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Loading three phased transformer following the quadergy

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Abstract. In this work, the authors propose a simple and fast method to establish the minimal real power for loading a three phased transformer of a specific power, such that power factor does not drop below a previously defined value. The method can be applied to transformers that are placed between a consumer's metering point and the electric power distribution network. In this situation, the billing energy and quadergy include the transformer energy and quadergy losses. This method establishes the moment where, due to low energy consumption, the transformer should be replaced with a lower power one, which still ensures the necessary energy for the consumers behind it. Our analysis has been done on a 100 kVA, an 80 KVA, and a 16 kVA transformer. Applying this method expedites the process of establishing the energy and the power factor where a transformer should be replaced by a lower power transformer, such that the power factor stays in acceptable ranges.

1. Introduction

Many economical units are connected to the electrical distribution network through 20 kV/0.4 kV transformers of various powers. As the electric load of these consumers varies irregularly, small energy loads appear, with negative technical effects (noise) [1] such that the associated quadergy causes a power factor below 0.65, having a negative impact on the consumed energy billing.

Most of the time, the metering point differs from the connection to the 20 kV energy network point, which is considered to be the billing point. In this situation, the specific legislation [2] establishes a methodology to compute the transformer energy and quadergy losses. Depending on the transformer's power, the bill will include energy and quadergy corrections, which, together with the metered energy, will make up the total sum for a given time period (usually a month).

When the metering point is not the same as the billing point [3], for a period of time, even though no energy consumption is registered, the energy bills include high energy and inductive quadergy correction values, as can be observed in Figure 1.

2. Theoretical Considerations on Correction Computations

According to Directive 24/2006 of the Romanian Energy Regulatory Authority (ANRE), when the metering point (PM) is different from the billing point (BP), and the meter can measure neither hourly energy consumption, nor the electric energy load curve, we have the following losses:

a. Constant energy losses, which can be:
- Electric energy ΔE_{ac}:

$$\Delta E_{ac} = P_0 \cdot T_f \quad \text{[kWh]} \tag{1}$$

- Electric quadergy ΔE_{rc}:

$$\Delta E_{rc} = \left(\frac{i_0\%}{100}\right) \cdot S_n \cdot T_f \quad \text{[kVArh]} \tag{2}$$

where P_0 [kW] stand for the transformer losses in the no-load operation state, T_f [h] is the time period for which the transformer is live, i_0% is the no-load operation current, and S_n [kVA] is the transformer's rated apparent output. For a consumer functioning without human staff, or for an automation equipment, we consider T_f 24 h (one day).

b. Variable energy losses, which can be:

- Electric energy ΔE_{av}:

$$\Delta E_{av} = P_{sc} \cdot \left(\frac{S_m}{S_n}\right)^2 \cdot \tau \quad \text{[kWh]} \tag{3}$$

- Electric quadergy ΔE_{rv}:

$$\Delta E_{rv} = \left(\frac{u_{sc}\%}{100}\right) \cdot \left(\frac{S_m}{S_n}\right)^2 \cdot S_n \cdot \tau \quad \text{[kVArh]} \tag{4}$$

where P_{sc} [kW] stand for the transformer losses in the short-circuit operation state, S_m [kVA] is the maximum apparent power, u_{sc}% is the short-circuit voltage, and τ [h] is the period on which the losses are computed, whose value is established by ANRE, depending on the number of functioning hours. During the short-circuit operation, even when very short, additional energy losses happen due to the high current values [4].

Specification	MU	Const	Read index 31.03.2018	Read index 01.03.2018	Quantity	Corrections BP ≠ MP	Other corrections	Measured quantity
Electric Energy	kWh	1	1685.8	1685.8	0	63	-	63
Inductive quadergy	kVArh	1	40.231	40.231	0	476	-	476
Capacitive quadergy	kVArh	1	57.493	55.314	2	-	-	2
			Inductive quadergy (kVArh)			**Capacitive quadergy (kVArh)**		
PF ≥ 0.90			0			0		
0.65 ≤ PF < 0.90			0			0		
PF < 0.65			445			0		

Figure 1. Energy corrections when the metered energies are zero

The consumer's power factor, φ_m, depends on the energy E_{am} and on the quadergy E_{rm} measured at the consumer location:

$$\cos\varphi_m = \frac{1}{\sqrt{1 + \left(\frac{E_{rm}}{E_{am}}\right)^2}} \tag{5}$$

To find the maximum apparent output, S_m, we must compute the maximum real output, P_m:

$$S_m = \frac{P_m}{\cos\varphi_m} = \frac{E_a}{\cos\varphi_m \cdot T_{sm}} \quad \text{[kVA]} \tag{6}$$

where T_{sm} is the duration use of the peak load whose value is established, depending on the number of operating hours, by the ANRE.

The energy and quadergy technical losses, ΔE_a and ΔE_a, show on the bills as corrections, are determined with the following equations:

$$\Delta E_a = \Delta E_{ac} + \Delta E_{av} \quad \text{[kWh]} \tag{7}$$

$$\Delta E_r = \Delta E_{rc} + \Delta E_{rv} \quad \text{[kVArh]} \tag{8}$$

All transformer losses can be determined already in the transformer design phase, during simulations of various regimes transformer operations [5-8].

The energy and quadergy which are used to compute the energy consumption at the billing point are computed using the following equations:

$$E_a = E_{am} + \Delta E_a \quad \text{[kWh]} \tag{9}$$

$$E_r = E_{rm} + \Delta E_r \quad \text{[kVArh]} \tag{10}$$

The lagging power factor at the delimitation point (including the transformer) is computed by:

$$\cos\varphi = \sqrt{\frac{1}{1+tg^2\varphi}} = \sqrt{\frac{1}{1+\left(\frac{E_r}{E_a}\right)^2}} \tag{11}$$

According the ANRE directives [2], [9] consumers pay the total capacitive quadergy, and for the inductive quadergy the consumers pay only the quantity that exceeds the power factor limit value at the delimiting point. The lagging power factor limit is 0.92 and the capacitive power factor limit is 1. When the consumer effects a power factor lower than 0.65, he will pay the rate difference between the recorded quadergy value and the value corresponding to the power factor limit value, multiplied by three. For lagging power factor values between 0.92÷0.65 the quadergy price rate is the one fixed by ANRE.

3. Case Study

In this work we analyse an industrial consumer where the metering point is different from the billing point, while at the consumer point an hourly time counter and a transformer with the following nominal values are installed:

- Nominal power S_n = 100 kVA;
- Primary rated voltage U_{1n} = 20 kV;
- Secondary rated voltage U_{2n} = 0.4 kV;
- Primary winding current flow I_{1n} = 20 A;
- Secondary winding current flow I_{2n} = 0.4 A.

According to ANRE directives [10] for this transformer type we have the following technical parameter values defined:

- No-load operation transformer losses P_0 = 0.6 kW;
- Short-circuit operation transformer losses P_{sc} = 2.76 kW;
- No-load operation current $i_0\%$ = 3.3;
- Short-circuit voltage $u_{sc}\%$ = 4;
- Loss computation time for a monthly continuous operation with 24 hours per day, τ = 203;

- Peak load use duration for a monthly continuous operation with 24 hours per day, $T_{sm} = 430$.

Table 1 presents the energy and quadergy values we measured, as well as their corrections according to the energy distribution provider bills.

Table 1. Power factor, energy and quadergy values, correction factors for 2008

Month	E_{am} [kWh]	ΔE_a [kWh]	E_{ar} [kVArh]	ΔE_r [kVArh]	Cos φ
Jan.2008	4268	451	301	2538	0.857
Feb.2008	2590	420	186	2370	0.762
Mar.2008	2385	448	263	2532	0.712
Apr.2008	2364	434	150	2451	0.732
May.2008	2576	449	406	2533	0.717
Jun.2008	1842	412	466	2450	0.612
Jul.2008	2504	448	913	2533	0.651
Aug.2008	2228	448	801	2532	0.626
Sep.2008	2086	433	872	2450	0.604
Oct.2008	2130	447	513	2532	0.646
Nov.2008	2060	434	507	2451	0.731
Dec.2008	1962	448	309	2531	0.647

Figure 2 shows the billed energy and quadergy variations and the power factor variations for 2008.

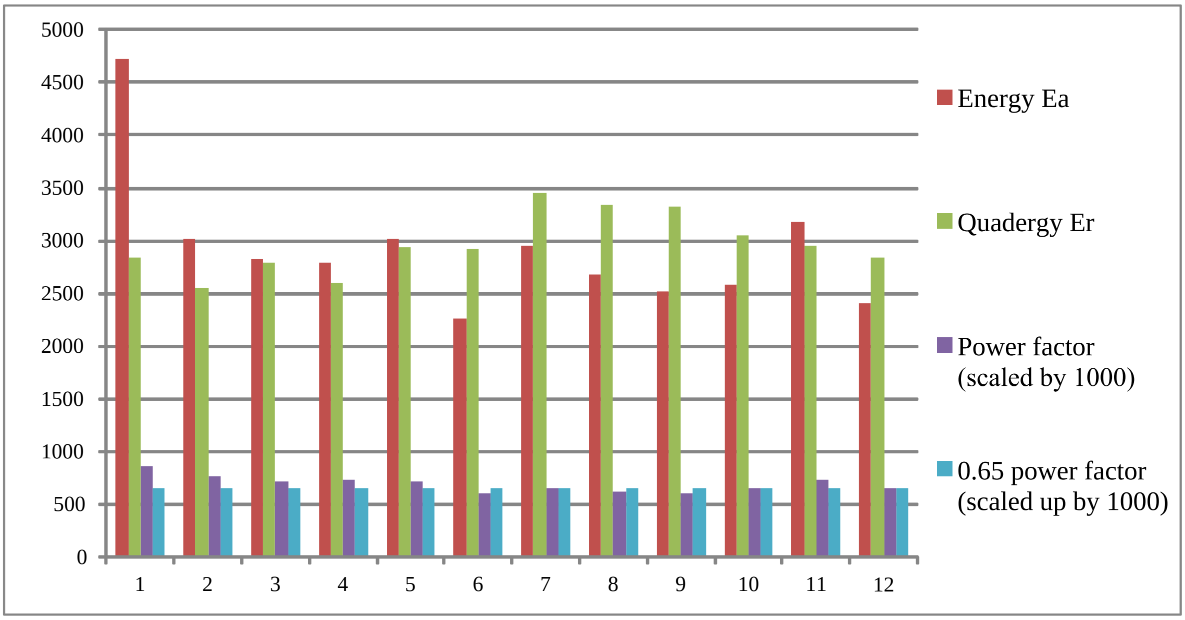

Figure 2. Billed energy and quadergy variations, power factors variations for year 2008

The power factor computed using equation (11) is scaled by a factor of 1,000 in order to represent it on the same coordinate system. On the same figure, scaled by a factor of 1,000 we show the 0.65 power factor where the quadergy is billed three times the regulated value.

We immediately notice that for June, August, September, October, and December the power factor value was below 0.65, which led to additional electricity costs.

To reduce these costs, the transformer was replaced with a 80 kVA apparent output transformer.

The measured energy and quadergy, as well as their corrections given by the electricity distribution provider are shown in Table 2.

Table 2. Power factor, energy and quadergy values, correction factors for 2012

Month	E_{am} [kWh]	ΔE_a [kWh]	E_{ar} [kVArh]	ΔE_r [kVArh]	Cos φ
Jan.2012	1859	0	69	0	0.999
Feb.2012	2092	261	63	1842	0.777
Mar.2012	1900	278	187	1968	0.711
Apr.2012	840	266	125	1902	0.479
May.2012	641	276	170	1965	0.395
Jun.2012	544	267	214	1901	0.358
Jul.2012	621	276	248	1965	0.376
Aug.2012	695	276	289	1965	0.396
Sep.2012	688	267	188	1901	0.416
Oct.2012	934	276	81	1965	0.509
Nov.2012	938	267	27	1902	0.530
Dec.2012	1350	276	25	1966	0.633

Figure 3 shows the energy and quadergy variations and the power factor variations for year 2012.

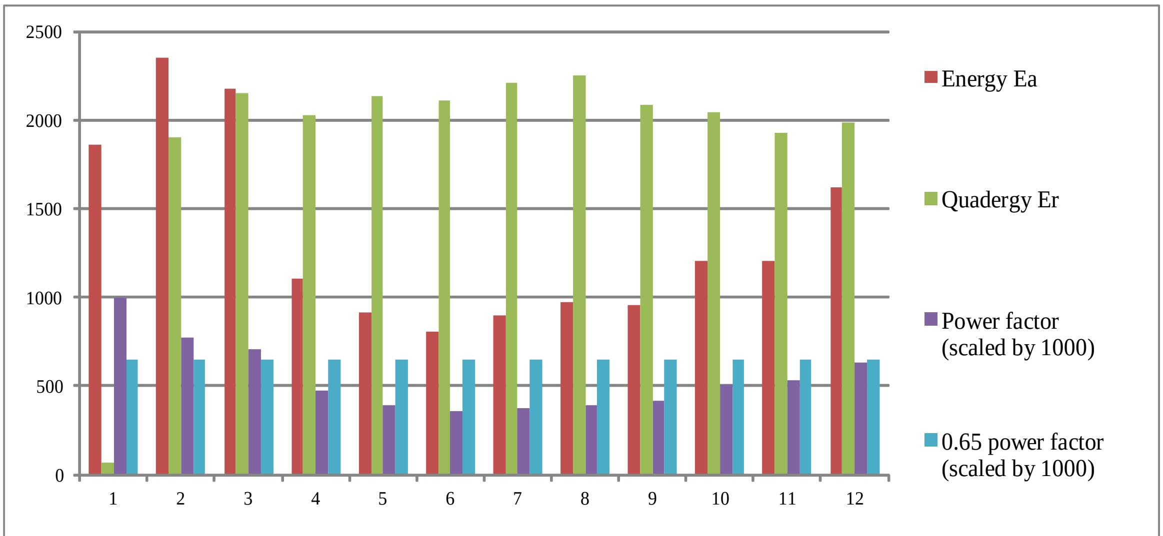

Figure 3. Billed energy and quadergy variations, power factors variations for year 2012

Using the data from Tables 1 and 2, and observing Figures 1 and 3, using equation (11), we obtain that for a 744 operation hours per month, to have a power factor higher than 0.65, the consumer's average power must not go below 3% of the 100 kVA transformer's nominal power, and not below 2.6% of the 80 kVA transformer's nominal power.

Beginning with 01.01.2017, with new ANRE directive [11] it was regulated that the 0.92 neutral power factor becomes the limit power factor, with a value of 0.90. This allowed the non-billing of inductive and capacitive reactive power up to a value of 0.90.

Analysing Figure 3 we note that in March 2012 the power factor is higher than 0.65, which followed a drastic decrease consumer energy use. By replacing the 80 kVA transformer by a 16 kVA transformer, at the same time when the energy consumer is suspended, the energy corrections are significant, considering the computed losses. For this type of transformer [10] we have the following technical parameters:

- No-load operation transformer losses $P_0 = 0.065$ kW;
- Short-circuit operation transformer losses $P_{sc} = 0.465$ kW;
- No-load operation current $i_0\% = 4$;
- Short-circuit voltage $u_{sc}\% = 4$.

Table 3 presents the measured energy and quadergy values, as well the corresponding corrections as they were calculated established by the energy distribution provider, as shown on the bill (Figure 1).

Table 3. The power factor, energy values, and corresponding corrections for 3 months in 2018

Month	E_{am} [kWh]	ΔE_a [kWh]	E_{ar} [kVArh]	ΔE_r [kVArh]	Cos φ
Feb.2018	0	57	2	430	0.131
Mar.2018	0	63	2	476	0.131
April 2018	0	61	2	461	0.131

Figure 4 shows the billed energy and quadergy variations and the power factor variations for February, March and April, 2018, when the consumer is using the 16 kVA transformer.

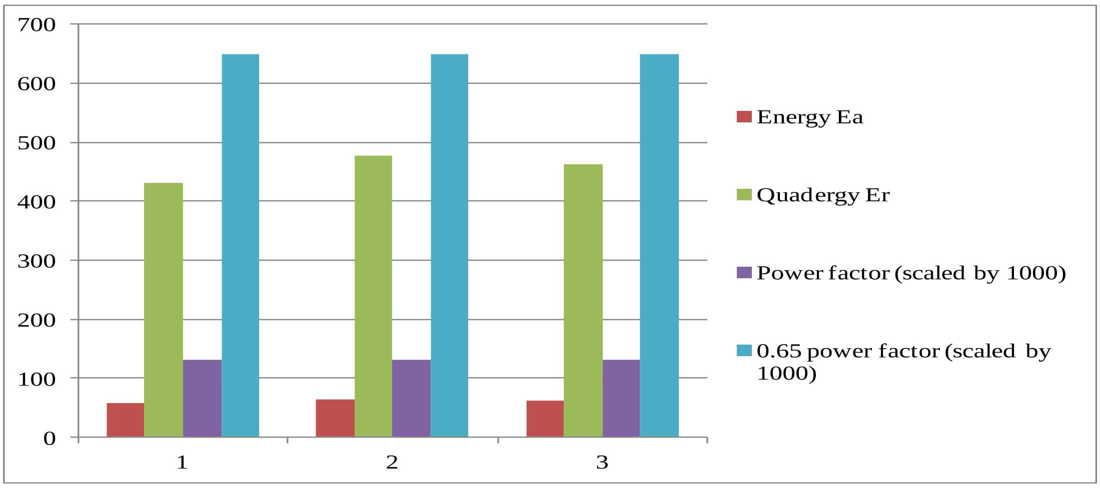

Figure 4. Billed energy and quadergy and the power factor for February, March and April, 2018

4. Conclusions

Analysing the data on the energy bills as well as the corresponding loss calculations we have determined the moment when, due to no energy consumption, a decision about a transformer replacement or about an energy contract change should be made.

The use of this method allows obtaining a quick, solid fact basis to show the energy distributor such that new, equally advantageous contracts between partners can be closed.

For a 100 kVA transformer, such that the power factor is higher than 0.65, the average consumer power must not drop below 3% of the transformer's nominal power. For the 80 kVA transformer, the consumer power must not drop below 2.6%.

We found that, although the original transformer has been replaced with a lower power one (16 kVA) for a no energy consumption the applied corrections are still rather high.

Looking at Figure 4 we see that for no energy nor quadergy consumption, in a three days interval, in two consecutive calendar months, the energy corrections are almost double. The cause of this must be spelled out and clarified by the energy distributor.

References

[1] Deaconu I D, Dragomir R C, Chirila A I, Deaconu A S, Saracin C G and Navrapescu V 2017 *Noise Analysis for No Load Operating Power Transformers*, 10th International Symposium on Advanced Topics in Electrical Engineering ATEE 2017, Bucharest, Romania, Mar 23-25, pp 128-131

[2] ***Ordinul 33/2014 *Metodologia privind stabilirea obligaţiilor de plată a energiei electrice reactive şi a preţului reglementat pentru energia electrică reactivă*, https://www.e-distributie.com/ro-RO/Documents/Ord%2033%2014.pdf, accessed at 13.04.2018

[3] ***Ordinul 24/2006 *Procedura privind corecţia energiei electrice în cazul în care punctul de măsurare diferă de punctul de decontare*, http://www.anre.ro/ro/legislatie/norme-tehnice/reglementari-tehnice 1387199450, accessed at 13.04.2018

[4] Deaconu I D, Ghita, C, Navrapescu V and Chirila A I 2010 *Radial and Axial Short-Circuit Electrodynamic Forces of Three Phase Power Transformers*, 12th International Conference on Optimization of Electrical and Electronic Equipment OPTIM 2010, Brasov, Romania, May 20-21, pp 185-190

[5] Munteanu A, Livadaru L, Simion A and Virlan B 2016 *An Efficient Approach for 3D Toroidal Transformers Simulation,*9th International Conference and Exposition on Electrical and Power Engineering EPE 2016, Iasi, Romania, Oct 20-22, pp 277-280

[6] Gong R H, Ruohan J J, Chen J Z, Quan Y, Wang J and Duan C H 2017 Analysis and Experiment of Hot-Spot Temperature Rise of 110 kV Three-Phase Three-Limb Transformer*, Energies* **10**(8) 1079

[7] Song Y D, Jia H D, Xu X F and Yu L 2017 *Simulation Analysis of Inrush Current of Three Phase Transformer Based on MATLAB*, 29th Chinese Control And Decision Conference CCDC 2017, Chongqing, Peoples R China, May 28-30, pp 3983-3985

[8] Quan F Y, Chen J, Liu Y, Wang Y, He W L and Wen X S 2017 *Calculation and Analysis of Transformer Transient Over-Voltage in no-Load Switching,* 2nd International Conference on Advances in Materials, Mechatronics and Civil Engineering ICAMMCE 2017, Guangzhou, Peoples R China, Jan 19-20, Book Series: AER-Advances in Engineering Research, Volume 121, pp 1-8

[9] ***Ordinul 35/2005 *Procedura privind asigurarea energiei electrice reactive şi modul de plată a acesteia*, http://www.electricafurnizare.ro/wp-content/uploads/2016/09/ordin-anre-35-2005-53.pdf, accessed at 13.04.2018

[10] ***Ordinul 75/2015 *Procedura privind corecţia datelor de măsurare în raport cu punctual de delimitare*, http://www.anre.ro/ro/legislatie/norme-tehnice/reglementari-tehnice1387199450, accessed at 13.04.2018

[11] ***Ordinul 76/2016 *Ordin pentru modificarea şi completarea Metodologiei privind stabilirea obligaţiilor de plată a energiei electrice reactive şi a preţului reglementat pentru energia electric reactivă*, http://www.anre.ro/ro/legislatie/metodologii-tarife/furnizare-energie-electrica, accessed at 13.04.2018