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HIGH VOLTAGE LINES: ISOLATED GUARD CABLES CAN BE POWER SOURCES FOR RURAL ELECTRIFICATION

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ABSTRACT

In Africa, rural electrification is still facing difficulties; The technique of isolated guard cables may be one of the promising solutions for villages located near high voltage lines.The guard cable of the high voltage lines is the conductor placed above the others, its main objective is to protect the line against atmospheric discharges.

This cable is normally linked to the earth through pylons and is not useful for any transmission of electricity.Once this cable is isolated from pylons, it becomes one of the armatures of the capacitor, the other being composed of other conductors and we can get inducedvoltage both capacitive (mainly) and inductive effects.

A conductor directly connected to this isolated guard cable can extract some energy owing to a one phase transformer, the return current going to the earth.

This paper describes such technique and show the predetermination method of obtained induced voltage and potential power to extract. Here, an example of calculation is detailed.

Such technique would benefit from a large dissemination especially to the developing countries where electric problems are not yet solved in rural area.

Keywords: Guard cable, Induced voltage, One phase transformer, Rural electrification, Developing countries.

1. INTRODUCTION

On an entirely different level, electrification emerges at an important moment in the history of energy which sees the evolution of the electricity service.

Fully on four feet: technological, ecological, economic and social, rural electrification is ready to take up the challenge of development.

Providing electricity in rural areas is becoming a necessity to meet the ever-increasing demand of rural people for energy.

For developing countries, it would seem appropriate to define the bases for continuing, widening, disseminating know-how tools and new technologies and ensuring their mastery in order to democratize access to electrical energy.

For a global evolution, more than in the past, we need to look closely at the realities of rural electrification in poor countries where some isolated strata of the population remain in this third millennium, still excluded from the modern world and sometimes even the limit of civilization.

High voltage lines cross entire territories, leaving behind countless villages that wait in vain for the connection to the electricity grid.

It would be profitable to exploit innovative techniques such as that described herein of the isolated guard cable which would offer a further possibility of supplying somewhat of a few single-phase electric charges located along the high voltage lines.

2. THEORETICAL PRINCIPLE

Regarding the induced voltage in isolated guard cables, other parameters such as line geometry, conductor dimensions and the topography of the ground beneath the conductor bundle also have a direct influence on the amount of energy coupled to guard cable.

This coupling is that achieved by the natural capacities of the line for drawing off the energy from a suspended conductor in the vicinity of the phase conductors of a line at HV, the conductor suspended here being the guard cable. Indeed, for a line with HV, there are natural capacities between the phase conductors and the guard cable on the one hand and between these conductors (active or guard) and the ground on the other hand.

A conductor connected directly to the isolated guard cable then makes it possible to extract the induced energy to supply a load through a transformer and a device for regulating the voltage, the return of the current being effected by ground or by another guard cable if any.

Thus, a fraction of the "lost" energy of the high voltage lines can be recovered by induction to supply a single-phase load according to the length of the isolated cable and the configuration of the line.

3. OPERATION OF THE SYSTEM

With this technique, small African villages can be supplied, for example, along a high voltage line, by means of optional single-phase MV / LV distribution transformers connected between the guard cable and the earth. In order to keep the supply voltage sufficiently constant in view of variations in the load, voltage regulating equipment is required (for example, thyristor-controlled reactors). The advantage that can result from this is the transport of energy by a single phase conductor to the single-phase MV / LV substation [1].

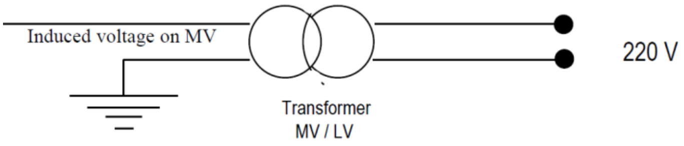

Fig 1: Schematic diagram of the system

The cost of insulation of the guard cable is negligible compared to that of an independent single-phase MT line. It will be necessary to concentrate on the following technical aspects [1]:

- The guard cable, isolated, must always provide protection against lightning as well as a guard cable connected to earth;
- Shielded spark gaps must be installed in order to discharge lightning currents of high intensity to earth;
- In steady state, the guard cable is subjected to induced voltages from the HV line (by capacitive and magnetic coupling);
- The unsymmetrical short-circuit currents of the HV line can induce relatively large overvoltages in the guard cable, which must be kept within acceptable limits;
- The overvoltages induced by the maneuvers of the HV line in the guard cable must be studied and the insulation coordinated accordingly;
- The earthing electrodes subjected to a permanent current must be checked for the temperature of the ground (thermal stability) and safety.

4. ADVANTAGES OF THE SYSTEM

The operation of this system would be autonomous and reliable, consequently its use proves suitable for the rural electrification of small isolated localities.

The available power is mainly a function of the voltage level of the line and its particular geometrical configuration. The higher the voltage level, the greater the power per kilometer of isolated guard cable. The MV / LV transformer must be equipped with a control circuit to maintain the output voltage stable [1].

5. PROTECTIVE EFFECT OF ISOLATED GUARD CABLE

It can be expected that the protection efficiency of the line will not be diminished. Indeed, in this practice, over the length of the isolated cable, it is isolated from the pylons by means of the spark gaps and when the lightning strikes, the cable is grounded through the arc, spark gap producing a short earth circuit.

The choice of the type of the spark gaps and their setting is important, a spark gap on each insulator will allow the guard cable to continue to fully fulfill its function of protection against lightning for the HV line.

5. 1 The induced surges

The overvoltages induced in the guard cable are proportional to the current which induces them and to the length of the exposed cable. The highest values for a short-circuit between phase and earth are obtained.

The correct dimensioning of the spark gaps and the regulation of the voltage collected from the isolated guard cable must be taken into account.

5. 2 Maneuver overvoltages and ferroresonance

In fact, iron core reactors become saturated as soon as the flow through it exceeds its saturation bend. In this case, the reactance of the MV / LV transformer and the capacity of the guard cable can be tuned to 50 Hz and to cause the circulation of a very significant overcurrent in the circuit and thus the appearance of an overvoltage of ferroresonance.In the case of series ferroresonance, we would have[1]:

$$\frac{1}{2}LI^{2} = \frac{1}{2}C^{2} \Rightarrow V_{c} = I\sqrt{\frac{L}{C}}\ [V](1)$$

V_C: the voltage at the terminals of the equivalent capacity of the guard cable.
This result shows how the overcurrent can it cause persistent surge in isolated custody of the cable network.

Two countermeasures are possibles**:**

- Installation of a battery of capacitors of rephasing between the guard cable and earth. This capacitor prevents the phenomenon and reduces the overvoltages to acceptable values.
- Determination of the minimum load of distribution transformers to avoid the phenomenon: a 10% load may be sufficient to reduce the overvoltages to acceptable values. In general, the techniques used to protect the circuits against overvoltages of ferroresonance consist in an application, as soon as the surges appear, of a damping load judiciously placed in the circuits. Its role is to absorb the reactive energy that was stored. This amortization charge must be triggered as soon as a steady state regime is restored. The above provisions or a combination of these arrangements reduce the induced voltage in the guard cable to values not hazardous to the equipment[1] :

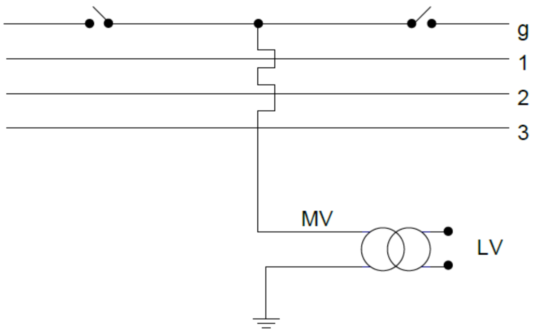

Fig 2: Isolated guard cable system

Notations:
C: rephasing capacitors providing protection against the phenomenon of ferroresonance (possibly) on the one hand and for correction of the power factor on the other hand.
F: fuse;
P: surge arrester;
T: single-phase distribution transformer (MV / LV);
E: guard cable insulation with horn spark gaps;
G: isolated guard cable.

6. THE RETURN OF THE CURRENT THROUGH THE GROUND

The main difficulty of returning the current through the earth is to prevent the earth from drying out in the vicinity of the electrodes, as this may lead to an uncontrolled increase in earth resistance and heat dissipation. The risk of thermal instability of the earthing electrodes can be eliminated if their resistance is very low and maintained in this state.
For safety reasons, the use of several well separated and looped electrodes is recommended. The main problem is how to extend the calculation criteria to the site's soil characteristics (moisture, resistivity, etc.), field studies are necessary[2], [3], [4].
In this type of installation in tropical areas, earthing must comply with current electrical standards[5].

7. DETERMINATION OF THE INDUCED VOLTAGE IN THE ISOLATED GUARD CABLE

7.1 Methodology

For the calculation of the induced voltage, the capacitive and magnetic couplings are considered on the isolated guard cable. We denote by V_{1G} the voltage induced by capacitive coupling and by V_{2G} the voltage induced by magnetic coupling. The principle of superposition is applied to the two voltages V_{1G} and V_{2G} in order to find the resulting induced voltage V_G on the isolated guard cable [1].

Notations:
F: fuse
P: surge protector
C_{ij}: coefficient of influence between the i^{th} and the j^{th}conductor (F/m)
C_{ii}: own capacitance per unit length of the i^{th}conductor (F/m)
$C_{55} = C_{GG}$: own capacitance per unit length of isolated guard wire (F/m)
Mij: mutual inductance between the i^{th} and the j^{th}conductor (H/ m)
Qi: electrical charge per unit length on the i^{th} conductor (Coulomb/m)
Vi: potential of the i^{th} conductor (V)
V_{IG}: induced voltage in the isolated guard cable by capacitive coupling (V)
V_{2G}: induced voltage in the isolated guard cable by magnetic coupling (V)
V_G: resulting induced voltage (V)
U: line voltage = 220 kV
I: current intensity (A)
L: length of isolated guard cable (m).

7.2 Voltage induced by capacitive coupling: a case study

Let us apply our calculations in the case of 220 kV high voltage lines from most African countries.By the method of the images, the matrix of the potential coefficients (K) is determined such that $[V]=[K]\cdot[Q]$with $[Q]=[C]\cdot[V]$and K= C^{-1} (2)

The characteristics of the line studied:
220 kV three-phase HV line with one conductor per phase of section 570 mm^2 and two guard cables of 94.1 mm^2 each, therefore radii of 15 mm and 6 mm respectively. The phase conductors $n^0$1 and $n^0$3 are located 14 m above the ground and the other dimensions are shown in the following figure with vertical symmetry [1]:

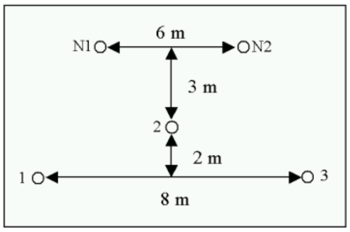

Fig. 3: Layout of 220kV line conductors

(1), (2), (3) are the phase conductors and N1, N2 the guard cables.
The matrix of potential coefficients (K, such that V = K.Q) is represented in the table below:

Table 1: Matrix of influence coefficients

K	1	2	3	N1	N2
1	1.37E+11	3.44E+10	2.32E+10	3.36E+10	2.46E+10
2	3.44E+10	1.40E+11	3.44E+10	3.80E+10	3.80E+10
3	2.32E+10	3.44E+10	1.37E+11	2.46E+10	3.36E+10
N1	3.36E+10	3.80E+10	2.46E+10	1.59E+11	3.34E+10
N2	2.46E+10	3.80E+10	3.36E+10	3.34E+10	1.59E+11

with $$K_{kj}=\frac{1}{2\pi\varepsilon}\ln\left(\frac{r_{jk}}{r_{jk}}\right)\text{(m/F)}\quad(3)$$

$r_{jk} = r_{kj}$ and $K_{jk} = K_{kj}$
r_{kj} is the distance between the axes of the j^{th} conductor and the k^{th}conductor.
r_{jk} is the distance between the axes of the j^{th} conductorand the image of the k^{th} conductor in relation to the ground.The$K_{jk}$are the potential coefficients.
By inversion of the matrix K, we obtain the matrix of the linear capacitances C= K^{-1}, such thatQ = CV (Table 2):

Table 2: Capacitive coupling matrix

C	1	2	3	4=N1	5=N2
1	8.12E-12	-1.36E-12	-6.92E-13	-1.17E-12	-5.37E-13
2		8.52E-12	1.36E-12	-1.27E-12	-1.27E-12
3			8.12E-12	-5.37E-13	-1.17E-12
4=N1				7.11E-12	-8.96E-13
5=N2	**SYM**				7.11E-12

$\bar{V}_1 = V_1 = U/\sqrt{3} = 127$ kV and $\bar{V}_2 = a^2.\bar{V}_1$;$\bar{V}_3 = a.\bar{V}_1$ witha = $-1/2 + j\sqrt{3}/2$

First case:

Assuming that the guard cables N1 and N2 are isolated, that is to say they carry no load (QN1 = QN2 = 0), the solution of the system is as follows (Table 3):

Table 3: System solution

Q_1	$1.17E\text{-}06\sqrt{2}$	$\sin(\omega t)$	Coulombs/m
Q_2	$1.23E\text{-}06\sqrt{2}$	$\sin(\omega t-120°)$	Coulombs/m
Q_3	$1.17E\text{-}06\sqrt{2}$	$\sin(\omega t+120°)$	Coulombs/m
V_{N1}	$12.17\sqrt{2}$	$\sin(\omega t-75°)$	kV
V_{N2}	$12.17\sqrt{2}$	$\sin(\omega t-160°)$	kV

By finite element calculations:

$$V_{N1} = 12{,}7\sqrt{2}\sin(\omega t-73°) \quad \text{kV}$$
$$V_{N2} = 12{,}7\sqrt{2}\sin(\omega t-167°) \quad \text{kV} \qquad (4)$$

Second case :

We will consider the case where only one of the two guard cables is isolated (N2 isolated) and N1 grounded, we have: (VN1 = 0 and QN2 = 0)

The result obtained is illustrated in Table 4 here [1].

Table 4: System solution

Q_1	1.17E-06	$\sqrt{2}\sin(\omega t)$	Coulombs/m
Q_2	1.25E-06	$\sqrt{2}\sin(\omega t-120°)$	Coulombs/m
Q_3	1.16E-06	$\sqrt{2}\sin(\omega t+120°)$	Coulombs/m
V_{N2}	12,30	$\sqrt{2}\sin(\omega t-172°)$	kV

By finite element calculations :

$$V_{N2} = 13\sqrt{2}\ \sin(\omega t-175°) \qquad (5)$$

It will be noted that the induced voltage $V_{N2} = V_{IG}$ does not depend on the length of the isolated guard cable, but only on the geometry of the high voltage line conductors.

Equivalent scheme of Thevenin

Consider the situation of the second case of a single isolated guard cable(N2 isolated).

The equivalent circuit of Thevenin is represented by an electromotive force$E_{TH} = \mathbf{V_{1G}}$ and an impedance Z_{TH}.

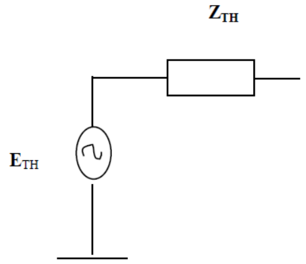

Fig. 4: Equivalent scheme of Thevenin

The electromotive force obtained is E_{TH} = 13 kV= V_{1G}
C_{44} being the capacitance per unit length, the impedance sought is then
Z_{TH}= 1/ $\omega L C_{44}$[Ω] (6)
L: length of the isolated cable. According to the capacity matrix ,$C_{44}=7{,}11.10^{-12}$ F/m.

7.3 Induced voltage in the guard cable by magnetic coupling: V_{2G}

The isolated guard cable is therefore influenced by the resulting induction from the three phase conductors:

$$\vec{B} = \frac{\mu \cdot i_1}{2\pi \cdot r_1}\vec{u}_1 + \frac{\mu \cdot i_2}{2\pi \cdot r_2}\vec{u}_2 + \frac{\mu \cdot i_3}{2\pi \cdot r_3}\vec{u}_3 \quad (7)$$

$\vec{u}_i$ a unit vector tangent to the circle of radius (r) centered on each conductor. The linear mutual inductance between the isolated guard cable and the i^th^phase conductor traversed by a current I_k is denoted by Mi[6].

$$M_i = \frac{\mu}{2\pi}\ln\left(\frac{r_{in} \times r_{jn}}{r_{ij}}\right) \text{(H/m)(8)}$$

r_{ij}: distance between the guard cable and the i^{th} conductor.
r_{in}: distance between the i^{th} conductor and the ground
r_{jn}: distance between guard cable and ground
$\mu = \mu_o . \mu_r$: permeability, $\mu_o = 4\pi.10^{-7}$H/m ;(air , μ_r=1).
The voltage induced by magnetic coupling is proportional to $M_1\bar{I}_1 + M_2\bar{I}_2 + M_3\bar{I}_3$
This tension is $\bar{V}_{2G} = -j\omega L\,(M_1\bar{I}_1 + M_2\bar{I}_2 + M_3\bar{I}_3)$ [V] (9)
L: the length of the isolated guard cable
In our case study, (three-phase line, simple dull, balanced in current),
we have: $\bar{I}_1$=I ; $\bar{I}_2 = a^2$.I and $\bar{I}_3$= a.I with a = -1/2 + j$\sqrt{3}/2$
then $\bar{V}_{2G} = -j\omega L\,[\,(M_1 - \frac{1}{2}(M_2+M_3) + j\frac{\sqrt{3}}{2}(M_3-M_2)].I$ [V] (10)
(I denotes the current intensity of the line).
The coefficients Mi are generally low value and we will understand that this voltage induced by magnetic coupling V_{2G} is small and negligible in front of the voltage induced by capacitive coupling V_{1G}.For the case study considered, the calculation gives:
$M_1=7{,}91.10^{-7}$ H/m ; $M_2= 8{,}43.10^{-7}$ H/m; $M_3=6{,}86.10^{-7}$ H/m
We find :$\bar{V}_{2G}$ = (- 426,72 x10^{-7} - j83,2 x10^{-7}).LI (V) (11)
and we have $V_{2G} = 434.10^{-7}$ L.I . For example, L=1000m and I=90A , we find
V_{2G} = 3.9 Volts therefore very negligible!

We conclude that$V_{2G} \approx$ 0 and $V_{1G} \approx V_0$ .The largest induced voltage in the isolated guard cable is simply that of the capacitive coupling.

8. ELECTRICAL POWER AVAILABLE ON ISOLATED GUARD CABLE(ONLY THE CAPACITIVE COUPLING).

The induced voltage $\mathbf{V_0}$is proportional to the nominal voltage of the line and the length of the isolated guard cable.
The Thevenin impedance of the circuit equivalent to the isolated guard cable is denoted by
$\bar{Z}$= R+jXand the voltage at the terminals can be written: :$\overline{V_0} = \overline{V_R} + \overline{V_X} = \overline{V_R}$+jX$\bar{I}$whereas on the resistance, we have:$\overline{V_R} = V_R$ that is to say a pure real.
Let I be the intensity of the current which passes through the system of the isolated guard cable supplying a load; the delivered complex power ($\bar{P}$)is :$\bar{P} = \overline{V_0} \cdot \bar{I}$
The relation $\bar{I} = \frac{\bar{V}_0 - \bar{V}_R}{jX}$leads to $\bar{P} = \overline{V_0}(\frac{\bar{V}_0 - \bar{V}_R}{jX})$
If we write$\overline{V_0} = V_0$(cosδ + j sinδ) , we find : $\bar{P} = \frac{[V_0(\cos\delta + j\sin\delta)]^2 - \overline{V_0}V_R}{jX}$

The active power produced is the real part of $\bar{P}$:

Real of $(\bar{P}) = P = \frac{2V_0{}^2 \cos\delta \sin\delta - V_0 V_R \sin\delta}{|X|}$ [W] (12)

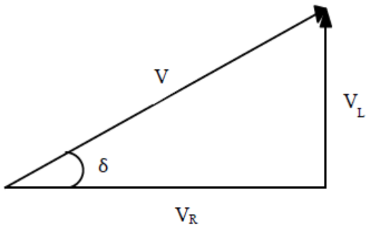

Fig 5: Construction of Fresnel

From the construction of Fresnel, it follows that $V_R = V_0 \cos\delta$ and so

$$P = \frac{2V_0{}^2 \cos\delta \sin\delta - V_0{}^2 \cos\delta \sin\delta}{|X|} = \frac{V_0{}^2 \cos\delta \sin\delta}{|X|} \quad [W] \qquad (13)$$

The active power produced by the system is :

$$\mathbf{P} = \frac{V_0{}^2 \sin 2\delta}{2|X|} \quad [W] \qquad (14)$$

This equation shows that it is possible to raise this active power produced either by increasing the transport angle between the two points or by artificially reducing the X reactance of the link.

The maximum power that the isolated guard cable can provide is thus:

$$\mathbf{P}_{\mathbf{max}} = \frac{V_0{}^2}{2|X|} [W] \quad (15)$$

L: the length of the isolated guard cable

$|X| = 1/ C_{44}.L.\omega$ and $\mathbf{P}_{\mathbf{max}} = \frac{V_0{}^2}{2} \mathbf{C_{44}.L.\omega}$ [W](16)

The power to be extracted on the guard cable is therefore proportional to the length L of the isolated part.

9. CONCLUSION

The technique of isolated guard cables can prove beneficial for rural electrification in developing countries where innumerable power lines run through the territories for the sole purpose of supplying the main cities. These mainly rural populations, hope to be fed by the lines that pass over their heads. For these countries, new techniques such as the one studied here are particularly welcome for an energy deployment for the benefit of local populations along or near high-voltage power lines.

10. REFERENCES

[1] A. OMBOUA - Thèse de doctorat 2002 - Université de Liège : Alimentation de faibles charges directement des lignes à haute tension. PP 47-71.

[2] I1iceto F, Gatta F. M, S. Lauria, G. Dokyi, "Three-Phase and Single- Phase Electrification in Developing Countries Using the Isolated Shield Wires of HV Lines Energized at MV, /1 in Proc. CI RED 1999, Nice (France), Paper N° 5/pl0.

[3] Iliceto F., Gatta F.M., Lauria S., Debebe M., Hussen M., "Rural Electrification in Ethiopia with the Shield Wire scheme", CIRED paper N° 5/plO, 2005 Session, Nice (France).

[4] Iliceto F., Gatta F.M., Masato P., Sysoulath H, "Rural Electrification in Developing Countries with the Shield Wire Scheme. Applications in Laos," in Proc. CIGRE General Session 2004, Paper C6-301.

[5] Jean Louis Lilien, Monfils Pierre André, Alphonse Omboua :One phase rural distribution installation with direct connection to HV trunk line - 17 th International Conference and exhibition on Electricity Distribution – Barcelona 12 -15 May 2003.

[6] Treatise on Electricity-Volume XII
Michel Aguet and Jean Jacques Morf, Edition Georgi– 1981

[7] AlidouKoutou . Février. 2015 - Etude des déséquilibres d'amplitude et de phase des tensions d'un réseau a câbles de garde isolés de lignes de transport d'énergie électrique – Mémoire de maîtrise en génie électrique - Université du Québec à Trois-Rivières.

[8] C.F . Dalziel , "Electric Shock Hazard," IEEE Pectrum, pp.41-50, February 1972

[9] A. Omboua, "The High Voltage Line Becomes aPower Distributor : A Successful Test in Congo-Brazzaville", Journal of Electrical Systems 2-1 (2006) pp 52-63. http://journal.esrgroups.org/jes/

[10] Iliceto F., Gatta F.M., Lauria S., Debebe M., Hussen M., "Rural Electrification in Ethiopia with the Shield Wire scheme", *CIRED paper N° 5/plO, 2005* Session, Nice (France).

[11] I1iceto F, Cinieri E, Casely-Hayford L, Dokyi G, "New Concepts on MY Distribution from lnsulated Shield Wires of HV Lines. Operation Results of an Experimental System and Applications in Ghana", *IEEE Trans. on Power Delivery*, VolA, N°4, October 1989, pp. 2130-44.

[12] Iliceto F., Gatta F.M., Cinieri E., " Rural Electrification of Developing Countries using the insulated Shield Wires of HV lines. New design criteria and operation experience,"in Proc. *CIGRE General Session 1994*, Paper 37/38-03.