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The Reactances as Voltage Divider

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ABSTRACT: *In the developing countries, rural electrification continues to face hardships because traditional solutions remain expensive for the very poor rural population.For these countries, new technologies are needed when dealing with rural electrification.We developed here the survey of a system for reducing the voltage reactance means; unlike conventional transformers, the output voltage is obtained by dividing the input voltage; this division is provided by two coils in series as it is developed in this article. Such a monophase system that requires deep studies could be profitable in African rural electrification.*

Keyswords: *Reactances, Voltage divider , African rural electrification*

I. INTRODUCTION

Conventional transformers (high voltage / medium voltage and medium voltage / low voltage) cost too much for the electrification of African rural populations; these unrealistic posts below a threshold of power to be provided delay rural electrification in developing countries.

Moreover, the maximum profit calculations of energy distributors show that they have no interest in supplying electrical energy where production costs are removed and for low and dispersed energy demands.

New and Renewable Energies are still expensive for those populations who hope to be connected to the public electricity grid.

It was in the search for solutions that we thought that voltage dividers, which can be used as simple measuring transformers in high voltage substations, could be subjected to serious studies, appropriate dimensioning, experimentation for use in rural electrification along or near power lines. These systems could be sized as HV / MV or MV / LV as appropriate.

On high voltage lines, the capacitive effect generates too much reactive energy; it is often difficult to absorb this too much reagent because of the weakness of the industrial loads with consumption of the reagent. The technique of the inductive voltage divider stations proposed here, using reactors, would contribute somewhat to the absorption of this excessive reactive energy which remains a problem to be solved in the high-voltage electricity networks of poor countries.

In high voltage systems, voltage dividers can be used to:

- Voltage measurement.
- Power measurement.
- Protection relays, etc.

Notations used in this document:
HV: high voltage $U \geq 110$ kV
MV: medium voltage $1\text{kV} < U \leq 50$ kV
LV: low voltage $U \leq 1000$ V

II. SYSTEM DESCRIPTION

Apart from the protective and control equipment inherent in any electrical system, the single-phase station would mainly comprise the two inductors in series. Unlike conventional transformers based on primary and secondary windings which inductively transform a voltage U_1 into a voltage U_2; here, the output voltage is simply obtained by dividing the input voltage.

The division of the voltage is ensured by two coils in series of respective inductances L_1 and L_2.

The principle could be applied to an MV or HV network

2.1On a medium voltage line

The system can be designed to be connected to a phase of an MV network in order to deliver directly from the low voltage from the division of a medium voltage without any further additional transformer.

V_2 :Voltage at the output of the divider ;

$\overline{V}_{\phi}$: phase-ground voltage of the MV line on which the system is connected.

We have presented here the principle of the system, it will be necessary to provide devices for protection of the station and regulation of the output voltage.

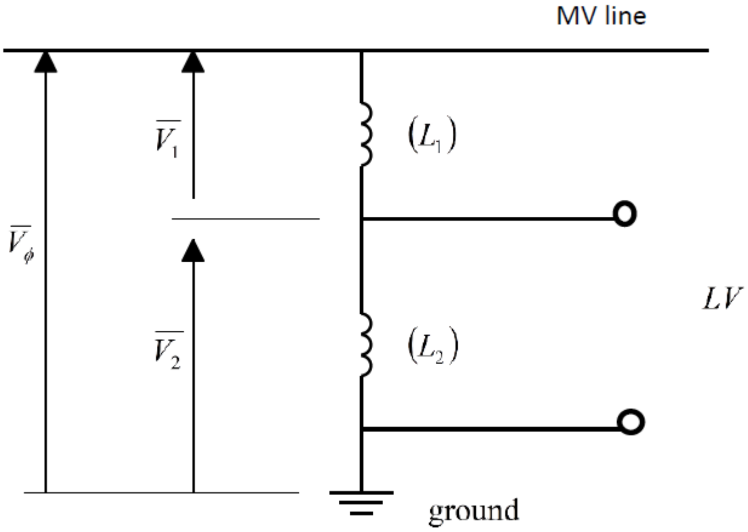

Fig.1: Block diagram except for the protective and control elements

2.2 On a high voltage line

For this type of power supply, the power would be withdrawn from a phase of the line at H.V through these coils constituting the inductive voltage divider; the return of the current being through the ground. Thus, the transport voltage level is reduced to a level of distribution; enabling the use of an MV / LV transformer to switch from the level of distribution to that of use [1] , [2], [3].

$\overline{V}_{\phi}$: phase-ground voltage of the HV line on which the system is connected.

We have presented here the principle of the system, it will be necessary to provide protection devices of the station and regulation of the output voltage

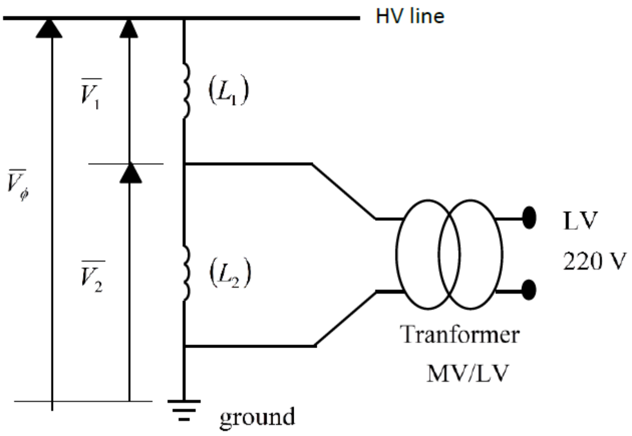

Fig.2: The voltage divider and the MV / LV transformer

III. THE RATIO OF THE TENSIONS DIVISION

Thisratiois $\bar{k} = \overline{V}_{\phi} / \overline{V}_2$

Let Z the impedance equivalent to the whole of the network subjected to the output voltage V_2.
There is the simplified scheme of the system [3]:

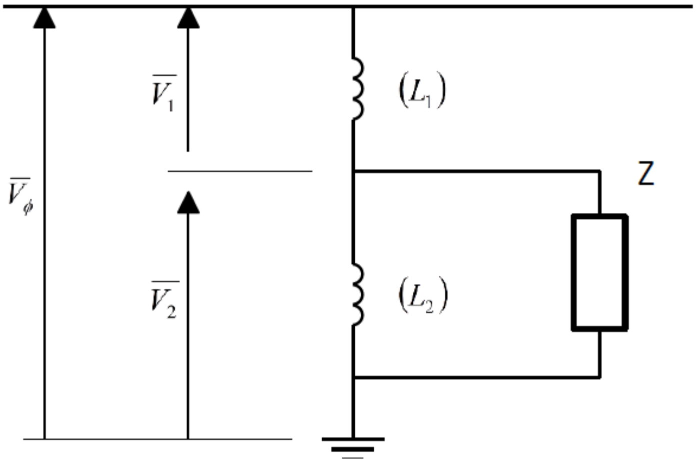

Fig.3: Simplified scheme of the system

Ohm's law gives $\overline{V_1} = \overline{Z_1}\,\overline{I}$ and $\overline{V_\phi} = \overline{V_1} + \overline{V_2}$ leads to $\overline{V_2} = \overline{V_\phi} - \overline{V_1} = \overline{V_\phi} - \overline{Z_1}\,\overline{I}$

Let s $\overline{Z}_{éq} = \overline{Z}_1 + \overline{Z}_2 // \overline{Z}$ ie $\overline{Z}_{éq} = \overline{Z}_1 + \frac{\overline{Z}_1 . \overline{Z}}{\overline{Z}_2 + \overline{Z}}$ (1)

$\overline{Z}_{éq}$ is the equivalent impedance of the entire system connected to the line.The intensity of the main current is then $\overline{I} = \frac{\overline{V_\phi}}{\overline{Z}_{éq}}$ and $\overline{V_2} = \overline{V_\phi} - \overline{Z_1}(\frac{\overline{V_\phi}}{\overline{Z}_{éq}}) = \overline{V_\phi}\left[1 - \frac{\overline{Z_1}}{\overline{Z}_{éq}}\right] = \overline{V_\phi}(1 - \frac{\overline{Z_1}}{\overline{Z_1} + \frac{\overline{Z_2} \times \overline{Z}}{\overline{Z_2} + \overline{Z}}})$

$$= \overline{V_\phi}(\frac{\overline{Z_1}\,\overline{Z_2} + \overline{Z_1}\,\overline{Z} + \overline{Z_2}\,\overline{Z} - \overline{Z_1}\,\overline{Z_2} - \overline{Z_1}\,\overline{Z}}{\overline{Z_1}\,\overline{Z_2} + \overline{Z_1}\,\overline{Z} + \overline{Z_2}\,\overline{Z}}) = \overline{V_\phi}(\frac{\overline{Z_2}\,\overline{Z}}{\overline{Z_1}\,\overline{Z_2} + \overline{Z_1}\,\overline{Z} + \overline{Z_2}\,\overline{Z}}) = \overline{V_\phi}(\frac{1}{1 + \frac{\overline{Z_1}}{\overline{Z_2}} + \frac{\overline{Z_1}}{\overline{Z}}})$$

We have shown that [3]. $\overline{V_2} = \overline{V_\phi}(\frac{1}{1 + \frac{\overline{Z_1}}{\overline{Z_2}} + \frac{\overline{Z_1}}{\overline{Z}}})$ (2)

By writing $\overline{Z_1} = jL_1\omega$; $\overline{Z_2} = jL_2\omega$, we find for division ratio $\overline{k} = \overline{V_\phi} / \overline{V_2}$

A empty, we have $\overline{Z} = \infty$ and $\boxed{\overline{k} = (\frac{L_1 + L_2}{L_2})\left[1 + \frac{jL_1L_2\omega}{\overline{Z}(L_1 + L_2)}\right]}$ (3) therefore $\overline{k} = k_0 = \frac{L_1 + L_2}{L_2}$

IV. THE OUTPUT VOLTAGEV$_2$

The output voltage is such that [3] : $\overline{V_2} = \frac{\overline{V_\phi}}{\overline{k}} = \frac{\overline{V_\phi}}{(\frac{L_1 + L_2}{L_2})\left[1 + \frac{jL_1L_2\omega}{\overline{Z}(L_1 + L_2)}\right]}$

$$\overline{V_2} = \overline{V_\phi}(\frac{L_2}{L_1 + L_2}) \times \frac{1}{(1 + \frac{jL_1L_2\omega}{\overline{Z}(L_1 + L_2)})}$$

At empty , Z=∞, and the output voltage is :

$$\boxed{\overline{V}_{20} = \frac{\overline{V}_{\phi} L_2}{L_1 + L_2}} \qquad (4)$$

V. DETERMINATION OF THE REACTIVE POWER INVOLVED BY THE REACTORS

It has been established that[3]

$$\frac{1}{\overline{Z}_{éq}} = \frac{\overline{Z}_2 + \overline{Z}}{\overline{Z}_1\overline{Z}_2 + \overline{Z}_1\overline{Z} + \overline{Z}_2\overline{Z}} \; ;$$

By writing $\overline{Z}_1 = jL_1\omega$; $\overline{Z}_2 = jL_2\omega$ in the expression of $\overline{Z}_{éq}$, we find :

$$\frac{1}{\overline{Z}_{éq}} = \frac{jL_2\omega + \overline{Z}}{j^2 L_1 L_2 \omega^2 + \overline{Z} j\omega (L_1 + L_2)} = \left(\frac{L_2}{L_1 + L_2}\right) \times \left(\frac{1 + \dfrac{\overline{Z}}{jL_2\omega}}{\dfrac{jL_1L_2\omega}{L_1 + L_2} + \overline{Z}}\right)$$

$$\frac{1}{\overline{Z}_{éq}} = \frac{1}{\overline{Z}} \times \left(\frac{L_2}{L_1 + L_2}\right) \times \left(\frac{1 + \dfrac{\overline{Z}}{jL_2\omega}}{1 + \dfrac{jL_1L_2\omega}{(L_1 + L_2)\overline{Z}}}\right)$$

The relation $\overline{I} = \dfrac{\overline{V}_{\phi}}{\overline{Z}_{éq}}$ gives $\overline{I} = \overline{V}_{\phi}\left(\dfrac{L_2}{L_1 + L_2}\right) \times \left[\dfrac{\dfrac{1}{\overline{Z}} + \dfrac{1}{jL_2\omega}}{1 + \dfrac{jL_1L_2\omega}{(L_1 + L_2)\overline{Z}}}\right]$ (5)

Given that $\overline{V}_2 = \overline{V}_{\phi}\left(\dfrac{L_2}{L_1 + L_2}\right) \times \dfrac{1}{\left(1 + \dfrac{jL_1L_2\omega}{\overline{Z}(L_1 + L_2)}\right)}$, we have : $\overline{V}_{\phi} = \left(\dfrac{L_1 + L_2}{L_2} + j\dfrac{L_1\omega}{\overline{Z}}\right)\overline{V}_2$

$$\overline{V}_{\phi} = \left(\frac{L_1 + L_2}{L_2}\right)\overline{V}_2\left(1 + \frac{jL_1L_2\omega}{\overline{Z}(L_1 + L_2)}\right) ,$$

so $\overline{V}_{\phi}\left(\dfrac{\dfrac{1}{\overline{Z}} + \dfrac{1}{jL_2\omega}}{1 + \dfrac{jL_1L_2\omega}{\overline{Z}(L_1 + L_2)}}\right) = \left(\dfrac{L_1 + L_2}{L_2}\right)\overline{V}_2\left(\dfrac{1}{\overline{Z}} + \dfrac{1}{jL_2\omega}\right)$ (6)

then $\overline{I} = \left(\dfrac{L_2}{L_1 + L_2}\right)\left(\dfrac{L_1 + L_2}{L_2}\right)\overline{V}_2\left(\dfrac{1}{\overline{Z}} + \dfrac{1}{jL_2\omega}\right) = \overline{V}_2\left(\dfrac{1}{\overline{Z}} + \dfrac{1}{jL_1\omega}\right)$

Express $\dfrac{1}{\overline{Z}} + \dfrac{1}{jL_2\omega}$ as a function of $\overline{k}$:

$$\overline{k} = \left(\frac{L_1 + L_2}{L_2}\right) \times \left(1 + \frac{jL_1L_2\omega}{\overline{Z}(L_1 + L_2)}\right) = j\omega L_1\left(\frac{1}{\overline{Z}} + \frac{(L_1 + L_2)}{jL_1L_2\omega}\right)$$

$$\frac{1}{\bar{Z}} = \frac{\bar{k}}{j\omega L_1} - \frac{(L_1 + L_2)}{jL_1 L_2 \omega}) \text{ so } \frac{1}{\bar{Z}} + \frac{1}{j\omega L_2} = \frac{\bar{k}}{j\omega L_1} - \frac{(L_1 + L_2)}{jL_1 L_2 \omega}) + \frac{1}{j\omega L_2} = \frac{1}{j\omega L_1}(\bar{k} - (\frac{L_1 + L_2}{L_2}) + \frac{L_1}{L_2}$$

$$= \frac{1}{j\omega L_1}(\bar{k} - \frac{L_1}{L_2} - 1 + \frac{L_1}{L_2}) = \frac{\bar{k}}{j\omega L_1} - \frac{1}{j\omega L_1} = \frac{1}{j\omega L_1}(\bar{k} - 1)$$

then

$$\boxed{\bar{I} = \frac{\bar{V}_2}{j\omega L_1}(\bar{k} - 1)} \tag{7}$$

The reactive power required by the inductors L_1 and L_2 is :

$$Q_L = (\omega L_1) I^2 + (\omega L_2) I_2^{\ 2} = \omega L_1 \frac{V_2^{\ 2}}{(\omega L_1)^2} \left|\bar{k} - 1\right|^2 + (\omega L_2) \frac{V_2^{\ 2}}{(\omega L_2)^2}$$

$$= \frac{V_2^{\ 2}}{\omega L_1} \left|\bar{k} - 1\right|^2 + \frac{V_2^{\ 2}}{\omega L_2} = (\frac{\left|\bar{k} - 1\right|^2}{L_1} + \frac{1}{L_2}) \frac{V_2^{\ 2}}{\omega} = Q_L$$

It is noted that the higher the output voltage (V_2) is, the greater the reactive power consumption of the reactancesbecause Q_L is proportional to $(V_2)^2$. [3].

At empty, we have $\bar{Z} = \infty \quad \bar{k} = k_0 = \frac{L_1 + L_2}{L_2}$ and $\bar{V}_{20} = \frac{\bar{V_\phi} L_2}{L_1 + L_2}$

then :

$$\boxed{Q_L = \frac{V_\phi^{\ 2}}{(L_1 + L_2)\ \omega}} \tag{8}$$

VI. REACTIVE COMPENSATION POWER

According to the characteristics of the electrical network, the system of the inductive divider can operate with or without compensation of the reactive energy requested by the reactances. In the event that compensation is required, the calculation of the capacitor bank is necessary. The battery of compensating capacitors is the one that would be capable of supplying locally with all the reactive energy that could be applied by the two reactances, that is to say with reactive power equal to the consumption of the two inductances L_1 and L_2. [3].

VII. APPLICATIONS

Several African countries have transport networks in 220 kV. Starting from the example of an inductive divider which provides an average voltage of U = 20kV from a 220kV high voltage line, one can end up with a phase-to-ground voltage of $V_\Phi = 127$ kV.

The case of the vacuum system makes it possible to write:

$$k_0 = \frac{L_1 + L_2}{L_2} = \frac{V_\phi}{U} = 6{,}35 \text{ then } \frac{L_1}{L_2} = 5{,}35$$

Assuming a fairly low current to the ground of 0.2Afor example, we write the relation

$$I_0 = \frac{V_\phi}{\omega L_2 (\frac{L_1}{L_2} + 1)} = \frac{V_\phi}{(L_1 + L_2)\omega} = 0{,}2\text{A} \quad \text{with } \omega = 314 \text{ rad/s} \tag{9}$$

The combination of these two relations leads to the values of inductances:

L_1 = **1658 Henry et L_2= 310 Henry**

If empty, such a divider would remove from the network a reactive power of Q_L

$Q_L = L_1 \omega I_0^{\ 2} + L_2 \omega I_0^{\ 2} = (L_1 + L_2)\omega I_0^{\ 2}$ Q_L=24718 VAR

Let (n) be the number of turns per unit length of the inductance coil (L) and of length (l), the induction at the center of the coil is B = μ (n) i. In this expression (i) is the current which passes through the coil of average radius (r).The induction flux through a coil is : $\Phi=B\pi(r^2)$and for the set of (nl) turns :

$\Phi=(nl)\ \mu(n)i\pi(r^2) = \mu(n^2)\pi l(r^2)i = Li$

$$n = \sqrt{\frac{L}{\mu(l)\pi(r)^2}} \quad ; \mu= \mu_0\ \mu_r \text{ with} \mu_0=4\pi 10^{-7} \text{ H/m} \qquad (10)$$

Increasing the permeability may make it possible to obtain a smaller number of turns.

By taking l = 1.5m and r = 0.5m for length and average radius of the coils $n^0 1$ and $n^0 2$ and for ferromagnetic material such as $\mu=1000\ \mu_0 = 4\pi 10^{-4}$ H/m for example; 1057 turns/m and 457 turns/m are found to be numbers of respective turns N_1 = 1585 turns and N_2 = 685 turns

VIII. CONCLUSION

A theoretical study is carried out; It is a question of continuing to carry out investigations for possible experiments in order to see the practical feasibility of such electrical systems.

In the design of the project, consideration must be given to the regulation of the output voltage and the protective equipments of the substation. The advantages of such a system are numerous in rural electrification:

- reduction of the space required for the substation;
- the soundness of the system;
- ease and speed of installation;
- the low cost

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