result slightly on the safe side. The PPC takes the negligible fault current contribution of the PV units as zero.

Table 2 shows the fault current contribution of the DG units to SCL_{max} for each one of the three power substations. From the data of Table 2, it is obvious that the SCL constraint outlined in Section 3 is not breached. Only the substation of Iasmos has an SCL_{max} very close to its design value (SCL_{rated} = 250 MVA), which must be seriously considered, as there is an additional MV line departing from this substation towards the Rodopi prefecture. Additional DG units may be connected to this line, which will increase the SCL_{max} of Iasmos substation even further.

Table 2. Fault current contribution of the DG units to the SCL_{max}.

Line	Fault Current Contribution (MVA)
Substation of Xanthi (existing SCL_{max} = 138 MVA)	
X21	2.57
X22	18.70
X32	0.40
X33	6.60
X34	4.54
X35	-
X36	5.31
X37	0.74
X38	2.22
Overall Contribution = 41.08 MVA	
Substation of Magiko (existing SCL_{max} = 129 MVA)	
M33	0.04
M34	0.40
M35	0.20
M36	10.02
M37	8.56
M39	3.43
M40	0.20
M41	0.40
M42	0.55
Overall Contribution = 23.81 MVA	
Substation of Iasmos (existing SCL_{max} =230 MVA)	
I21	5.33
I22	6.89
I23	0.60
Overall Contribution = 12.82 MVA	

The power flow, voltage profile, currents, and losses of the network lines were examined through power flow analysis using the NEPLAN software package. Specifi cally, the following limit network operating situations were examined in order to find the worst scenario:

S1. Maximum load, zero DG penetration (PV and hydroelectric units out of service).

S2. Maximum load, maximum DG penetration (full operation of PV and hydroelectric units).

S3. Daily minimum load, zero DG penetration.

S4. Daily minimum load, maximum DG penetration.

S5. Absolutely minimum (night) load, zero DG penetration.

S6. Absolutely minimum (night) load, maximum night DG penetration (full operation of the hydroelectric units only).

The last situation S6 concerns only the line X22, which has two small hydroelectric units of a total power equal to 2.36 MW. These units continue to contribute to the load during the night, when the absolutely minimum load exists and the PV units do not produce power.

Table 3 shows the results of the power flow analysis concerning the departure current, the maximum recorded ratio I_i/I_{irated} of the branch current I_i as a percentage of the rated current I_{irated} of the conductor used in this branch, and the total active P_{loss} and reactive Q_{loss} losses per line, for the first four of the above mentioned limit operating situations.

The DG penetration reduces the departure current. The greater the DG penetration, the greater this reduction is. In the S4 case, there is an inverse power flow for the lines X33, X36, M36, M37, M39, I21, and I22, as shown by the negative sign of the departure current in the shaded cells of Table 3. Even in the case of coincided reverse currents, the total reverse current per power substation corresponds to a reverse power flow much smaller than its capacity. So the second technical constraint (*Transformer Capacity*) is satisfied. The third technical constraint (*Thermal Constraint*) is also satisfied, as shown by the values of the ratio I_i/I_{irated}% in Table 3, which are mostly much smaller than 100%.

The active losses P_{loss} are reduced when the DG units are connected, for all the network operating situations, as a comparison of the relevant columns of Table 3 shows. An increase of the active losses appearing in the line M37 (shaded cells) for the daily minimum load is mainly due to a 2 km ACSR 3 × 16 mm^2 line connecting a 2 MW PV unit, which is planned for construction, and it is not taken into account in the examination of the S3 net-

Table 3. Line currents and losses for the limit network operating situations.

Line	Departure Current (A)				Max (I_i/I_{irated}) %	Active and Reactive Losses							
						S1		S2		S3		S4	
	S1	S2	S3	S4		P_{loss} (kW)	Q_{loss} (kVAr)	P_{loss} (kW)	Q_{loss} (kVAr)	P_{loss} (kW)	Q_{loss} (kVAr)	P_{loss} (kW)	Q_{loss} (kVAr)
Substation of Xanthi													
X21	146	113	104	70	36	63	94	43	64	32	47	18	27
X22	129	72	89	33	80	241	237	152	237	125	117	121	176
X32	135	130	96	91	33	26	41	24	37	13	21	12	18
X33	112	25	80	−25	56	37	56	18	17	22	33	18	17
X34	150	93	107	51	37	28	43	10	15	14	22	4	7
X35	15	15	11	11	1	0	0	0	0	0	0	0	0
X36	100	28	73	−10	25	68	101	22	22	33	50	16	13
X37	80	71	61	52	23	38	41	28	30	21	23	14	16
X38	85	57	66	44	21	41	63	26	40	32	50	23	36
Substation of Magiko													
M33	71	70	50	50	23	16	19	16	19	8	10	8	10
M34	85	80	60	55	21	21	33	20	31	11	16	10	15
M35	7	5	5	3	6	0	0	0	0	0	0	0	0
M36	161	23	112	−37	43	231	312	148	185	115	155	74	90
M37	105	−35	75	−52	43	78	85	62	34	39	43	54	39
M39	63	19	41	−11	16	15	23	3	4	6	9	1	2
M40	185	182	129	126	46	149	233	146	228	73	113	70	109
M41	216	211	154	149	69	34	43	32	41	17	22	16	20
M42	148	141	104	97	37	158	246	142	221	78	122	67	105
Substation of Iasmos													
I21	60	−23	43	−34	56	16	25	34	25	8	13	42	36
I22	105	−32	74	−34	26	110	170	23	33	55	84	15	22
I23	105	96	72	64	26	101	145	84	121	48	69	37	53

work operating situation. The active losses of the other M37 line branches are reduced.

The reactive losses Q_{loss} are also reduced when the DG units are connected, except for two cases (lines X22 and I21), shown with shaded cells in **Table 3**, where the daily minimum load in combination with considerable DG penetration causes an increase in the reactive losses.

Table 4 shows the results of the power flow analysis concerning the limit values of the node voltages of the examined network. Specifically, the absolutely maximum node voltages $U_{max,maxi}$, the absolutely minimum node voltages $U_{min,mini}$, the maximum value of the median voltage, and the maximum value of the quantity U_{maxi} -U_{mini} per line are recorded.

Taking into account that the nominal voltage of the examined network is 20 kV, the EN 50160 [14] is satisfied if the node voltages remain inside the range 18 kV ≤ U_i ≤ 22 kV. This does not apply only for the line X22, where the possible operation of the hydroelectric units during the night (operating situation S6), in combination with the fixed capacitors, causes voltage rise exceeding the acceptable limits in some nodes.

The requirements of [15,16] are satisfied for the data of the examined network if 19kV ≤ $(U_{maxi} + U_{mini})/2$ ≤ 21 kV and $U_{maxi} - U_{mini}$ ≤ 1.2 kV. The first requirement is not satisfied for the majority of the lines according to the

Table 4. Limit values of the node voltages.

Line	$U_{max›maxi}$ (kV)	$U_{min,mini}$ (kV)	$max\{U_{maxi} + U_{mini})/2\}$ (kV)	$max\{U_{maxi} - U_{mini}\}$ (kV)
		Substation of Xanthi		
X21	21.4	20.6	21.1	0.4
X22	22.3	19.4	21.0	2.9
X32	21.4	20.9	21.2	0.4
X33	21.5	20.9	21.2	0.5
X34	21.4	20.8	21.2	0.5
X35	21.4	21.0	21.2	0.4
X36	21.4	20.6	21.2	0.7
X37	21.4	20.8	21.2	0.4
X38	21.6	21.0	21.4	0.4
		Substation of Magiko		
M33	21.4	20.8	21.1	0.4
M34	21.4	20.5	21.2	0.4
M35	21.4	21.0	21.2	0.4
M36	21.4	20.1	21.2	0.5
M37	21.4	20.3	21.2	0.7
M39	21.4	20.9	21.2	0.5
M40	21.2	20.5	21.0	0.3
M41	21.4	20.3	21.2	0.4
M42	21.4	20.9	21.2	0.4
		Substation of Iasmos		
I21	21.7	20.8	21.2	0.9
I22	21.3	20.3	21.0	0.7
I32	20.9	20.4	20.9	0.3

upper limit, but the excess, although concerning enough nodes, is marginal. Only the line X22 has a remarkable problem, according to the second requirement, concerning many nodes near the connection point of a 1.08 MW hydroelectric plant and the simultaneous existence of a 900 kVAr fixed capacitor near it. Several alternative scenarios were examined in order to overcome the problem, and the operation of the network was significantly improved by replacing the fixed capacitor with switched capacitors. Otherwise, the above mentioned hydroelectric plant is not permitted to be connected, in order to avoid exceeding the technical constraints.

5. Conclusions

The purpose of this paper was to investigate the impacts of DG penetration in a real rural MV power distribution network. The network is very extensive, consisting of twenty one overhead lines fed by three power substations.

Power flow and short-circuit analysis were carried out using a commercial-grade software package to determine the changes caused by the DG penetration to the currents, losses, voltage profile, and short-circuit level of the examined lines. The majority of the DG units to be connected are PV units, the penetration is not very high, and the connection points are at sublateral branches with small cross sections.

The results of the analysis are as follows:

- The losses are reduced in all the lines when the DG units are connected.
- There is not any extension of the conductor rated currents, since the DG penetration remains small compared to the load and there is also no significant reverse power flow.
- The short-circuit level at the MV busbars of the in-feeding substation, where it has the highest value, remains below the network design value, as the DG units are connected at remote sites and the lines have many kilometres of conductors with small cross section (high resistance).
- The main impact of the connected DG units is on the voltage profile of the examined lines, particularly for the daily minimum load (voltage rise) and for lines with fixed capacitors. In these cases, except for the appropriate regulation of the transformer tap changer, solutions should be sought, such as the replacement of the fixed capacitor with switched capacitors.

The general conclusion is that the arbitrary DG accommodation leads to network sterilisation, as recorded in [6,7], and perhaps to violation of important technical constraints. So, every new DG penetration in any network must be examined using the appropriate tools in order to find solutions to the problems that arise.

The extended accommodation of PV resources in a distribution network reduces the losses, because of their close vicinity to the network loads. However, as the PV units operate with a capacitive power factor, they cause impermissible voltage rise during the low load periods. So, either a differentiation in the power factor of the PV units or an integration of voltage control methods is appropriate in order to avoid problems relating to the network voltage profile.

6. List of Symbols

I_i: current of the branch i
I_{irated}: rated current of the branch i
$I_k^{"}$: initial symmetrical short-circuit current
I_{rG}: rated current of the PV unit
P_{loss}: active losses

Q_{loss}: reactive losses
SCL: short-circuit level
SCL_{max}: maximum short-circuit level
SCL_{rated}: short-circuit level network design value
U_i: voltage value in the node *i*
U_N: nominal voltage value
U_{maxi}: maximum voltage value in the node *i*
$U_{max,maxi}$: absolutely maximum node voltage value in the node *i*
U_{mini}: minimum voltage value in the node *i*
$U_{min,mini}$: absolutely minimum node voltage value in the node *i*

REFERENCES

[1] T. Ackermann, G. Andersson and L. Soder, "Distributed Generation: A Definition," *Electric Power Systems Research*, Vol. 57, No. 3, 2001, pp. 195-204. http://dx.doi.org/10.1016/S0378-7796(01)00101-8

[2] A. Wallace and G. Harrison, "Planning for Optimal Accommodation of Dispersed Generation in Distribution Networks," *Proceedings of the CIRED 17th International Conference on Electricity Distribution*, Barcelona, May 2003, 6 p.

[3] A. Bhowmik, A. Maitra, S. M. Halpin and J. E. Schatz, "Determination of Allowable Penetration Levels of Distributed Generation Resources Based on Harmonic Limit Considerations," *IEEE Transactions on Power Delivery*, Vol. 18, No. 2, 2003, pp. 619-624. http://dx.doi.org/10.1109/TPWRD.2003.810494

[4] A. Keane and M. O'Malley, "Optimal Allocation of Embedded Generation on Distribution Networks," *IEEE Transactions on Power Systems*, Vol. 20, No. 3, 2005, pp. 1640-1646. http://dx.doi.org/10.1109/TPWRS.2005.852115

[5] G. Celli, E. Ghiani, S. Mocci and F. Pilo, "A Multi-Objective Evolutionary Algorithm for the Sizing and Siting of Distributed Generation," *IEEE Transactions on Power Systems*, Vol. 20, No. 2, 2005, pp. 750-757. http://dx.doi.org/10.1109/TPWRS.2005.846219

[6] G. N. Koutroumpezis, A. S. Safigianni, G. S. Demetzos and J. G. Kendristakis, "Investigation of the Distributed Generation Penetration in a Medium Voltage Power Distribution Network," *International Journal of Energy Research*, Vol. 34, No. 7, 2010, pp. 585-593.

[7] G. N. Koutroumpezis and A. S. Safigianni, "Optimum Allocation of the Maximum Possible Distributed Generation Penetration in a Distribution Network," *Electric Power Systems Research*, Vol. 80, No. 12, 2010, pp. 1421-1427. http://dx.doi.org/10.1016/j.epsr.2010.06.005

[8] B. Kuri, M. Redfern and F. Li, "Optimization of rating and positioning of dispersed generation with minimum network disruption," *Proceedings of the IEEE Power Engineering Society General Meeting*, Denver, June 2004, pp. 2074-2078.

[9] K. Nara, Y. Hayashi, K. Ikeda and T. Ashizawa, "Application of Tabu Search to Optimal Placement of Distributed Generators," *Proceedings of the IEEE Power Engineering Society Winter Meeting*, 2001, pp. 918-923.

[10] G. Celli and F. Pilo, "Optimal Distributed Generation Allocation in MV Distribution Networks," *Proceedings of the 22nd IEEE PES International Conference on Power Industry Computer Applications PICA*, Sydney, 20-24 May 2001, pp. 81-86.

[11] K. H. Kim, Y. J. Lee, S. B. Rhee, S. K. Lee and S. K. You, "Dispersed Generator Placement Using Fuzzy-GA in Distribution Systems," *Proceedings of the IEEE Power Engineering Society Summer Meeting*, Chicago, 21-25 July 2002, pp. 1148-1153. http://dx.doi.org/10.1109/PESS.2002.1043458

[12] W. El-Khaltam, K. Bhattacharya, Y. Hegazy and M. M. A. Salama, "Optimal Investment Planning for Distributed Generation in a Competitive Electricity Market," *IEEE Transactions on Power Systems*, Vol. 19, No. 3, 2004, pp. 1674-1684. http://dx.doi.org/10.1109/TPWRS.2004.831699

[13] http://www.neplan.ch/html/e/e_home.htm

[14] European Norm EN 50160: Voltage Characteristics of Electricity Supplied by Public Distribution Systems, *CENELEC*, 1999.

[15] S. A. Papathanassiou, "A Technical Evaluation Framework for the Connection of DG to the Distribution Network," *Electric Power Systems Research*, Vol. 77, No. 1, 2007, pp. 24-34. http://dx.doi.org/10.1016/j.epsr.2006.01.009

[16] Technical Requirements for the Connection of Independent Generation to the Grid, Public Power Corporation (PPC), Greece, 2004.

[17] IEC 60909-0: Short-Circuit Currents in Three-Phase a.c. Systems, Parts 0-4, 2002.

[18] T. Boutsika and S. A. Papathanassiou, "Short Circuit Calculations in Networks with Distributed Generation," *Electric Power Systems Research*, Vol. 78, No. 7, 2008, pp. 1181-1191. http://dx.doi.org/10.1016/j.epsr.2007.10.003