

INDUCTANCE MEASUREMENT IN TIME DOMAIN

M.T. Galewski, M. Woloszyk and S. Wojtas

Chair of Electrical Measurements

Faculty of Electrical and Control Engineering, Technical University of Gdansk
ul. Narutowicza 11/12, 80-952 Gdansk, Poland

Abstract: Paper proposed concerns measurement of inductance in time domain. Authors propose new notions: 'impulse resistance', impulse inductance' and 'impulse effectiveness of earthing'. The principle of the measuring method is presented, its advantages in respect to frequency methods are discussed. This paper is a continuation of our work on measurements of features of earthing in time domain, with short current impulses [1,2,3].

Keywords: inductance, time domain, short current impulse

1 INTRODUCTION

The method itself was worked out while searching technical possibility of measuring features of earthing during atmospheric discharge. This kind of measurement should be done in conditions similar to the real atmospheric discharge, which is of short current impulse shape. Minimal value of the current which produces phenomena similar to the natural one is more than 1A, so measurement of components of such impedance in frequency domain is absolutely impractical, since it would require testing signal of power of kW. Measurement time in time domain test can be very short. In minimal case it can be equal to the time of rising slope of the testing signal - so this kind of measuring way enables us to use high power impulse and prominently reduce energy of the test waveform at the same time.

Many electrical objects can be described as a series connection of resistance and inductance not only earthing, but shunts or electrical motors as well. In the case of shunts, or other devices, measuring time reduction leads to very short measuring procedure, which is very important in today production process.

2 THE METHOD

Let us consider simple model of impedance, consisting of serially connected inductance and resistance.

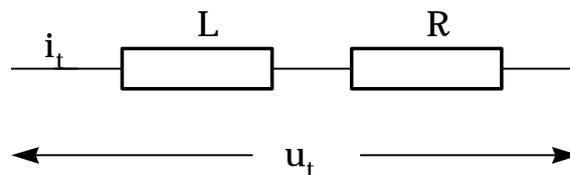


Figure 1. Model of impedance

Relation between current and voltage of above impedance in time domain can be expressed as:

$$u_t = L \cdot \frac{di}{dt} + R \cdot i_t \quad (1)$$

If we integrate both sides of the equation, we obtain:

$$\int_0^t u_t dt = L \cdot i_t + R \cdot \int_0^t i_t dt \quad (2)$$

so inductance L can be calculated as:

$$L = \frac{\int_0^t (u_t - R \cdot i_t) dt}{i_t} \quad (3)$$

We can find unknown value of resistance R as:

$$R = \frac{u_{t_d}}{i_{t_d}} \quad \text{where } t_d \text{ is the time at which differential } \frac{di}{dt} = 0 \quad (4)$$

So the final formula to calculate the inductance L of series connection of resistance and inductance is as follows:

$$L = \frac{\int_0^t (u_t - \frac{u_{t_d}}{i_{t_d}} \cdot i_t) dt}{i_t} \quad (5)$$

where u_t = voltage drop on the impedance caused by test current
 i_t = test current
 int. = integral (numerator of formula 5)
 u_{ind} = voltage drop on inductance
 L = inductance

Graphical illustration of the above formulae is presented in Fig 2.

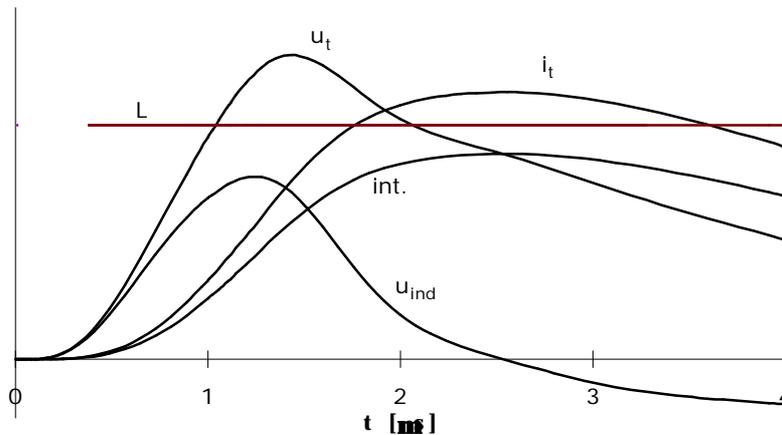


Figure 2. Graphical illustration to the equation 5

The way presented of measurement of inductance can be easily applied with digital or analogue technique, or combination of them. For very short test current (time measured in μs , as in earthing tests) it is easier to make analogue signal processing, in the case of slower test currents, like in shunt or coils tests, the application of 'pure' digital technique could be more convenient. The basic principle of the method presented can be used not only in the measurement of inductance but also - after certain modification - capacitance as well. An example of block scheme of device realising the proposed method is presented in Fig 3.

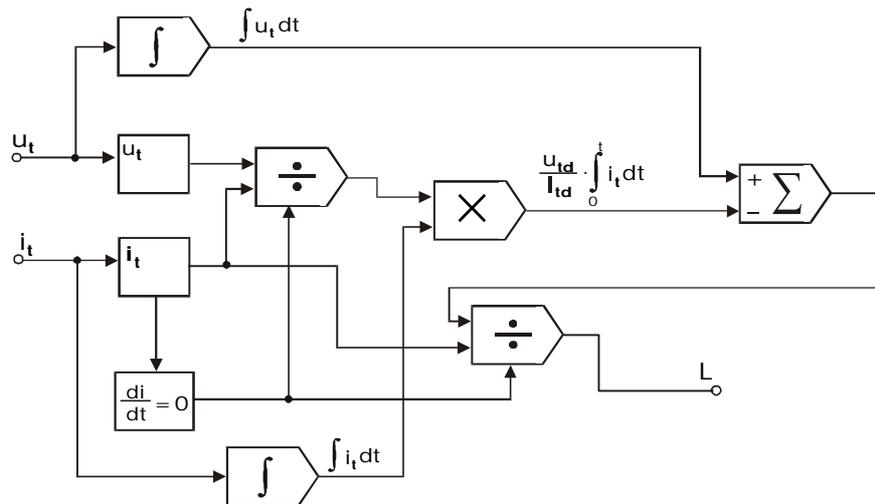


Figure 3. Block scheme of device for measuring impulse resistance and inductance

3 IMPULSE QUANTITIES

It is worth mentioning that both above calculated values, resistance and inductance in the case of geometrically large objects depend on the rise time of the testing impulse - or in frequency terms - on the frequency bandwidth. 'Large' means that dimensions of the object are comparable to the length of the testing wave. This feature of the method is very useful in the case of earthing, because we can measure now so-called 'impulse resistance', which describes the ability of a large, complex earthing to disperse the current of an atmospheric discharge at low voltage drop.

This kind of problem is often faced in the case of power substation, where the same big, grid type earthing plays different roles. On one hand it is used to ground low voltage apparatuses like transformer secondary winding, but on another hand it must also protect the station from the danger caused by atmospheric discharges. In the first case the whole protecting system takes part in spreading out low frequency currents, but in the second one, fast thunder currents are conducted only by the part of the system, the part that is close to the point of the surge hit. Farther area of the system does not participate in the protecting process. It is because fast currents must be treated as waves so the system must be meant as an object of wave nature [4,5,6,7].

3.1 Impulse resistance

Keeping in mind above remarks it becomes clear that low-voltage measurement of the resistance of such an earthing is misleading, since it does not take into account neither wave nature of thunder current nor the geometric dimensions of the earthing. As a result, resistance value measured in this way is very low, but actual value of this partial resistance - we call it 'impulse resistance' - can be a few times higher. This means that with low-voltage test we can not estimate the behaviour of the protecting system in real situation and - what makes it worse, the measuring errors are negative in any case, so it is very likely that protected objects could be in dangerous position. Generally speaking, low frequency tests are too much optimistic.

3.2 Impulse inductance

The value of 'impulse Inductance' gives another important information. It tells us whether the earthing is properly designed and constructed from the geometric point of view. The same number of metal elements burned in soil can give quite different protecting system of different inductance. Described impulse inductance measurement can also be used to find 'illegal' connection of the protecting system to a water supplying net or to far working earthing system. Both above methods are sometimes applied by 'smart' earthing constructors to improve the resistance of their product when other means are too complicated (read expensive).

3.3 Impulse effectiveness

Proposed above 'impulse' values lead us to the notion of 'impulse effectiveness' of the earthing, which can be meant as a ratio of the value of low-frequency resistance to impulse resistance value. Good earthing should have this ratio close to one, but it is obvious that large protecting system must have the ratio of 0.2 or so, rather than 1.

4 TIME DOMAIN V. FREQUENCY DOMAIN METHOD

Commonly known frequency domain methods like balanced bridge methods or ac potentiometers require multi-step procedures to obtain the final result. The methods are very sensitive to instantaneous states, the whole measuring process must be performed in steady conditions. In the case of low values to be measured (shunt for instance), there is another problem how to provide strong enough test signal for relatively long time necessary to perform the measuring procedure.

Time domain method is free from disadvantages presented above. The measurement can be done in one test current impulse time, let say $1\mu\text{s}$. The energy consumed by such an impulse can be low, but power high, so there is no problem how to obtain good signal to noise ratio. Besides, the high power to energy ratio of presented method is also of great importance in the case of field instruments, in which we often can face problem of battery supply. The method will probably be not as accurate as bridge or AC potentiometer can be, but it seems to be very useful in field earthing measurements and in fast tests during mass production process.

The method has been introduced to Polish Patent Office.

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AUTHORS: Dr. Miron T. GALEWSKI, Dr. Stanisław WOJTAS, Dr. Marek WOŁOSZYK, Chair of Electrical Measurements, Faculty of Electrical and Control Engineering, Technical University of Gdańsk, 80-952 Gdańsk, ul. Narutowicza 11/12, Poland, Phone +48 58 347 12 84, Fax +48 58 347 18 02, E-mail: mawo@sparc10.ely.pg.gda.pl