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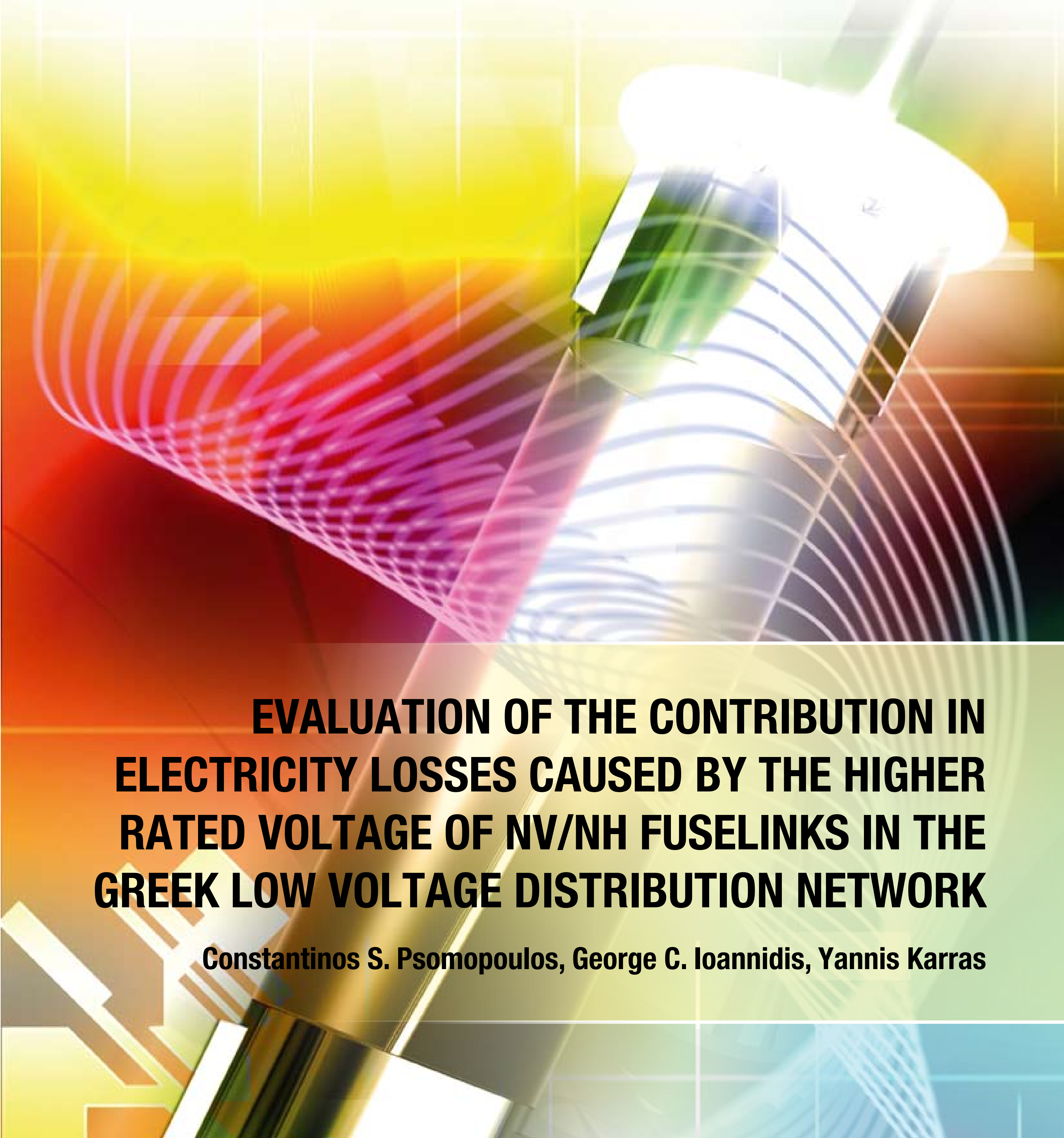

EVALUATION OF THE CONTRIBUTION IN ELECTRICITY LOSSES CAUSED BY THE HIGHER RATED VOLTAGE OF NV/NH FUSELINKS IN THE GREEK LOW VOLTAGE DISTRIBUTION NETWORK

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Evaluation of the contribution in electricity losses caused by the higher rated voltage of NV/NH fuselinks in the greek low voltage distribution network

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Abstract

The Public Power Corporation (PPC), operator of the Greek low voltage electricity distribution network still does not accept LV NH fuses with rated voltage 400VAC which is the network's nominal operating voltage. Based on a rather old internal standard (a PPC 's standard of 1975), PPC is using fuses with 500V AC rated voltage and rejects the fuses with 400V rated voltage. This work is aiming to evaluate the reduction of the low voltage network losses in case that PPC used fuses with rated voltage 400VAC instead of 500-690VAC. The evaluation was based on statistical data since there are no records about the actual number per size of installed fuses, or the average load per fuse. Even though the evaluation presents an uncertainty, the results showed that the electricity losses reduction is not negligible and the use of fuses with rated voltage of 400V instead of 500-690V will increase the network's efficiency.

Keywords: high-breaking-capacity fuse links, fuses rated voltage, power dissipation, power distribution losses, efficiency in electricity distribution.

1. Introduction

Low voltage (LV) high-breaking-capacity (HRC or most commonly NH) fuse links are mainly used to protect the LV electrical installations of the LV electricity distribution networks, public and private, as well as a significant amount of LV electrical equipment used in industrial, commercial and residential facilities and infrastructures. Being a typical electric device, a fuse is consuming energy which is transformed into heat as long as current flows through its body [1-4]. This power consumption should not exceed specific values depending on the type and fuse's rated voltage, as per IEC 60269-2:2006 [5]. As it can be found in the technical data sheets, the higher the rated voltage is, the higher the fuses' power losses are. It is also true that the previous mentioned consumption or power dissipation, as it is also called, is also increased following the rated current of the fuse link [6-9].

Furthermore, since this consumption is converted into thermal energy, high temperatures are developed inside the IP54 or IP55 enclosures in which the fuses are installed. These high temperatures also affect other electrical equipment's operation in case they are installed in the same enclosure [1-4,5]. The aforementioned overheating problem, which also affects the fuses behaviour, was one of the reasons that electricity distribution companies, nowadays, prefer to use fuses with rated voltage equal to their network's rated voltage [2-4,8,10,11].

In Greece, the Public Power Corporation (PPC) which has the operation of the Greek low voltage electricity distribution network still does not accept LV NH fuses with rated voltage 400VAC which is the network's nominal operation value. Based on a rather old internal standard (a PPC 's standard of 1975), the PPC is using fuses with 500V AC rated voltage in the Greek network and rejects the fuses with 400V rated voltage [12].

In this paper an attempt is made to evaluate the reduction of the low voltage network losses in case that PPC uses fuses with rated voltage 400VAC instead of 500-690VAC. This evaluation was based on statistical data since there are no records about the actual number per size of installed fuses, or the average load per fuse. Even though the evaluation presents an uncertainty, the results showed that the electricity losses reduction is not negligible and the use of fuses with rated voltage of 400V instead of 500-690V will probably affect positively the network efficiency.

2. Electricity Losses in Distribution Networks

Total system losses are the difference between the energy purchased (or produced) and the energy delivered (or sold) to end users. Losses can come from two sources: 1) technical losses, those that result from the heating of conductors and coils and from the excitation of the windings of transformers and other devices, and 2) nontechnical losses, those associated with inadequate or missing revenue metering, with problems with billing and/or collection systems, and/or with consumer pilferage [11, 13-15].

There are two sources of technical losses: a) the load losses, consisting of the I^2R and I^2X losses in the series impedances of the various system elements (e.g., lines and transformers); when the system is unloaded (i.e., I=0), the load losses are obviously nonexistent and b) the no-load losses, which are independent of the actual load served by the system. The majority of the no-load losses are due to the transformer core losses resulting from the excitation current [3, 4, 10, 11, 14,15].

There are both capacity (or demand) losses and energy losses. Capacity losses contribute to the system peak load demand, while energy losses increase the electricity requirements of the system load. Both capacity and energy losses can be subdivided into their active and reactive elements [11,14,15].

Electricity networks allow many diverse points of demand to share access to many generators, thus reducing the cost of the overall system and increasing the security of supply [3,4]. However, an electricity network loses a proportion of the electrical energy passing through it before that energy can be delivered to customers. Energy losses are not measured directly, but calculated in their most simple definition as the difference between electrical energy entering and exiting (distributed by) the network [11, 14, 15].

Losses are a combination of physical technical losses (resistive and transformer losses) and commercial non-technical losses. The non-technical losses include theft and systematic errors in metering, settlements or billing. In some countries, the non-technical losses are likely to dominate the overall losses figure [11, 16]. Losses can be subdivided according to whether or not they depend on power flow. The 'iron' losses in transformers do not vary with power flow, so are considered 'fixed' for a given network. Non-technical losses are likely to be relatively insensitive to total power or energy demands, so can also be classed as 'fixed'. In contrast, the resistive losses vary as the square of the power flow. Thus, electricity transmission and distribution at peak periods lead to a higher loss of power, and over time contributed is proportionately to the variable component of energy losses [10,11]. Any strategy to reduce losses is an opportunity to reduce the environmental impact of the electricity supply system [10, 11, 16, 17].

Figure 1 presents the average transmission and distribution power losses components in European networks. These components include technical and non – technical losses, as these were described above [11].

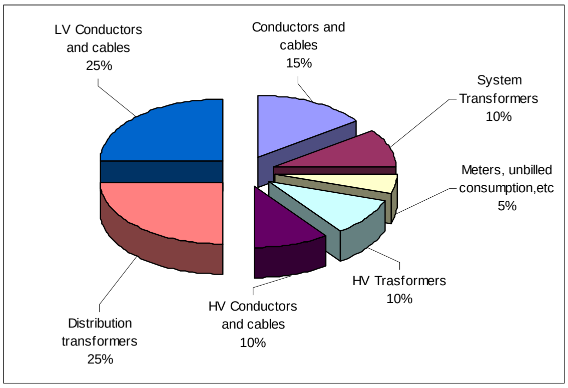

Fig. 1: Transmission and distribution power losses' components in European Networks (average estimations by MMA).

3. The Greek Distribution Network

According to Law 2773/1999, Public Power Corporation through the Distribution Unit constitutes the only power supplier in Greece while acts as the Operator of the Distribution Network. The Distribution Unit is responsible for the power distribution within the whole Greek territory, not only to the interconnected system area but also to the non-interconnected islands. The energy is received from the Transmission Network providing the possibility to supply all Network users with the energy needed [12].

The Greek distribution network is a typical European one. The main quantitative figures of Distribution network for the year 2009 were as follows [12]:

- 7,554,289 Customers (9,772 MV - 7,544,517 LV)
- 47,186 GWh consumptions (11,725 in MV and 35,461 in LV). High voltage consumptions and network leakages are not included.
- 104,415 km Medium Voltage Network (M.V.),
- 117,657 km Low Voltage Network (L.V.)
- Total 227,072 km of Network
- Annual increase of network length up to 1.87%, that is, 4,074 km of Network.
- 149,178 MV/LV Substations Annual increase of 2.23%, that is, 3,254 of new Substations
- 205 km of HV Network and 14 HV/MV Substations in Attica.

Table 1 presents the quantities of transformers used per type of substations in Greece according to 2009 inventory data of PPC. Table 2 shows the number of feeders per size of transformer used by PPC-Distribution Unit, as these were standardized by their internal orders. Depending on the feeding loads the number of feeders could be different than the ones shown on Table 2 [12].

Table 1. Transformers' quantities installed in MV/LV substations in 2009, per substation type.

Transformers in outdoor substations installed over poles (one or two poles)		**Transformers in other type substations (compact type, indoor installed, or installed in ground level)**	
Rated Power (kVA)	**Quantity (pcs)**	**Rated Power (kVA)**	**Quantity (pcs)**
15	38	15	1
25	2,427	25	0
50	38,228	50	8
75	4,291	75	1
100	34,528	100	3
150	3,962	150	1
160	27,394	160	6
200	363	200	2
250	20,000	250	42
300	1	300	10
400	8,630	400	171
500	95	500	206

600	5	600	445
630	1,933	630	6,468
750	0	750	25
1000	10	1000	1,010
20,527,800	141,905	5,557,790	8,399

Table 2. Standardized number of feeders per transformers' size used by PPC-Distribution Unit.

Rated Power (kVA)	**Standard number of feeders**
15 ÷ 25	1
50	3
75	2 or 4
100	2 or 4
150 or 160*	4
250*	4
400*	6
630*	8
1000	12

* : The rated power values of 200kVA, 500kVA, 600kVA and 750kVA, corresponds to existing transformers on the distribution network. These units are old (over 10 years), while in the new order PPC – Distribution Unit orders standard sizes: 160kVA, 250kVA, 400kVA, 630kVA and 1000kVA.

Figure 2 presents a typical low voltage panel configuration used in the Greek Distribution Network. Typically the low voltage panels of every MV/LV substation, constitutes of a number of 3phase LV feeders protected by High Breaking Capacity fuses (NH-fuses). The usual configuration includes one main switching device for protection of the main panel and an odd number of feeders, five or seven most commonly, with rated currents of 160A, 250A, 315A, 400A usually [10,12].

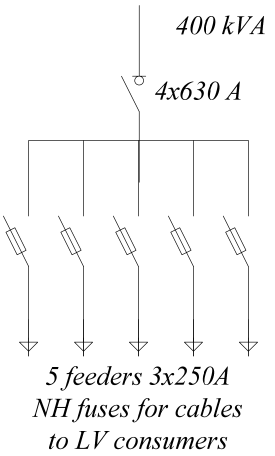

Fig. 2: Typical low voltage panel configuration used by Distribution Unit of PPC (400kVA transformer, 1 3ph disconnector of 630A, 5 3ph rail type fuse-disconnectors of 250A).

Table 3. NH Fuses' quantities used by PPC-Distribution Unit for 3 years (2007 to 2009)

NH Fuses	**Quantities used in the years 2007-2009**
size 1 63A	12,000
size 1 80A	38,000
size 2 63A	21,000
size 2 80A	18,000
size 2 100A	91,000
size 2 125A	88,000
size 2 160A	76,000
size 2 200A	53,000
size 2 250A	111,000
size 2 315A	24,000
size 2 400A	3,600

The most common magnitude of NH fuses used by PPC-Distribution Unit are "size 2" 250A/500V, 100A/500V, 125A/500V and 150A/500V. Table 3 presents the quantities used by PPC-Distribution Unit for 3 years (2007 to 2009), during scheduled maintenance procedures or after short-circuits. These data was given by the commercial department of ELMA N. Karras S.A. for the aforementioned years.

Figure 3 presents the transmission and distribution losses in Greece, over the last years, and figure 4 the losses as a percentage of the final electricity consumption. As it can be seen, the network losses are increasing through out the years, following the increment of power consumption. It can also be noted that these losses are decreasing in the last three years [16].

In recent years the network's losses seem to become stable around 8% which is close to the EU – 15 mean value of 7%. One important reason is that the main power production units of Greece are lignite fired plants (over 45% the last years, over 60% 15 years ago), and are located near by the existing lignite fields. These fields are located in two areas, one north, in Western Macedonia, where the major lignite mines are operating and one in the south, in Megalopoli – Peloponnese, where the other big lignite mine is operating [12,16].

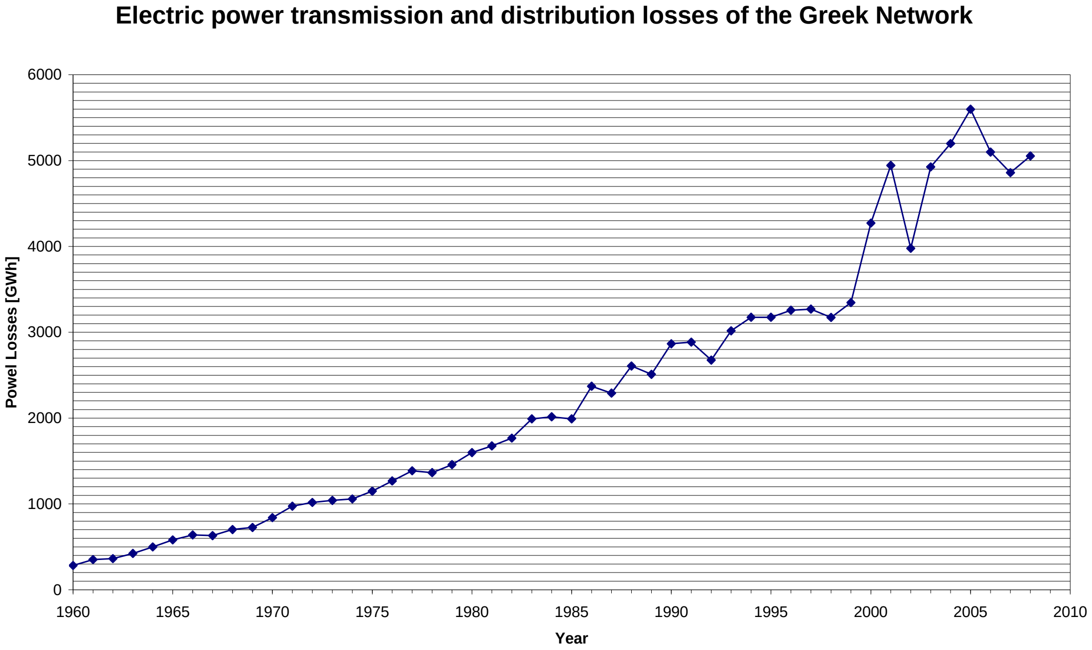

Fig. 3: Transmission and distribution losses of the Greek network for the last fifty years' period.

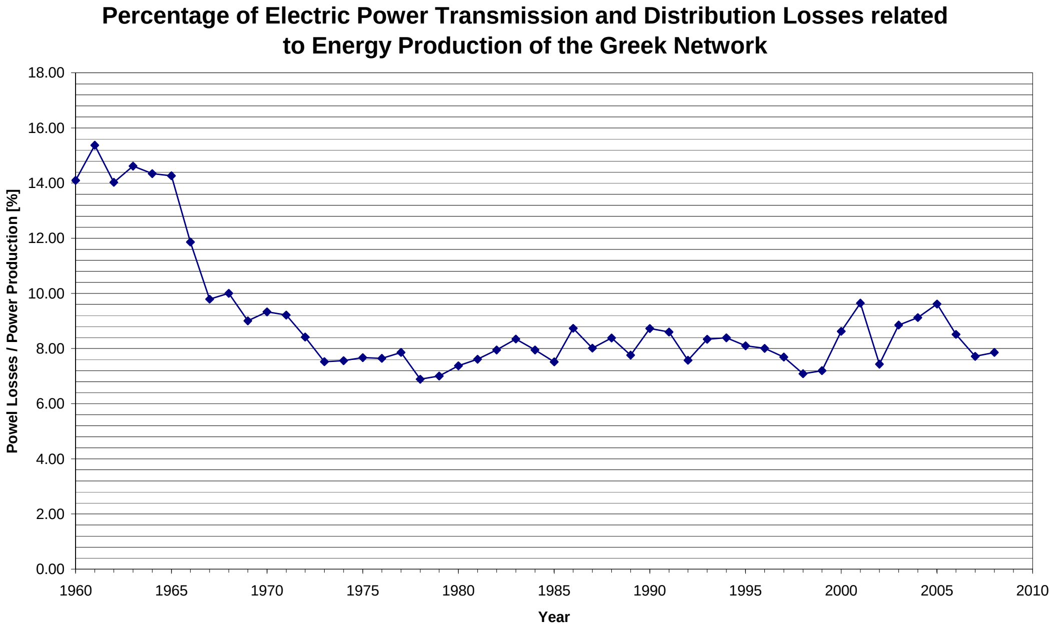

Fig. 4: Transmission and distribution losses of the Greek network as a percentage of the electricity production by for the last fifty years' period.

4. NH-fuses Power Dissipation Evaluation

Fuse, like any other overcurrent protective device, is installed in a circuit and it is flown by the circuit's current. The fuse-elements usually consist of metallic strips with restrictions that melt by electric heat at a certain current value [1,2]. It is obvious that the fuse-element presents electric resistance and hence Joule heating when a current flow through it. Fuse operation is based on a defined temperature rise and melting of the fuse-element by electric heat. The heating process requires electric energy that will be dissipated to the environment [1,2,9, 18-21]

This energy is considered as power loss and is included in the low voltage distribution network, by network operators. This power loss is non-metered energy, but on the other hand is a physical necessity for the fuse operation, and the fuse design engineers have to balance the speed of current interruption against power losses under normal load and design parameters [2,9,19,20]. The common used term "power dissipation" describes fuses power losses under nominal loads [2,9].

Table 4. NH Fuses' maximum permissible "power dissipation" according to IEC60269-2:2006

gG						
Size	**400 V a.c.**		**500 V a.c.**		**690 V a.c.**	
	In A	**Pn W**	**In A**	**Pn W**	**In A**	**Pn W**
000	100	5.5	100	7.5	63	12
00	160	12	160	12	100	12
0	160	12	160	16	100	25
1	250	18	250	23	200	32
2	400	28	400	34	315	45
3	630	40	630	48	500	60
4	-	-	1000	90	800	90
4a	1250	90	1250	110	1000	110

The international standards and mainly the IEC60269-2:2006 determine the maximum permitted values of the rated "power dissipation P_n per size and nominal current value. For the "gG" fuses, which are the most common ones in the distribution networks, table 4 present these maximum values for selected sizes and nominal current values [5]. As it can be seen this values could be considered small ones for a single fuse. Furthermore, considering that most of the time the current flow is small comparing to the nominal one, it can be easily concluded that this consumption is usually very small, and occasionally reaches zero (when the circuit 's current is zero) [1,2]. But considering the number of the installed fuses this small consumption seems that should not be neglected. In following paragraphs this will be proven and the current flowing through the fuse will be also considered.

For the evaluation of the power dissipation of the fuses under lower current flow, the following equation could be considered, based on the existing literature [3,4,10]:

$$P = P_n \left(\frac{I_b}{I_n} \right)^2 \qquad (1)$$

where :

P is the actual power loss;

P_n is the rated power loss (at I_r)

I_b is the actual current

I_r is the rated current

Based on this equation, figure 5 presents the power losses versus the actual current for two selected fuse cases. Table 5 presents the values of power dissipation as these are presented in the official data sheets of fuse manufacturers. As it can be seen, the power dissipation of fuses is increasing as the nominal operating voltage is increasing. For the lower nominal current and the small sizes these differences are very small, but as the nominal current or the size is increased the difference is increasing significantly [6,7].

Table 5. NH Fuses' "power dissipation" (data from a fuse manufacturer) for the fuses used by PPC – Distribution Unit.

Size	**In (A)**	**400V Pn (W)**	**500V Pn (W)**	**690V Pn (W)**
1	63	5.1	5.5	6.9
1	80	5.4	7.2	8.9
2	63	5.7	5.5	6.88
2	80	6.4	7.1	8.91
2	100	7.6	8.1	10.5
2	125	8.7	9.5	12.7
2	160	12.3	14.9	15.3
2	200	13.5	16.9	18.5

2	250	17.6	21.8	23.3
2	315	21.9	23.7	29.5
2	400	26.3	30.5	38.2

Based on the above figures, the power losses of the fuses in the electrical network have a wide variation depending on the nominal operating voltage, the load and the number of fuses installed. For the case under examination, since there are no records available to make accurate calculations, the evaluation of the magnitude of power losses will be estimated based on the following considerations:

1. The volume of fuses installed in the Greek distribution network will be estimated using the combination of the data presented in Tables 1 and 2, considering the lowest values. These results can be seen in table 6.
2. The volume of fuses per size and rated current can be estimated considering the data presented in Table 3. These results are presented in table 7.

Table 6. Evaluation of the NH Fuses' installed in the Greek Distribution Network.

Transformers installed in the Greek Distribution Network		**Circuits Feed by Fuses**	
Rated Power (kVA)	**Quantity (pcs)**	**Number of 3 phase Circuits per Transformer**	**Fuses Quantity (pcs)**
15	39	1	117
25	2,427	1	7,281
50	38,236	3	344,124
75	4,292	3	38,628
100	34,531	3	310,779
150	3,963	4	47,556
160	27,400	4	328,800
200	365	4	4,380
250	20,042	4	240,504
300	11	4	132
400	8,801	6	158,418
500	301	6	5,418
600	450	8	10,800
630	8,401	8	201,624
750	25	8	600
1000	1,020	12	36,720
26,085,590	150,304		1,735,881

Since there are no records for the actual current flowing from each 3 phase feeder protected by fuses, the evaluation of these increased losses will be done based on the estimations of table 7, considering the number of fuses per size and rated current installed in the Greek Distribution Network, and typical values for average load factor of the Network. The average load factor multiplied with the rated current will be considered as the actual current flowing through the fuse. This value will be used in the equation (1) in order to evaluate the power dissipation of each fuse for the cases of fuses with rated voltage 400V and 500V. The power dissipation value under rated current was the one mentioned in Table 5. The results of the evaluation can be seen in tables 8, 9 and 10, for average load factors m=0.30, m=0.45 and m=0.65 respectively.

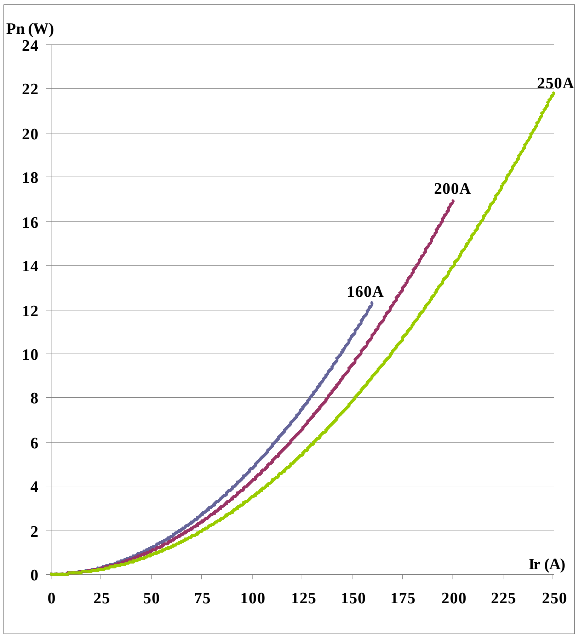

Fig. 5: NH-Fuses power dissipation related to the actual current, for rated current 160A, 200A, 250A.

Table 7. Evaluation of the NH Fuses' installed in the Greek Distribution Network per size and rated current.

NH Fuses	**Quantities per size and rated current**
size 1 63A	38,892

size 1 80A	123,158
size 2 63A	68,061
size 2 80A	58,338
size 2 100A	294,931
size 2 125A	285,208
size 2 160A	246,316
size 2 200A	171,773
size 2 250A	359,751
size 2 315A	77,784
size 2 400A	11,668

Table 8. Evaluation of the increment of the power losses due to higher nominal voltage of NH Fuses' installed in the Greek Distribution Network per size and rated current, for average load factor m=0.30.

Size	In (A)	m=0.30 Ir (A)	400V Pn (W)	500V Pn (W)	ΔPn (W)	ΣΔPn (kW)
1	63	18.9	0.46	0.50	0.04	1.40
1	80	24.0	0.49	0.65	0.16	19.95
2	63	18.9	0.51	0.50	-0.02	-1.23
2	80	24.0	0.58	0.64	0.06	3.68
2	100	30.0	0.68	0.73	0.05	13.27
2	125	37.5	0.78	0.86	0.07	20.53
2	160	48.0	1.11	1.34	0.23	57.64
2	200	60.0	1.22	1.52	0.31	52.56
2	250	75.0	1.58	1.96	0.38	135.99
2	315	94.5	1.97	2.13	0.16	12.60
2	400	120.0	2.37	2.75	0.38	4.41
Total NH-fuses Increment in Power Dissipation with load factor m=0.30						***320.81***

Table 9. Evaluation of the increment of the power losses due to higher nominal voltage of NH Fuses' installed in the Greek Distribution Network per size and rated current, for average load factor m=0.45.

Size	In (A)	m=0.45 Ir (A)	400V Pn (W)	500V Pn (W)	ΔPn (W)	ΣΔPn (kW)
1	63	28.35	1.03	1.11	0.08	3.15
1	80	36.00	1.09	1.46	0.36	44.89
2	63	28.35	1.15	1.11	-0.04	-2.76
2	80	36.00	1.30	1.44	0.14	8.27
2	100	45.00	1.54	1.64	0.10	29.86
2	125	56.25	1.76	1.92	0.16	46.20
2	160	72.00	2.49	3.02	0.53	129.69
2	200	90.00	2.73	3.42	0.69	118.27
2	250	112.50	3.56	4.41	0.85	305.97
2	315	141.75	4.43	4.80	0.36	28.35
2	400	180.00	5.33	6.18	0.85	9.92
Total NH-fuses Increment in Power Dissipation with load factor m=0.45						***721.82***

As it can bee seen from these tables the increment in the distribution losses cannot be neglected even in small network loads, like the ones represented by an average load factor m=0.30. In that case the distribution network losses are increased by 320.81kW and if a higher average load factor is considered, such as m=0.45, then these losses are increased significantly to 721.82kW. If the average load factor is even higher, like m=0.65, then the increment is higher reaching 1506kW. These differences correspond to significant power losses if the operating hours under these conditions are included in the calculations. The resulting values for the energy losses are as follows:

- m=0.30, ΔPn=320.81kW and energy losses E=320.81kW x 8760h = 2.81GWh
- m=0.45, ΔPn=721.82kW and energy losses E=721.82kW x 8760h = 6.32GWh
- m=0.65, ΔPn=1506.01kW and energy losses E=1506.01kW x 8760h = 13.19GWh

Table 10. Evaluation of the increment of the power losses due to higher nominal voltage of NH Fuses' installed in the Greek Distribution Network per size and rated current, for average load factor m=0.65.

Size	In (A)	m=0.65 Ir (A)	400V Pn (W)	500V Pn (W)	ΔPn (W)	ΣΔPn (kW)
1	63	40.95	2.15	2.32	0.17	6.57
1	80	52.00	2.28	3.04	0.76	93.66
2	63	40.95	2.41	2.32	-0.08	-5.75
2	80	52.00	2.70	3.00	0.30	17.25
2	100	65.00	3.21	3.42	0.21	62.30
2	125	81.25	3.68	4.01	0.34	96.40

2	160	104.00	5.20	6.30	1.10	270.58
2	200	130.00	5.70	7.14	1.44	246.75
2	250	162.50	7.44	9.21	1.77	638.38
2	315	204.75	9.25	10.01	0.76	59.15
2	400	260.00	11.11	12.89	1.77	20.70
Total NH-fuses Increment in Power Dissipation with load factor m=0.65						***1506.01***

The results even though present inaccuracy due to the lack of measured values of the loading curves for each feeder in the low voltage distribution network of Greece, clearly show that the procurement policy followed by the PPC – Distribution Unit for the NH-fuses, correspond to higher power losses which cannot be neglected. It is rather obvious that the PPC-Distribution Unit should replace the old internal PPC standard No 75, which rejects fuses with rated voltage of 400V, and replace gradually all installed fuses with rated voltage of 500V and 690V with new ones having 400V rated voltage in order to reduce the distribution network's losses and increase its efficiency. In this way, as it has already been stated before, the equipment installed in the same panels with fuses will suffer less thermal stress as the NH-fuses will produce less thermal power. This will affect positively the operation of the whole equipment installed in the panel and reduced consequently the faults related to thermal stress. Furthermore, as it is well known, the life expectancy of the equipment and especially the insulations will not be reduced.

5. Conclusions

In this paper the potentially reduction of power losses in the Greek low voltage distribution network is explored. Fuses due to their operating characteristics present power losses widely known as "power dissipation". One important parameter that affects the volume of losses is the rated voltage. The higher the operating voltage is the higher the losses are. The low voltage power distribution network and especially the distribution power lines is the main application of NH fuses. In every distribution network several hundreds of thousands NH-fuses are installed and operating continuously. In Greece, the PPC utilizes 500 V or even 690V fuses for the 400V low voltage network, rejecting the 400V counterparts according to an old internal standard. This practise is directly related with increased power losses as it can be seen from presented results. Due to lack of accurate data concerning the actual number per size of installed fuses and the average load per fuse, the analysis is based on statistical data. Although this approach is not very accurate, shows clearly that the power losses of the low voltage distribution network can be sufficiently reduced and thus improving its capacity. Therefore, it is suggested that the Distribution Unit of PPC should reject its old internal standard and proceed as the other Electric Power Distribution Companies in EU Member States to accept and widely utilise NH-fuses with rated voltage of 400V.

References

[1] Wright A., Newbery P.G.: "Electric fuses (2nd Edition)". London: IEE-Peter Peregrinus Ltd. 1995.

[2] Bessei H., Fuse Manual. NH-HH-Recycling e.V., Frankfurt, 2007.

[3] ABB : "Electrical Installation Handbook, Protection, control and electrical devices, (6th Edition)", ABB SACE, 2010

[4] Schneider Electric SA, 2007. "The Electrical Installation Guide". ed., Les Deux Ponts, France, September 2007

[5] IEC60269-1,2,3:2006

[6] http://www.etigroup.eu/electrotechnical_products.aspx

[7] http://www.ferrazshawmutsales.com/

[8] http://www.profuseinternational.com/

[9] Bessei H., *Power Dissipation of Fuses –afflicted with prejudice*, 2009. www.fuseXpert.de

[10] ABB Switchgear Manual, 11th Ed, 2006

[11] www.leonardo-energy.org

[12] http://www.dei.gr/

[13] González-Longatt F.M., "Impact of Distributed Generation over Power Losses on Distribution System", *9th ICEPQU*, Barcelona, 2007

[14] Dortolina C.A., Nadira R., "The Loss that is Unknown is No Loss At All: A Top-Down/Bottom-Up Approach for Estimating Distribution Losses", *IEEE Trans. Power Systems*, Vol. 20, No. 2, 2005,p.p.1119-1125.

[15] Nagendra Rao P. S., Deekshit R., "Energy Loss Estimation in Distribution Feeders", *IEEE Trans. Power Delivery*, vol. 21, No. 3, 2006, p.p.1092-1100

[16] http://data.worldbank.org/

[17] European Environmental Agency 2007. Europe's Environment, The 4th Assessment, Copenhagen.

[18] Chapman Alan J.: "Heat Transfer, 4th Edition". New York: Maxwell Macmillan International. 1989.

[19] Psomopoulos C.S. and Karagiannopoulos C.G. "Measurements of fusible elements during current interruption and interpretation of related phenomena", *Measurement,* (32), p.p.15-22, 2002.

[20] Psomopoulos C.S. and Karagiannopoulos C.G.: "Temperature distribution of fuse elements during pre-arcing period", *Elec. Pow. Syst. Res.*, 61, p.p.161-167, 2002.

[21] Reinhold Rüdenberg: Transient Performance of Electric Power Systems, M.I.T. Press, 1970.