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# NORMATIVE AND TEHNICAL ASPECTS CONCERNING REACTIVE POWER TARIFF SETTING

**Igor LUCINSCHI, Ion PĂDURARU**

*Technical University of Moldova, i_lucinschi@hotmail.com, ion_paduraru@mail.md*

***Abstract*** **– This paper analyses the importance of both neutral power factor and of reactive power reimbursement mechanism, taking into consideration specific features of this kind of power. Relevant power suppliers and consumers views are also analyzed with regard to their economic interests in a power market environment and with regard to their motivation to perform reactive power compensation.**
**An incentive for power consumers to reduce power networks losses resulting from reactive power traveling through these networks is the tariff paid for electricity consumed.**
**After analyzing the regulatory environment of Moldova's power industry, normative and technical aspects concerning reactive power tariff setting are presented below.**

***Keywords***: *reactive power, power factor, reactive power economic equivalent.*

## 1. INTRODUCTION

As incentive for consumers reducing electric networks power losses caused by reactive power circulation serves the electricity tariff. In order to make costs reflecting reactive power consumption signal to consumers, motivating them to invest into local reactive power production equipment, a correct assessment of real power network losses is necessary. And, to determine the real influence of active power consumption as a result of additional reactive power consumption as well as to exclude cross-subsidy, a complex study of reactive power tariff setting is also necessary.
Cross-subsidy, a heavily used (also in power industry) tariff policy instrument during planned economy period, became inefficient together with transition to new market reality [1].

## 2. REACTIVE POWER PAYMENT SYSTEM

The National Energy Regulatory Agency from the Republic of Moldova, for the purpose of motivating electricity consumers to maintain a steady power factor at their plants, has adopted "Instructions for calculation of technological consumption of electricity in distribution networks depending on the value of consumer's equipment power factor" [2]. The Instructions explains to electricity supplier the order and conditions for calculation of technological consumption of active power in distribution networks, depending on the power factor value at consumer's plants, stipulating that this amount is also billed to the consumer.
Thus, the supplier bills the technological consumption when during the billing period the power factor, *cos(φ)*, calculated in the point separating supplier's and consumer's power assets, is lower than 0.92 for consumer connected to 0.4 kV-voltage network, and lower than 0.87 for consumer connected to 6-10 kV-voltage network. The formula for calculating technological consumption billed to the customer is:

$$CT = kC \times \left(W_{rif} + W_{rcf}\right) \qquad (1)$$

Where:
*kC* – reactive to active power conversion coefficient; it represents specific increase of active power loss in the distribution network as a result of reactive power circulation (kWh/kVArh), *kC* = 0.1 kWh / kVArh;
$W_{rif}$ – inductive reactive power amount, for which technological consumption is billed;
$W_{rcf}$ – capacitive reactive power amount, injected from consumer's plant into distribution network, which is subject to billing when the consumer would not provide the regime necessary for the operation of reactive power compensating equipment and this regime was not metered.
In other words, additional consumption of reactive power (with *cos(φ)*=0.92 for consumers connected to 0.4 kV-voltage network and with *cos(φ)*=0.87 for consumer connected to 6-10 kV-voltage network) shall be billed a 10% value of the cost of active power, and this consumption of reactive power is measured in an equivalent amount of kWh.

## 3. NEUTRAL POWER FACTOR DETERMINATION

Own technological consumption shall be billed both in case of reactive power consumption from the distribution network and in case of injecting reactive power into the network by consumer's compensating equipment. And the power factor, *cos(φ)*, shall be

calculated for the separation point according to active and reactive power meters data, taking into consideration technical electricity losses in transformers, electric lines and connections situated between separation and electricity measuring point [2].
Based on the above, this paper presents an analysis regarding the variation of own technological consumption resulting from the variation of power factor in 10, 35, 110 kV voltage lines for different consumers supply conditions (line stretching, type of conductor, grid loading) while maintaining supplying voltage in admissible limits.
For radial networks a 0.9-0.65 power factor variation had been considered and for different voltages were chosen characteristic sections of consumer supplying conductors (respectively, the highest current allowed) and characteristic end connection lengths.
And in order to highlight the variation of own technological consumption due to power factor variation, constant active power consumption was considered for each analyzed option.
Based on information obtained for 10, 35, 110 kV network voltages, the relation ΔP/ΔQ towards *cos(φ)* variation is the following:

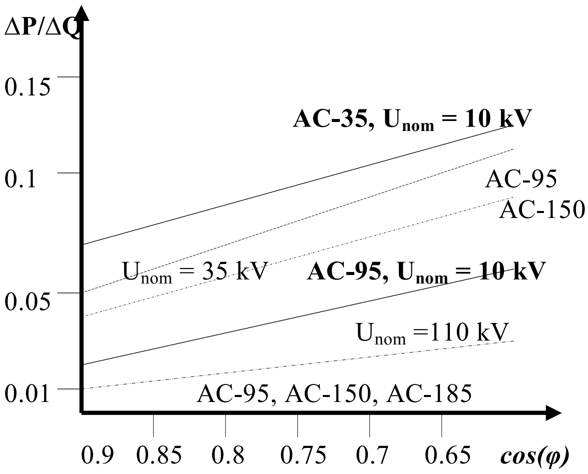


Figure 1: Relation ΔP/ΔQ towards cos(φ) variation

Given the fact that ΔP/ΔQ is influenced by neutral power factor, it is necessary to determine *cos($\varphi_n$)* values for different voltage levels. More than that, real *cos(φ)* for households is one of the reasons why it is necessary to determine the power factor for different voltage levels.

## 4. ACTIVE POWER CONSUMPTION RESULTING FROM ADDITIONAL REACTIVE POWER CONSUMPTION [3]

Below is presented the calculation method for determination of own real technological consumption happening when additionally circulating reactive power, for high voltage electric network (including 35 kV) and medium- and low voltage networks. Taking into consideration the fact that own technological consumption depending on the power factor needs to be outlined, the paper considers a constant consumption of active power for each option analyzed. The determination of this consumption of active power was done for the minimal power factor 0.65.
In order to determine the increase of technological consumption during power factor variation for high voltage networks and 35 kV networks, electric line voltage drops were not taken into account because calculations are made for the electric line and the transformer as a whole (Figure 2).
$P_{max}$ is the highest possible load assuring reliable functioning in real conditions of the power industry of the Republic of Moldova. The analysis was done for 100% and 50% transformer loading in order to determine exactly variation limits of the reactive power economic equivalent DP/DQ.

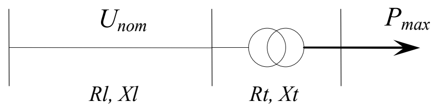


Figure 2: Calculation scheme for high voltage electric networks (including 35 kV)

Taking into consideration specific aspects of medium voltage electric networks (the existence of institutional transforming stations) and low voltage networks (huge variety of conductor sections and line lengths), for different voltages (10 kV and 0.4 kV) were chosen characteristic sections of consumer supplying conductors (respectively, the highest current allowed $I_{max}$) and characteristic end connection lengths (Fig. 3).

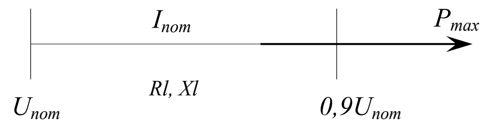


Figure 3: Calculation scheme for medium and low voltage electric networks

To determine the highest active power that can be transmitted through the line, longitudinal and transversal components of a voltage drop are used:

$$\Delta U_L = \frac{P_{\max} \cdot (R_l + 1{,}169 \cdot X_l)}{0{,}9 \cdot U_{nom}} \tag{2}$$

$$\Delta U_T = \frac{P_{\max} \cdot (X_l - 1{,}169 \cdot R_l)}{0{,}9 \cdot U_{nom}} \tag{3}$$

Line voltage drop is given by the following formula:

$$\Delta U^2 = \Delta U_L^2 + \Delta U_T^2 \tag{4}$$

$$U_{nom} = 0{,}9 \cdot U_{nom} + \Delta U \tag{5}$$

Taking into consideration (2), (3), (4), from (5) we have:

$$U_{nom}^2 = \left[0{,}9 \cdot U_{nom} + \frac{P_{\max} \cdot (R_l + 1{,}169 \cdot X_l)}{0{,}9 \cdot U_{nom}}\right]^2 + \left[\frac{P_{\max} \cdot (X_l - 1{,}169 \cdot R_l)}{0{,}9 \cdot U_{nom}}\right]^2 \tag{6}$$

From equation (6) is obtained the formula for calculating the highest active power $P_{max}$ that can be transmitted through the line. This load is highest possible for assuring normative voltage limits, including for *cos(φ)*=0.65. The ultimate value of the load is obtained after comparing the values of calculated- vs. highest allowed current.

$$I = \frac{\sqrt{P_{\max}^2 \cdot (1 + 1{,}169^2)}}{\sqrt{3} \cdot 0{,}9 \cdot U_{nom}} = \frac{P_{\max} \cdot \sqrt{1 + 1{,}169^2}}{\sqrt{3} \cdot 0{,}9 \cdot U_{nom}} \le I_{\max} \tag{7}$$

The reactive power economic equivalent DP/DQ shall be determined according to the following formulas:

- for high and medium voltage electric networks:

$$\frac{DP}{DQ} = \frac{\Delta P_{li} - \Delta P_{l(\cos(\varphi)=0,87)}}{Q_i - Q_{(\cos(\varphi)=0,87)}} \tag{8}$$

- for low voltage electric networks:

$$\frac{DP}{DQ} = \frac{\Delta P_{li} - \Delta P_{l(\cos(\varphi)=0,92)}}{Q_i - Q_{(\cos(\varphi)=0,92)}} \tag{9}$$

For different voltage levels, active power consumption resulting from additional reactive power consumption, expressed through reactive power economic equivalent is given in the following tables and figures.

The need to determine limit values of reactive power economic equivalent *DP/DQ* for 330 kV power network (PN) is due to the fact that not having sufficient generating capacity, the Republic of Moldova has to import around 75% of electricity used.

| DP/DQ | cos(φ) | 0,9 | 0,85 | 0,8 | 0,75 | 0,7 | 0,65 |
|---|---|---|---|---|---|---|---|
| PN | P | | | | | | |
| | 0,5P | | | | | | |
| PN330/110 kV | | - | 0,007 | 0,0078 | 0,0085 | 0,0094 | 0,0102 |
| | | - | 0,0035 | 0,0039 | 0,0043 | 0,0047 | 0,0051 |
| PN330/35(10) kV | | - | 0,0089 | 0,0099 | 0,0109 | 0,0119 | 0,013 |
| | | - | 0,0045 | 0,0049 | 0,0055 | 0,006 | 0,0065 |
| PN110/35 kV | | - | 0,0167 | 0,0186 | 0,0204 | 0,0224 | 0,0244 |
| | | - | 0,0084 | 0,0093 | 0,0102 | 0,0112 | 0,0122 |
| PN110/10 kV | | - | 0,0149 | 0,0166 | 0,0181 | 0,02 | 0,0218 |
| | | - | 0,0075 | 0,0083 | 0,0091 | 0,01 | 0,0109 |
| PN35/10 kV | | - | 0,0307 | 0,0341 | 0,0374 | 0,041 | 0,0448 |
| | | - | 0,0153 | 0,017 | 0,0187 | 0,0205 | 0,0224 |
| Open-air PN 10 kV | | - | 0,0751 | 0,0834 | 0,0913 | 0,1003 | 0,1093 |
| | | - | 0,0376 | 0,0417 | 0,0456 | 0,0502 | 0,0547 |
| Cable PN 10 kV | | - | 0,0698 | 0,0777 | 0,0853 | 0,0935 | 0,1021 |
| | | - | 0,0349 | 0,0388 | 0,0426 | 0,0468 | 0,0511 |
| Transformer PN 10/0,4 kV | | 0,075 | 0,0851 | 0,0946 | 0,1037 | 0,1141 | 0,1247 |
| | | 0,038 | 0,0425 | 0,0473 | 0,0519 | 0,0571 | 0,0624 |
| Open-air PN 0,4 kV | | 0,123 | 0,1401 | 0,1561 | 0,1722 | 0,1901 | 0,2087 |
| | | 0,061 | 0,0701 | 0,0781 | 0,0861 | 0,0951 | 0,1044 |
| Cable PN 0,4 kV | | 0,142 | 0,1621 | 0,1816 | 0,2002 | 0,2206 | 0,2422 |
| | | 0,071 | 0,0811 | 0,0908 | 0,1001 | 0,1103 | 0,1211 |

Table 1: Limit values of DP/DQ coefficient

| *DP/DQ* | *cos(φ)* | 0,9 | 0,85 | 0,8 | 0,75 | 0,7 | 0,65 |
|---|---|---|---|---|---|---|---|
| Voltage level | *P* | | | | | | |
| | *0,5P* | | | | | | |
| 110 kV | | - | 0,015 | 0,017 | 0,019 | 0,021 | 0,023 |
| | | - | 0,008 | 0,009 | 0,009 | 0,01 | 0,011 |
| 35 kV | | - | 0,016 | 0,018 | 0,02 | 0,022 | 0,024 |
| | | - | 0,008 | 0,009 | 0,01 | 0,011 | 0,012 |
| 10 kV | | - | 0,072 | 0,081 | 0,088 | 0,097 | 0,106 |
| | | - | 0,036 | 0,04 | 0,044 | 0,048 | 0,053 |
| 0,4 kV | | 0,132 | 0,151 | 0,169 | 0,186 | 0,205 | 0,225 |
| | | 0,066 | 0,076 | 0,084 | 0,093 | 0,103 | 0,113 |

Table 2: Limit values of DP/DQ coefficient for different voltage levels [4]

Table 2 presents limit values of reactive power economic equivalent *DP/DQ* for different voltage levels, at which consumers interested in a reactive power payment system are connected, based on regulation environment provided for power market players.

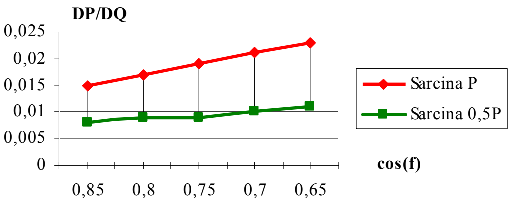


Figure 4: DP/DQ reactive power economic equivalent limits for 110 kV

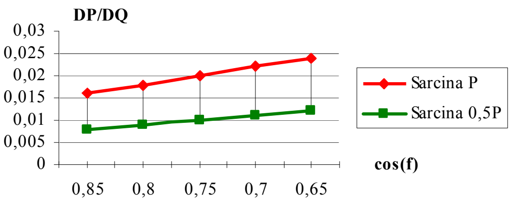


Figure 5: DP/DQ reactive power economic equivalent limits for 35 kV

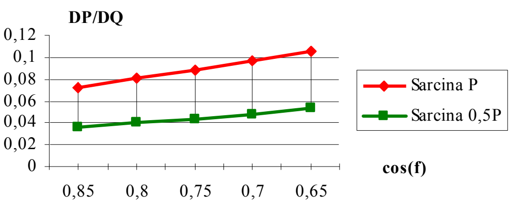


Figure 6: DP/DQ reactive power economic equivalent limits for 10 kV

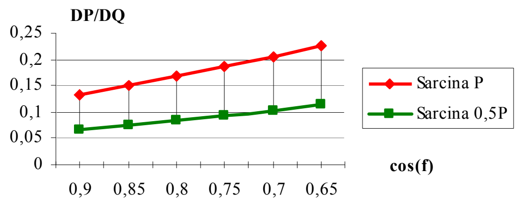


Figure 7: DP/DQ reactive power economic equivalent limits for 0.4 kV

## 5. CONCLUSIONS

Given the fact that ΔP/ΔQ is influenced by neutral power factor, there is necessary to determine *cos* $(\varphi_n)$ values for different voltage levels.

Calculations performed show that a consumer connected to a low voltage determines power losses of 0.16 kW/kvar, a consumer connected to a medium voltage - of 0.09 kW/kvar, and the consumer connected to high voltage - 0.015 kW/kvar.

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