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Equivalent Structures for Nonlinear-Signal Cable Networks

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Introduction

The effects of harmonic resonance between the supply source and large cable networks with large harmonic sources, such as railway systems, are well known. The harmonics generated by large semiconductor drives may excite the resonance between the source and the load by the cable tract. This will have the effect of amplifying the generated harmonics, resulting in lower efficiencies of operating equipment and the possible damage to equipment. A frequently encountered case is that of one power supply driving another, so that we have the same case of a power supply driven by an input filter. If the power supply feedback loop does not have sufficient bandwidth, the output impedance of the source can be to high [1]. If this impedance exceeds the input impedance of the supply source, which is acting as a load, and the phase of the impedance is close to 180 degrees, the system will oscillate or it will be dangerously close to do so. In the case of a distributed power cables supply, where one power cable is driving many others, the same principles still apply. Analysis for these cases requires the conversion of impedances into admittances for each branch of interest, at the point where the system is to be analyzed. At any frequency, admittances can be converted to an equivalent T structure with capacitive and inductive admittances and a resistor. All this quantities will be functions of frequency. At the frequency where the sum of the admittances is negative, the system has a stability problem. This calculation is a hard task since in practice, usually, loads are combinations of series and parallel elements that have to be accurately combined, and exact calculation of cable impedance is essential. Some new methods derived from original models of cable networks are proposed in the following sections, in order to avoid the perturbations caused by nonlinearities induced by cable networks. We consider these issues necessary, as with any piece of electrical equipment there are a number of applications regarding the energy transport that engineers need to be aware of. These issues are addressed based on the authors' experience and research work in various capacities, consulting with end users, engineers from maintenance field, thus having a global view over the energy transport in the cable networks.

Equivalent structures for the nonlinearities cable ampacities

A simplified equivalent circuit, incorporating parasitic, for the expansive odd-order nonlinearly cable circuit is shown in Fig. 1.

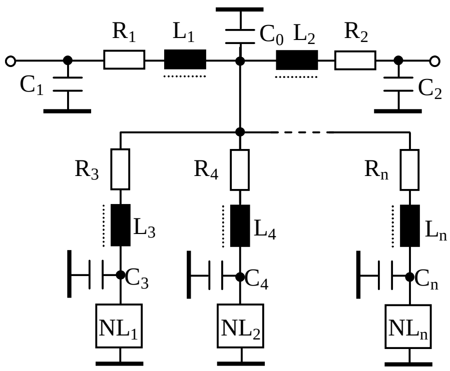

Fig. 1. Equivalent circuit of the odd-order nonlinearity with parasitic

In Fig. 1 resistors R_1, R_2, …, R_n represents the ohmic resistance of the cable length (between two consecutive junctions), C_1 represents the capacitance of the cable distributor junction, NL_1, NL_2, …, NL_n represent ideal memory less nonlinearities [2]. Inductances L_1, L_2, …, L_n represent parasitic like lead inductance and bonding pods. In order to explain the model given in Fig. 1 we recall the basic T–network cable junction (distributer) structure, as it is shown in Fig. 2 [3].

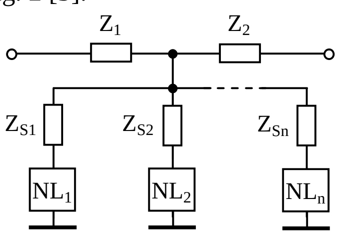

Fig. 2. General T cable network lossy linearizer topology

NL_1, NL_2, …, NL_n are one-port nonlinearities. We also notice the similarities between the cable elements shown in Fig. 1 and the cable elements in Fig. 2. All non-linearities NL_i, i = 1, …, n are assumed to be weak, which enable them to be expressed as a finite power series [4]. Therefore, a one-port nonlinearity NL can be defined by the following relationship

$$I(V) = \sum_k b_k \cdot V^k \ , \tag{1}$$

where k = integer greater than 0; b_k = complex.

The nonlinearity can also be defined by the relationship as

$$V(I) = \sum_j a_j \cdot I^j \ . \tag{2}$$

A one-port nonlinearity can therefore be represented either by a linear conductance b_1 and controlled current sources representing higher degree terms or by a linear resistance a_1 and controlled voltage sources, as shown in Fig. 3, respectively in Fig. 4.

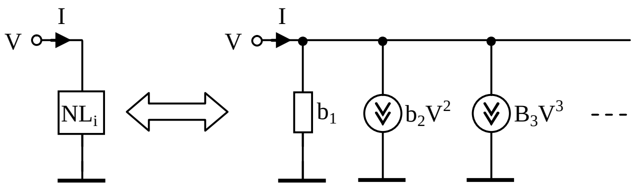

Fig. 3. Representation of a one-port nonlinearity modelled with current sources

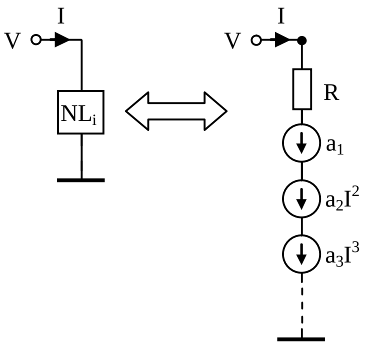

Fig. 4. Representation of a one-port nonlinearity modelled with voltage sources

Using the above principle, the generalized lossy nonlinear network can be redrawn as shown in Fig. 5, where the current source representation has been used.

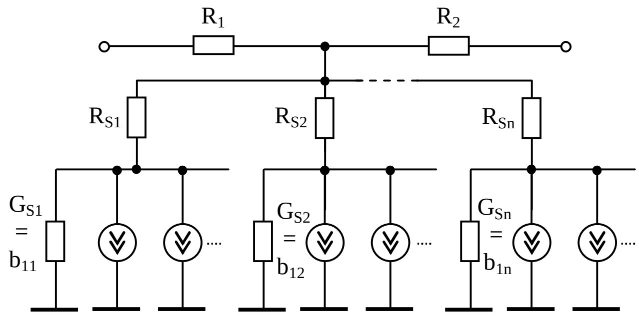

Fig. 5. Detailed example for the cable network lossy linearized given in Fig. 2

The linear equivalent cable network for the model given in Fig. 5 is shown in Fig. 6.

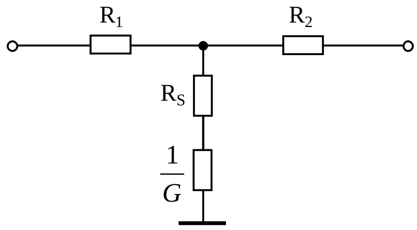

Fig. 6. Linear equivalent circuit of a T network lossy linearizer

We notice in Fig. 6 that $R_S + \dfrac{1}{G}$ is equivalent to the parallel combination of elements $R_{S_i} + \dfrac{1}{G_i}$ in Fig. 5, where i = 1, …, n; n being the number of wires of the cables connected in a general T network.

The principle of weakly nonlinear cable networks permits the excitation (I or V) of the one-ports to be calculated using the linear equivalent network. The nonlinear current or voltage sources can be computed subsequently. These derived sources, together with the fundamental sources, can be treated as part of a linear network. Considering the linear approximate model, the linear equivalent network can be designed as a lossy two-port network as appropriate.

As an example it may be a symmetric amplifier (or a differential one) with a characteristic impedance and back current or back voltage source proportional to the parasitic signals induced in the cable network, as we show in Fig. 7:

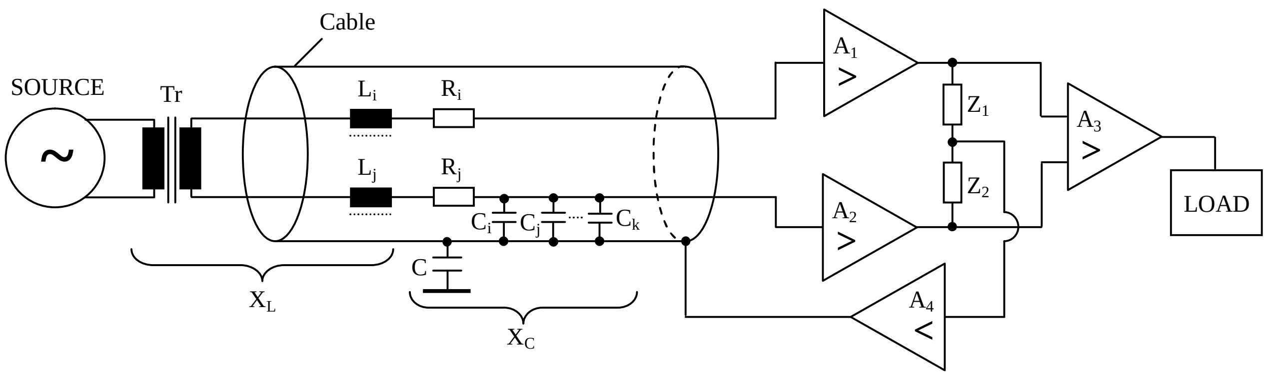

Fig. 7. Voltage magnification circuit for weakly nonlinear cable networks

where L_i, L_j are cable inductances, C_i, C_j,…,C_k are the cable parasitic capacitors, A_i, i = 1, …, 4 are the amplifiers used to magnify the voltage in order to neutralize the nonlinear influences gathered by the cables length and the source / load characteristics.

There are a few techniques for minimizing the nonlinearities NL_i from cable networks [5–8]. Experimentally it is proven [9] that these nonlinearities influence in a negative sense the admittance of cable networks, and especially capacitances C_i from impedances Z_i in cable networks given in Fig. 1 and Fig. 2 are responsible for this fact. Therefore, in order to calculate the required amount of capacitance to raise the power factor of an electric power system, respectively the cable networks admittances, to a specified higher power factor, we notice that some utilities calculate the power factor as an average during the 30 – 40 min interval coincident with the peak kW or kVA demand, depending on how utility bills for peak demand. Other utilities accumulate kilowatthours (kWh) and kilovarhours (kvarh) over the course of the month, in effect calculating an average power factor over the entire month. For the first case mentioned above, one may use the power factor and the peak kW or kVA during the demand interval to do the required kvar calculation. For the second case, one may use the accumulated kWh or kvarh to first calculate the required kvarh of correction needed over the month and then divide out the hours in the month to get the required capacitor bank size.

In practice, power factor correction calculations based on peak kW / kVA and power factor in a short demand interval needs a larger capacitor bank to correct the power factor than the accumulated kWh or kvarh over a month method. This is due to the fact that the kvar calculation is done at peak load, even if the power factor during the interval may not be as low as the power factor during periods of lighter load. We notice that one may be below the target factor sometimes, because this may allow one to choose a smaller fixed capacitor, as opposed to a larger switched capacitor bank. It is not practical to cover all the possible variations on how power factor might be calculated. We conclude that one should remind that the way power factor is calculated affects the required kvar calculation.

Harmonics in electrical cable

Talking about harmonics of signals transmitted by electrical cables is a must. We do not intend to analyze harmonic resonance but to discuss the issues related to electric resonance. We notice that resonance is a self-correcting process: when it appears fuses will blow, breakers will trip, thus changing the resonant points and detuning the cable. IEEE Std. 519-1992 discusses the possible effects of harmonics on electrical cable as a consequence of harmonics in capacitors. The parallel between these two harmonics arise from the use of capacitors in a power system, which makes possible the appearing of system resonance. This effect imposes voltages and currents that are considerably higher than would be the case without resonance.

As it is known [3], the reactance of a capacitor decreases with frequency (including the parasitic capacitor in electrical cables) and the bank, therefore, acts as a sink for higher harmonic currents. This effect increases the heating and dielectric stresses. The result of the increased heating and voltage stress brought about by harmonics is a shortened cable life.

There are two fundamental resonances in electrical cables: series resonance and, respectively, parallel resonance.

Series resonance occurs when a cable network lossy linearizer "sees" an inductance (in the form of a cable or transformer) in series with a power factor correction capacitor. At some frequency the series combination of the inductance and capacitance PFCap will be equal and will sum to nearly zero plus the cable resistance. This is a path for harmonic current at that frequency. Fig. 8 shows series resonance as it is "seen" by the cable load.

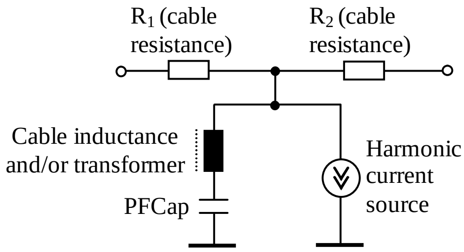

Fig. 8. Equivalent circuit of series resonances in a lossy linearizer cable network

A palliating device used in cases of series resonance is the harmonic filter that is purposely "series resonant" at a fixed frequency to attract harmonic currents and reduce harmonic voltage distortion. Uncontrolled series resonance generally results in nuisance fuse operation or tripping of circuit.

Parallel resonance appears when the power system is tuned to a certain harmonic, usually due to a capacitive growth PFCap of cable ampacities. A parallel resonance presents high impedance to injected harmonics at or near the resonant frequency, thus amplifying harmonics at these frequencies. There are problems only if a source of harmonics exists at or near that frequency. Fig. 9 shows parallel resonance as it is "seen" by the cable load.

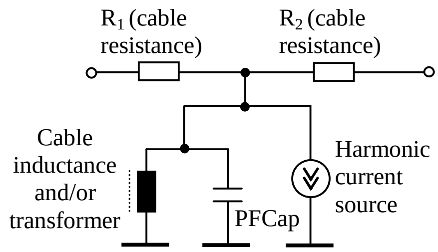

Fig. 9. Equivalent circuit of parallel resonance in a lossy linearizer cable network

We notice that it is unlikely to inject harmonics at precisely the parallel resonant frequency, but near-resonance may be very damaging as well. We conclude that parallel resonance is conditioned by the following issues:

- Harmonic-producing loads (for example arcing devices, switch made power devices, AC/DC drives etc.);

- Parallel resonance exists at a frequency equal to or near the harmonic frequencies made by the above loads, especially on long feeders supply.

The resonant frequency of a cable network can be estimated with the following formula

$$w = \sqrt{\frac{X_C}{X_L}}\ , \qquad (3)$$

where w is the tuned harmonic of the system, X_C is the capacitive reactance (see Fig. 9), and X_L is the inductive reactance (see also Fig. 9).

When harmonics appear, it is recommended to follow the next algorithm [7] in order to avoid damages in the cable network and in the loads:

- Perform a resonance calculation for each amount of reactances;
- If the harmonic resonance is not close to characteristic harmonics of typical harmonic-producing leads (5^{th}, 7^{th}, 11^{th}, 13^{th} etc.), apply the procedure shown in Fig. 7 and described in the second section, or apply straight supplementary capacitors;
- If the harmonic resonance is close to characteristic harmonics use filters, or redesign the cable network (basically one may include supplementary T cells) as shown in Fig. 5.

Conclusion

The issues discussed in this paper are not as well documented in the literature, therefore we focus our researches on this area and we have as a goal underlining and summarizing the effects that are either not always noted or not traced. These problems occur in practice and designers of electrical power systems are cognisant of these difficulties and will usually install power factor correction in the form of harmonic filters. An alternative solution was presented here. Our future work will focus on detailed examples for data cable networks such as those used for computer networks.

References

1. **Simpson R. H.** Misapplication of power capacitors in distribution systems with nonlinear loads – three case histories // IEEE Trans. Ind. Appl. – Jan.-Feb., 2005. – Vol. 41, No. 1. – P. 134–143.
2. **Carnovale D. J.** Power factor correction and harmonic resonance: A volatile mix // EC&M Magazine. – Jun. 2003. – P. 16–19.
3. SPD Electrical Protection Handbook – Selecting Protective Devices Based on the National Electric Code. – Bussman, Cooper Ind. – Ellisville, MO. – 1992.
4. **Middlebrook R. D.** Design Techniques for Preventing Input Filter Oscillations in Switched-Mode Regulators // Proc. Of the 5th Solid-State Power Conversion Conference, POWERCON 5. – May 1998. – P. A3-1–A3-16.
5. IEEE Standards Interpretations for IEEE Std. 18–2002. – Institute of Electrical and Electronics Engineers Inc. – 2005 [interactive]. Accessed at: http://standards.ieee.org/reading/ /ieee/interp/18-2002.html.
6. **Carnovale D. J., Dionise T. J., Blooming T. M.** Price and performance considerations for harmonic solutions // Proc. Power Syst. World, Power Quality Conference. – Long Beach, CA. – 2003.
7. **Greenwood A.** Electrical Transients in Power Systems, 2nd edition. – WileyBlackwell. – 1991.
8. **Ciufudean C.** Discrete Event Systems – Applicative Themes. – Bucharest: Matrix Rom Publishing House, 2007.
9. **Parise G., Martirano L.** Circuits Operation Control and Overloads Protection: Power Cables Equivalent Ampacities // IEEE Trans. on Ind. Appl. – 2000. – Vol. 36, No. 1. – P. 22–29.

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C. Ciufudean, A. Larionescu, C. Filote. Equivalent Structures for Nonlinear-Signal Cable Networks // Electronics and Electrical Engineering. – Kaunas: Technologija, 2009. – No. 5(93). – P. 65–68.

This paper focuses on the effects of nonlinearities of electrical signals driven through cable networks. Some new methods derived from original models are proposed here in order to avoid the damages caused by nonlinearities induced by cable networks. Ill. 9, bibl. 9 (in English; summaries in English, Russian and Lithuanian).

Ц. Цюфудеан, А. Ларионеску, Ц. Филоте. Эквивалентные структуры кабельных сетей, передающих нелинейные сигналы // Электроника и электротехника. – Каунас: Технология, 2009. – № 5(93). – С. 65–68.

Анализируются аспекты нелинейностей электрических сигналов, передаваемых кабельными сетями. Приводятся новые методы, созданные используя оригинальные модели. Используя эти методы, можно избежать потерь из-за нелинейности кабельных сетей. Ил. 9, библ. 9 (на английском языке; рефераты на английском, русском и литовском яз.).

C. Ciufudean, A. Larionescu, C. Filote. Netiesinius signalus perduodančių kabelinių tinklų ekvivalentinės struktūros // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2009. – Nr. 5(93). – P. 65–68.

Analizuojami kabeliniais tinklais perduodamų elektrinių signalų netiesiškumų aspektai. Pateikiami nauji metodai, sukurti naudojant originalius modelius. Taikant šiuos metodus galima išvengti sutrikimų dėl kabelinių tinklų netiesiškumo. Il. 9, bibl. 9 (anglų kalba; santraukos anglų, rusų ir lietuvių k.).

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