METHOD FOR DETERMINING QUALITY INDICATORS OF ELECTRICAL POWER

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Abstract. *This paper proposes to introduce a small number of quality indicators for electrical power in systems with three-phased consumers which are disbalanced, asymmetrical and distorting. These indicators are required for measuring and pre-determining the effects of such consumers on the supply network in order to establish measures for improving the quality of power supply in the electrical networks.*

Keywords: Quality indicators, electrical power, energy quality

1. Introduction

The problem related to the power quality in electrical networks are the following:

- frequency variations;
- active and reactive power shocks;
- distorting, asymmetrical and disbalanced regime.

This last problem has some very important consequences:

- the increase of power losses and active power;
- the interblocking of installations transport and supply capacity;
- difficulties related to the voltage regulating;
- parasitic torques in electrical machines;
- errors done by measure and control apparatus.

2. Three-phased disbalanced, asymmetrical and distorting consumer

Let it be a three-phased asymmetrical consumer R, S, T, whose impedances $Z_R \neq Z_S \neq Z_{T,}$

Supplied from a three-phased voltage system $u_R, u_S, u_T \in u_{Rst}$ with disbalanced currents $i_R, i_S, i_T \in i_{RST}$ running under distorting conditions.

Instantaneous value expressions and the phase voltage u_{RST} and the i_{RST} currents are:

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$$u_{c(RST)} = \sum_{1}^{\infty} U_{k(RST)} \times \sqrt{2} \times \cos(k\omega t + \alpha_{k(RST)}) = U_{c(RST)} \times \cos\omega t - U_{s(RST)} \times \sin\omega t$$

$$u_{s(RST)} = \sum_{1}^{\infty} U_{k(RST)} \times \sqrt{2} \times \sin(k\omega t + \alpha_{k(RST)}) = U_{s(RST)} \times \cos\omega t + U_{c(RST)} \times \sin\omega t$$

$$i_{c(RST)} = \sum_{1}^{\infty} I_{k(RST)} \times \sqrt{2} \times \cos(k\omega t + \beta_{k(RST)}) = I_{c(RST)} \times \cos\omega t - I_{s(RST)} \times \sin\omega t \qquad (1)$$

$$i_{s(RST)} = \sum_{1}^{\infty} I_{k(RST)} \times \sqrt{2} \times \sin(k\omega t + \beta_{k(RST)}) = I_{s(RST)} \times \cos\omega t + I_{s(RST)} \times \sin\omega t$$

where:

$$U_{c(RST)} = \sum_{1}^{\infty} U_{k(RST)} \times \sqrt{2} \times \cos[\alpha_{k(RST)} + (k-1)\omega t]$$

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$$I_{c(RST)} = \sum_{1}^{\infty} I_{k(RST)} \times \sqrt{2} \times \cos[\beta_{k(RST)} + (k-1)\omega t] \qquad (2)$$

$$I_{s(RST)} = \sum_{1}^{\infty} I_{k(RST)} \times \sqrt{2} \times \sin[\beta_{k(RST)} + (k-1)\omega t]$$

Current and voltage systems satisfy the following requirements:

$$u_{CR} + u_{CS} + u_{CT} = u_{CO}$$

$$u_{SR} + u_{SS} + u_{ST} = u_{SO}$$

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$$i_{SR} + i_{SS} + i_{ST} = i_{SO}$$

There has been demonstrated [1], [2], [3], that:

$$u_{RST}^2 = \frac{u_{C(RST)}^2 + u_{S(RST)}^2}{2}; \qquad i_{RST}^2 = \frac{i_{C(RST)}^2 + i_{S(RST)}^2}{2} \tag{4}$$

$$p_{RST} = \frac{u_{C(RST)} \times i_{C(RST)} + u_{S(RST)} \times i_{S(RST)}}{2} \qquad q_{RST} = \frac{u_{C(RST)} \times i_{S(RST)} - u_{S(RST)} \times i_{C(RST)}}{2} \tag{5}$$

$$s_{RST}^2 = u_{RST}^2 \times i_{RST}^2 \tag{6}$$

which represent characteristical functions of voltage u_{RST}, current i_{RST}, active power p_{RST}, complementary power c_{RST}, and apparent power s_{RST}. These functions of voltage and current are graphically represented in figure 1 and figure 2. Their property is that of being able to describe the variations of sizes characteristic to power quality as compared to the ideal conditions. The characteristic functions:

$$U_{RST}^2 = \sum_0^\infty U_k^2 = \frac{1}{T}\int_0^T u_{RST}^2 \times dt = f\int_0^{\frac{1}{f}} u_{RST}^2 \times dt \tag{7}$$

$$I_{RST}^2 = \sum_0^\infty I_k^2 = \frac{1}{T}\int_0^T i_{RST}^2 \times dt = f\int_0^T i_{RST}^2 \times dt \tag{8}$$

$$P_{RST} = \sum_0^\infty P_K = \frac{1}{T}\int_0^T p_{RST} \times dt = f\int_0^T p_{RST} \times dt \tag{9}$$

$$Q_{RST} = \sum_0^\infty Q_K = \frac{1}{T}\int_0^T q_{RST} \times dt = f\int_0^T q_{RST} \times dt \tag{10}$$

$$S_{RST}^2 = U_{RST}^2 \times I_{RST}^2 \tag{11}$$

enable us to obtain voltage, currents, active, inactive and apparent powers.

In them papers mentioned above these has been demonstrated that among the characteristic functions we have the relation:

$$s_{RST}^2 = p_{RST}^2 + q_{RST}^2 \tag{12}$$

which represents the principle of power separation introduced by C. I. Budeanu. It also may by rendered as:

$$S^2 = P^2 + Q^2 + D^2 \tag{13}$$

where D represents the distorting power.

3. Quality indicators

To define the power quality we do introduce two indicators (figure 1 and figure 2):

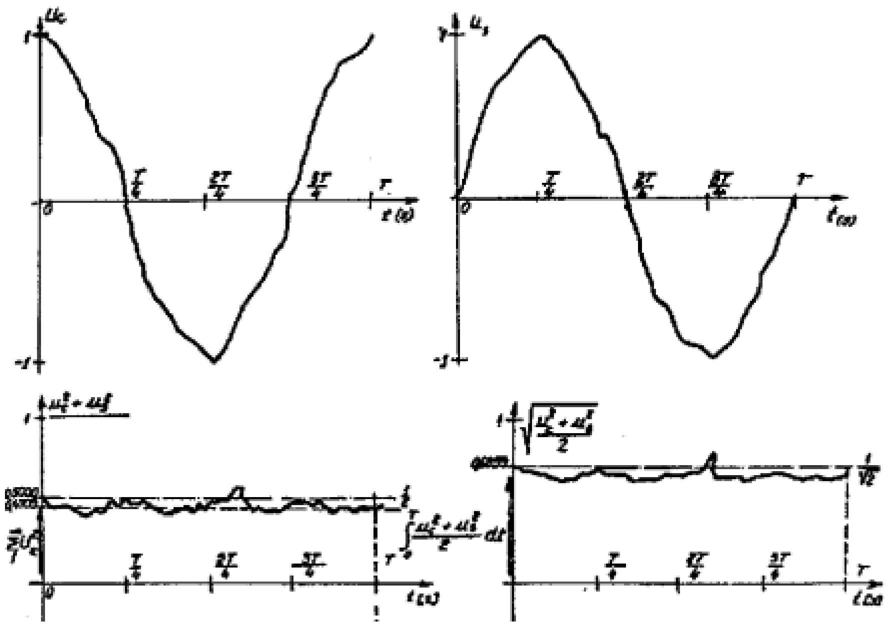

Fig. 1. The characteristic function of voltage.

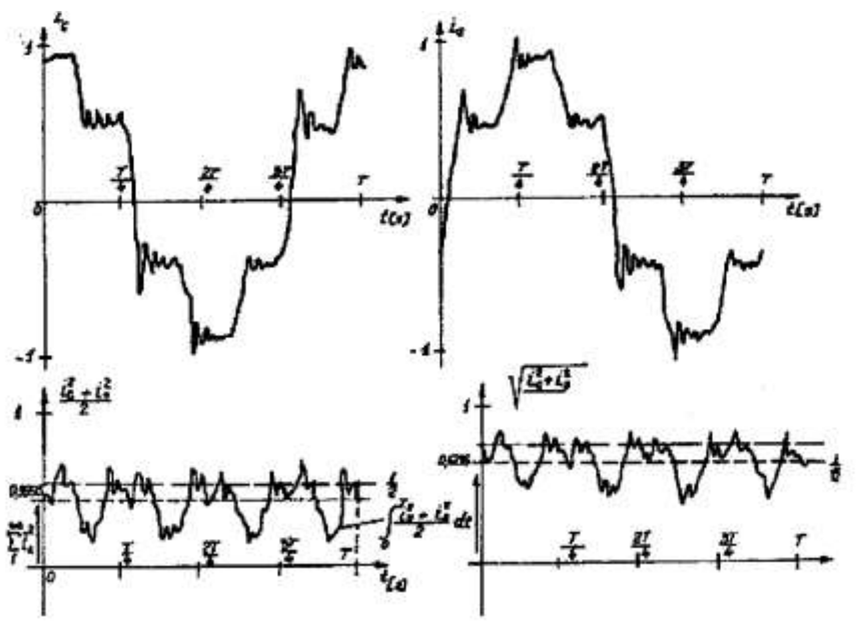

Fig. 2. The characteristic function of current.

- load of the isolation: S_u

$$S_u = \int_0^T u_{RST}^2 \times dt = U_{RST}^2 \times T \tag{14}$$

- thermal load: S_i

$$S_i = \int_0^T i_{RST}^2 \times dt = I_{RST}^2 \times T \tag{15}$$

These indicators are independent upon frequency variation and knid of sinusoidal energetical regime.

For sinusoidal energetical regime (S) there are two situations:

a) for frequency f = 50Hz, T = 1/f;

$$S_u(S,T) = \int_0^T u_{RS(RST)}^2 \times dt = U_{RS(RST)}^2 \times T \tag{16}$$

$$Si(S,T) = \int_0^T i_{RS(RST)}^2 \times dt = I_{RS(RST)}^2 \times T \tag{17}$$

b) for frequency f’ ≠ 50Hz, T = 1/f’

$$S_u(S,T') = \int_0^T u_{RST}^2 \times dt = U_{RS(RST)}^2 \times T' \tag{18}$$

$$Si(S,T') = \int_0^T i_{RS(RST)}^2 \times dt = I_{RS(RST)}^2 \times T' \tag{19}$$

For non-sinusoidal energetical regime (N) there are also situations:

a) for frequency f = 50Hz, T = 1/f;

$$S_u(N,T) = \int_0^T u_{RN(RST0}^2 \times dt = U_{RN(RST)}^2 \times T \tag{20}$$

$$Si(N,T) = \int_0^T i_{RN(RST)}^2 \times dt = I_{RN(RST)}^2 \times T \tag{21}$$

b) for frequency f’ ≠ 50Hz, T = 1/f’

$$S_u(N,T') = \int_0^T u_{RST}^2 \times dt = U_{RN(RST)}^2 \times T' \tag{22}$$

$$Si(N,T') = \int_0^T i_{RN(RST)}^2 \times dt = I_{RN(RST)}^2 \times T' \tag{23}$$

By using the representations in relative units of functions $u_{RST}^2(t)$ and $i_{RST}^2(t)$ in figure 1 and figure 2, we can define these function such as:

$$S_u(S,T) = U^2T = \frac{1}{2}\times T \qquad S_i(S,T) = I^2T = \frac{1}{2}\times T \tag{24}$$

$$S_u(S,T') = U^2T' = \frac{1}{2}\times T' \qquad S_i(S,T') = I^2T' = \frac{1}{2}\times T' \tag{25}$$

$$S_u(N,T) = \sum_1^n U_k^2T = 0{,}4709T \qquad S_i(N,T) = \sum_1^n I_k^2T = 0{,}3995T \tag{26}$$

$$S_u(N,T') = \sum_1^n U_k^2T' = 0{,}4709T' \qquad S_i(N,T') = \sum_1^n I_k^2T' = 0{,}3995T' \tag{27}$$

Having as reference basis the functions $S_u(S, T)$ and $S_i(S, T)$ corresponding to the distorting energetical regime at frequency f = Hz, any non-sinusoidal energetical regime at frequency f' ≠ f = 50Hz is characterized by functions S_u and S_i.

The deviation from energy quality (voltage and current) can be defined by following functions:

$$\Delta S_u(N,T') = \frac{S_u(N,T') - S_u(S,T)}{S_u(N,T')} = 1 - \frac{U^2T}{\sum_1^n U_k^2T'} \tag{28}$$

$$\Delta S_i(N,T') = \frac{S_i(N,T') - S_i(S,T)}{Si(N,T')} = 1 - \frac{I^2T}{\sum_1^n I_k^2T'} \tag{29}$$

The quality deviation due to the network frequency variation is defined by the functions:

$$\Delta S_u(S,T') = \frac{S_u(S,T') - S_u(S,T)}{S_u(S,T')} = 1 - \frac{T}{T'} \tag{30}$$

$$\Delta S_i(S,T') = \frac{S_i(S,T') - S_i(S,T)}{S_i(S,T')} = 1 - \frac{T}{T'} \quad (31)$$

and then we have the relations:

$$\Delta S(f) = 1 - \frac{T}{T'} = 1 - \frac{f'}{f} = \Delta S_u(S,T') = \Delta S_i(S,T') \quad (32)$$

The quality deviation due to non-sinusoidal energetical regime is defined by the following functions:

$$\Delta S_u(D,T) = \frac{S_u(N,T) - S_u(S,T)}{S_u(N,T)} = 1 - \frac{U^2}{\sum_1^n U_k^2} \quad (33)$$

$$\Delta S_u(D,T') = \frac{S_u(N,T) - S_u(S,T')}{S_u(N,T')} = 1 - \frac{U^2}{\sum_1^n U_k^2} \quad (34)$$

$$\Delta S_i(D,T) = \frac{S_i(N,T) - S_i(S,T)}{S_u(N,T)} = 1 - \frac{I^2}{\sum_1^n I_k^2} \quad (35)$$

$$\Delta S_i(D,T') = \frac{S_i(N,T') - S_i(S,T')}{S_u(N,T')} = 1 - \frac{I^2}{\sum_1^n I_k^2} \quad (36)$$

$$\Delta S_u(D) = S_u(D,T) = \Delta S_u(D,T'); \quad (37)$$

$$\Delta S_i(D) = S_i(D,T) = \Delta S_i(D,T); \quad (38)$$

Under these conditions, the deviation from energy quality (voltage and current) can be defined as follows:

$$\Delta S_u(N,T') = 1 - [1 - \Delta S_u(D)] \times [1 - \Delta S(f)] \quad (39)$$

$$\Delta S_i(N,T') = 1 - [1 - \Delta S_i(D)] \times [1 - \Delta S(f)] \quad (40)$$

These should be noted that from the representations of figure 1 and 2, when it is operated at a frequency, f = 47Hz, it results a deviation from energy quality $\Delta S_u(N,T')$ = 12% and $\Delta S_i(N,T')$ = 24,8%.

A unique energy quality indicator would be that which is including both insulation load and thermal load.

Laying down the characteristic $S_{ui(RST)} = (\frac{u^2_{c(RST)} + u^2_{s(RST)}}{2})(\frac{i^2_{c(RST})+i^2_{c(RST)}}{2})$ for an electrical period T or T', we obtain the characteristic of <u>insulations load and thermal load</u>, SIT.

For sinusoidal energetical regime at frequency f = 50Hz, T =1/f, we have:

$$SIT(S,T) = \int_{0}^{T} (\frac{u^2_{c(RST)} + u^2_{s(RST)}}{2})(\frac{i^2_{c(RST})+i^2_{c(RST)}}{2})dt = U^2 I^2 T \quad (41)$$

While for non-sinusoidal energetical regime at frequency f' ≠ f =50Hz, T' =1/f', we have:

$$SIT(N,T') = \int_{0}^{T'} (\frac{u^2_{c(RST)} + u^2_{s(RST)}}{2})(\frac{i^2_{c(RST})+i^2_{c(RST)}}{2})dt = \sum_{1}^{n} U_k^2 \sum_{1}^{n} I_k^2 T' \quad (42)$$

The deviation of isolation and thermal load characteristic is:

$$\Delta SIT(N,T') = \frac{SIT(N,T') - SIT(S,T)}{SIT(N,T')} = 1 - [1 - \Delta S_u(N,T')][1 - \Delta S_i(N,T')]\frac{T'}{T} \quad (43)$$

Conclusions

There have been suggested the indications for isolation load and thermal load to characterize the derivation from the electric power quality. With their help we can define a general energy quality indicator by means of the isolation and thermal load deviation. The main advantage is that these indicators can be determined without performing any harmonic expression.

R E F E R E N C E S

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