

Unified loss theory and its application on low voltage networks

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Abstract

Considering the present Hungarian network conditions the network losses run up to 10-12 % of the total electric power fed in, and ca. 40 % of these losses arise on the LV networks.

Therefore it is an important task to survey the components of the LV network losses, on the one hand in order to accurately estimate the losses, and on the other hand to enable a cost-benefit analysis of loss reduction investments.

The aims of the research reported on are:

- to determine the amount of information needed to estimate the LV network losses in a way as simple and as accurate as possible, and
- to establish a simple measurement procedure and a computation algorithm.

The proposed method comprises the determination of an ideal loss that arises due to the total energy consumed, and the calculation of additional loss-increasing components, such as

- capacity load factor
- fundamental frequency reactive power
- fundamental frequency current asymmetry (negative and zero sequence)
- harmonic currents.

Capacity load factor

The current $i(t)$ flowing through a line segment with a resistance R from time 0 to T causes a loss energy

$$W_v = R \cdot \int_0^T i^2(t) \cdot dt \quad [\text{W} \cdot \text{s}].$$
 If the current

was constant over time, the ideal loss would be $W_{v(id)} = T \cdot R \cdot i_k^2$ [W·s], where

$$i_k = \frac{1}{T} \int_0^T i(t) \cdot dt \quad [\text{A}].$$
 The capacity load

factor $K_{cs} = \left(\frac{W_v}{W_{v(id)}} \right)$ shows the loss

increase due to the fact that the current is varying over time.

Fundamental frequency reactive power

In the ideal case the current has only an active component I_P causing a loss power of $P_{v(id)} = 3 \cdot R \cdot I_P^2$ [W]. If the current I_S has non-zero reactive component, then the loss power is $P_v = 3 \cdot R \cdot |I_S|^2$ [W], and the loss increase expresses to

$$\left(\frac{P_v}{P_{v(id)}} - 1 \right) = \frac{1}{(\cos(\varphi))^2} - 1.$$

Harmonic currents

The loss increase due to harmonic currents can be expressed as $P_{vh}/P_{v(id)} = 1 + (\text{THD}_I)^2$ for harmonic orders h not being multiples of 3. Currents of harmonic orders that are multiples of 3 cause an additional loss in the earth wire, which can be expressed as $P_{vn,h,3}/P_{v3(id)} = 3(\text{THD}_I)^2$.

Asymmetry

Negative sequence current causes an additional loss only in the phase wires, whereas the zero sequence current produces an additional loss in the phase wires as well as in the earth wire. Latter is proportional to $9I_0^2$, because the current in the earth wire is three times the zero sequence current I_0 .

Aggregate treatment of network loss components

Let us consider a line segment with resistance R , and the current be time-variant, asymmetric and distorted with harmonics.

The loss on this line segment can be written as $P_v = P_a + P_b + P_c = 3P_+ + 3P_- + 3P_0$

where

$$P_a = (I_{a,rms})^2 R, \text{ etc.}$$

- $P_+ = (I_+)^2 R_+$ summarized for positive sequence fundamental and harmonic components
- $P_- = (I_-)^2 R_-$ summarized for negative sequence fundamental and harmonic components
- $P_0 = (I_0)^2 R_0$ summarized for zero sequence fundamental and harmonic components incl. the loss on the earth wire

If we denote the fundamental positive sequence current by I_+ , the power factor computed from I_+ and the corresponding voltage by $\cos\varphi$, then the 3 phase ideal-case loss is $P_{v,id} = 3(I_+ \cos\varphi)^2 R_+$.

We can define for the fundamental positive sequence current the capacity load factor:

$$K_{cs}^+ = \frac{\frac{1}{T} \int_0^T [i^+(t)]^2 dt}{\left(\frac{1}{T} \int_0^T i^+(t) dt \right)^2}$$

and similarly for the other sequences and harmonics.

If we assume, that

- $R_+ = R_- = R_0$
- $\cos\varphi = \text{constant over time}$
- $A_{I_-} = \frac{I_-}{I_+}$, $A_{I_0} = \frac{I_0}{I_+}$ asymmetry factors are constant over time
- $D_{I_{h,sorr}} = \frac{I_{h,sorr}}{I_+}$ harmonic distortion factors are constant over time, then

the ratio of the real-case loss energy to the ideal-case loss energy will be:

$$\frac{W_v}{W_{id}} = \frac{K_{cs}^+}{\cos^2 \varphi} \left(1 + \frac{K_{cs}^-}{K_{cs}^+} A_{I_-}^2 + \frac{K_{cs}^0}{K_{cs}^+} 4A_{I_0}^2 + \frac{K_{cs}^{I3,0}}{K_{cs}^+} 4D_{I3,0}^2 + \frac{K_{cs}^{I5,-}}{K_{cs}^+} D_{I5,-}^2 \right)$$

Using this formula it is possible to estimate the loss of a LV network based on measurements performed solely at the feeding point of the network, if we assume that the measured current is divided among

the consumers in the same proportion every time step.

It is also possible to compare the loss components and evaluate the effect of different loss-reduction investments.

In the paper we present how the above formula has to be modified if we assume more realistic conditions. At the same time some factors similar to the above mentioned will be derived that are also easily calculated from measurement data; using these factors it is possible to compare different LV networks and queue loss reduction investments.

Finally further investigations are shortly presented, which involve the construction of probabilistic consumer models based on measurement data. Using these models Monte-Carlo simulations are performed resulting in a probability density function of the network loss of a LV feeder.

The final goal of the research is to develop a loss evaluation software using input data as follows:

- network topology with the distribution line parameters
- annual energy consumption of consumers (kWh)
- consumer connection information (single phase or three-phase)
- current of large consumers (compared to the average consumer, e.g. shops, restaurants, etc.) measured or estimated based on long term profiles
- currents at the feeding point of the LV network measured for at least 1 week with a sampling time of 1 minute (fundamental and harmonic currents, every sequence)

The output of the software will be the probability density function of the different loss components and the total loss on the feeder.

References

- [1] A.Dán, D.Raisz, L.Hornýák, S.Rios: Power considerations and digital energy metering accuracy on distorted network, 48. Internationales Wissenschaftliches Kolloquium, TU Ilmenau, 22.-25. September 2003