CALITATEA TENSIUNII – CRITERIU PRINCIPAL DE ANALIZĂ A INTERDEPENDENȚEI DINTRE COMPENSAREA PUTERII REACTIVE, ECHILIBRAREA SARCINII ȘI FILTRAREA ARMONICILOR ÎN REȚELELE DE DISTRIBUȚIE PERFORMANTE

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În lucrare se analizează interdependența dintre compensarea puterii reactive, echilibrarea sarcinii și atenuarea regimului nesinusoidal în nodurile de consum ale rețelelor electrice de distribuție, considerînd drept criteriu principal calitatea tensiunii în nodul respectiv. Pe lîngă acestea se urmăresc și pierderile de putere în rețea și factorul de putere. Prezentarea se efectuează pentru o rețea cu trei conductoare.

This paper analyses the interdependence between the compensation of the reactive power, the balance of the load and the attenuation of the non-sinusoidal regime in the consumption buses in the distribution networks, considering as main criterion the quality of voltage in the respective bus. We will also analyse, the power loss and reactive factor in the network. We shall use for the a network with three conductors presentation.

Descriptori: tensiunea rețelei, calitate, compensare reactiv, simetrizare, filtre pentru regim nesinusoidal

Introducere

Regimul real de funcționare al rețelelor de distribuție nu este unul ideal, ci unul perturbat, caracterizat prin circulații de putere reactivă, nesimetrii și distorsiuni ale curbelor de tensiune și curent. Pentru îmbunătățirea lui trebuie luate măsuri care să reducă pierderile de putere și energie, să mărească randamentul distribuției, asigurînd în același timp și o calitate cît mai ridicată a energiei electrice livrate consumatorilor, în particular o tensiune cît mai stabilă ca valoare, simetrică și sinusoidală. Aceste cerințe trebuie îndeplinite cu atît mai mult în prezent, cînd tehnica informatică și electronica de putere oferă, pe de o parte, largi posibilități în ceea ce privește estimarea corectă a regimurilor de funcționare și, pe de altă parte, controlul on-line al unor dispozitive de compensare performante, FACTS, capabile să atenueze și să controleze regimurile perturbate de funcționare ale rețelelor electrice [1- 4].

Compensarea puterii reactive sau îmbunătățirea factorului de putere este o problemă cunoscută și urmărită în cadrul rețelelor de distribuție, mai ales la marii consumatori, datorită sistemului de penalizări introdus în acest sens de către furnizorul de energie. Totuși, de multe ori această compensare se face neîngrijit, conducînd la supracompensări care afectează defavorabil calitatea tensiunii la bornele receptorului.

Echilibrarea sarcinii pe fazele rețelei, deși cunoscută și de multe ori aplicată, nu este stăpînită sub aspectul implicațiilor ei asupra calității tensiunii, majorării pierderilor de putere și energie sau înrăutățirii factorului de putere.

Regimul deformant constituie o altă problemă sensibilă a rețelelor electrice, prezența lui făcîndu-se simțită mai ales în ultima vreme, ca urmare a dezvoltării și extinderii electronicii de putere. El se manifestă, în principal, prin deformarea curbelor tensiunii și curentului, determinînd funcționarea eronată a unor dispozitive de măsură, reglare și control, pierderi suplimentare de putere și energie, iar uneori fenomene de rezonanță armonică foarte periculoase pentru funcționarea sigură a rețelei.

De regulă, cele trei probleme sunt privite diferit și de cele mai multe ori separat, considerîndu-se că

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Metode noi de echivalare a rețelelor electrice de distribuție

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Abstract: **This paper presents two original equivalence methods for an electric power distribution network having any complex arborescent configuration, with a simple radial network, where each load is connected to the source by its own fictitious electric power line. One of these methods refers to the voltage drops equivalence and the other to the active power losses equivalence. These two methods become very helpful when solving many operation state optimisation problems in electric power networks and allows us to obtain accurate enough results with a reduced time and calculus effort. The paper presents the original equivalence analytical formulas that are applied then for validation to the establishing of the equivalent fictitious networks corresponding to a real network.**

Key words: **electric power distribution networks, equivalence methods, voltage drops, power losses**

Descriptori: rețele electrice de distribuție, metode de echivalare, căderi de tensiune, pierderi de putere

Notații

$\underline{Z}_l = r_l + j \cdot x_l$	- impedanța inductivă longitudinală echivalentă a liniei de indice *l*, cu cele două componente, rezistivă și reactivă, Ω;
$\underline{I}_l = I_{a\,l} - j \cdot I_{r\,l}$	- curentul ce circulă pe linia de indice *l* cu componentele activă și reactivă, A;
$\underline{S}_l = P_l + j \cdot Q_l$	- puterea aparentă ce circulă pe linia de indice *l* cu componentele activă și reactivă, VA;
$\Delta\underline{U}_l = \Delta U_l + j \cdot \delta U_l$	- căderea de tensiune produsă pe linia de indice *l*, cu componentele longitudinală și transversală, în valori înlănțuite, V;
$\underline{s}_n = p_n + j \cdot q_n$	- puterea aparentă a sarcinii de indice *n*, cu componentele activă și reactivă, VA;
$\underline{Z}_{n\,ech} = R_{n\,ech} + j \cdot X_{n\,ech}$	- impedanța inductivă longitudinală echivalentă a liniei fictive asociate nodului consumator de indice *n*, cu cele două componente, rezistivă și reactivă, Ω;
U_l, U_n	- tensiunea înlănțuită la sfârșitul liniei de indice *l*, respectiv în nodul de indice *n*;
φ_l, φ_n	- unghiurile de defazaj între fazorul tensiunii de fază și cel al curentului ce circulă pe linia de indice *l*, respectiv al fazorului curentului absorbit de consumatorul de indice *n*, °;
α_n	- unghiul de defazaj dintre fazorul tensiunii la sursă și fazorul tensiunii la bornele consumatorului de indice *n*, °.

Introducere

Optimizarea regimurilor de funcționare ale rețelelor electrice de distribuție este o problemă complexă, de mare dificultate, din două motive. Pe de o parte, este vorba de numărul mare de elemente componente, reflectat în numărul mare de noduri și de laturi din circuitul electric echivalent, ceea ce face ca metodele convenționale de calcul al circulației de puteri să solicite resurse importante. În plus, datorită faptului că pentru majoritatea liniilor electrice componente raportul *R/X* are valori ridicate, metodele amintite ridică deseori probleme de convergență. Din acest motiv, eforturile specialiștilor s-au concentrat în mare măsură asupra găsirii de versiuni modificate ale metodelor convenționale, respectiv de tehnici de simplificare a calculului circulației de puteri, având la bază proprietățile caracteristice principale ale rețelelor de distribuție: schema radială (arborescentă) de funcționare și posibilitatea neglijării parametrilor echivalenți transversali ai liniilor electrice. În [1-5] sunt prezentate o parte dintre aceste metode și tehnici.

Pe de altă parte, dificultatea circulației de puteri și a aplicării unor metode de optimizare bazate pe modele matematice sau pe tehnici ce aparțin inteligenței artificiale [6] este sporită de configurația complexă a rețelelor electrice de distribuție, buclată sau strâns buclată, chiar în condițiile păstrării unei funcționări radiale. Pentru depășirea acestei dificultăți, în literatura de specialitate se întâlnesc numeroase încercări de simplificare, orientate în principal pe reducerea rețelei reale complexe la o rețea echivalentă, având o structură simplă, pe care să se poată aplica mai ușor analize sau metode de optimizare a regimurilor de funcționare. Un exemplu în acest sens poate fi considerată metoda propusă în [7] pentru reglarea optimală a tensiunii într-o rețea de distribuție cu o configurație complexă. Conform acestei metode, valoarea optimă a tensiunii pe barele stației de transformare coborâtoare ce alimentează rețeaua în cauză, se stabilește pe baza valorii optime a tensiunii într-un nod al rețelei numit *nod caracteristic* sau *reprezentativ*, a cărui distanță electrică echivalentă față de barele stației de alimentare este denumită *impedanță imagine*. Aceasta este de fapt impedanța echivalentă a unei linii fictive, ce leagă nodul caracteristic de sursă, linie parcursă de întreaga sarcină a rețelei. Componentele activă și reactivă ale acestei impedanțe se determină din condiția de minimizare a unui indicator de calitate al tensiunii, scris analitic pentru nodul caracteristic. În articolul [8] sunt prezentate două metode de reducere a unui fider de configurație complexă, ce alimentează mai multe sarcini, la un singur nod consumator în care este conectată întreaga sarcină a rețelei, nod ce este legat la sursă printr-o linie electrică echivalentă fictivă. Lungimea acesteia se calculează în mod diferit, dacă se dorește echivalarea din punctul de vedere al căderii maxime de tensiune, respectiv al pierderilor totale de putere activă de pe fiderul în cauză. O metodă hibridă de echivalare, valabilă simultan pentru ambele criterii, se prezintă în [9], cu observația că sarcina rețelei este distribuită în două noduri alimentate prin același fider fictiv, unul dintre acestea fiind plasat la sfârșitul rețelei. În [10] se prezintă o metodă similară cu cea anterioară, îmbunătățită, cel de-al doilea nod consumator de pe fiderul fictiv fiind introdus pentru a permite efectuarea unei corecții, care să facă echivalarea valabilă pentru ambele criterii, putând avea caracter de consumator sau sursă, după caz. Reducerea la o singură linie fictivă ce alimentează sarcina totală a unui fider, de data aceasta pentru a obține o echivalare cu ajutorul căreia se

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A quickly method to estimate harmonic conditions changes in a bus of an electrical network, as a result of transversal impedance installation.

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Abstract – The installation of a capacitor bank in a distribution electrical network harmonically polluted will conduce to the amplification of the nonsinusoidal conditions by the increase of the harmonic voltages in the network buses and to the thermal overstressing of the capacitors due to the great values of harmonic currents which flow through them.

The paper presents a quickly method to estimate these effects, using the amounts for the steady-state anterior to the installation of the capacitor bank. The most important amount is the harmonic impedance "seen" in the respective bus. The mathematical expressions are deduced for two particular cases in which we can find a certain bus of a distribution electrical network: with or without transversal load already connected.

In the mathematical model, the transversal impedance has a general character. The greatest impact is the connection of capacitive transversal impedance. The validation of the mathematical model is done by MatLab simulation for a distribution electrical network where this kind of impedance is installed.

The results obtained by simulation confirm the correctness of the mathematical model.

Keywords: electrical distribution network, harmonic pollution, transversal capacitive compensation, harmonic impedance

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1. Introduction

In the presence of an harmonic regime in the network, the connection, disconnection or changing of the value of a transversal equivalent impedance, conduce to more or less influence on the nonsinusoidal conditions, depending on the character and the value of the impedance.

As we know, connecting a capacitor bank for reactive power transversal compensation in a distribution electrical network harmonically polluted, can conduce to the amplification of the nonsinusoidal regimen, if on the frequencies, nearly the parallel resonance frequency between the capacity of the capacitor bank and the equivalent inductance of the network, there are harmonic currents flow [1].

The amplification of the harmonic pollution depends on the value of the capacitance of the capacitor bank installed and on the values of the harmonic currents of the network. Usually result an increase of the voltage total harmonic distortion (THD) in the network buses, and the capacitor banc (CB) will be transit by a current with a rms value which can be dangerous from the point of view of thermal stability [1].

That's why before the installation of a CB in a bus of a harmonic polluted network, is suggest the risk evaluation of the increase on the THD voltage values in the bus and on the rms value of the current through the CB, after its installation.

This paper propose a quickly method for the calculus of the harmonic voltages in the compensation buses, respective of the harmonic currents through the CB, after its installation.

The method is based on the harmonic impedance "seen" in the bus where the CB is installed and is available for any type of transversal equivalent impedance. The general case is primary discussed, more exactly the case when in the bus where the CB will be installed there is no another transversal equivalent impedance, then, the case when in the bus there are already this kind of impedance.

2. Case 1: Bus without transversal impedance

In Fig.1 are presented the equivalent schemas for the *k* range harmonic, for the situations before and after the installation of the transversal impedance in a certain bus *m*.

Load Balancing by Unbalanced Capacitive Shunt Compensation – A Numerical Approach

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Abstract-- **The paper presents the results of few numerical applications for sustaining the idea of unbalancing transversal capacitive compensation like a method for balancing the load of the electrical distribution networks and consequently to increase the voltage quality and the efficiency. The load balancing, analytical described by the annulment of negative component of the currents on the load phases, is possible by using a three-phase shunt compensator in delta connection, which contains only capacitive susceptances and/or inductive susceptances. The authors sustain in this paper the advantages of using simplified compensators, which contains only capacitive susceptances, and which, in the most of practical situations allows the total or almost total balancing of the load. The structures of this compensators will conduce to low costs, even when this are used for an on-line compensation, the capacitive susceptances control is individually depending on the nature and the dimension of the load unbalancing. The paper contains numerical examples regarding a three-phase low voltage network.**

Index Terms-- **Power distribution network, reactive power shunt compensation, load balancing, power factor improving, voltage quality improving.**

I. Introduction

As we know, the active the balancing of an unbalanced load of a three-phase distribution network, by a three-phase unbalancing compensation was demonstrated for the first time by Steinmetz [1], [9] for a load supplied between two phases. The method was generalized for three-phase loads [2]-[4], [9], the elements of the compensator being determinate starting from the analytical condition of annulment of negative component of the currents on the load phases, through its real and imaginary parts. It was proved that this condition can be accomplished by an unbalanced three-phase compensator in delta connection, which contains only reactive elements (capacitive susceptances and/or inductive susceptances), able to debit in the network a three-phase currents set whit a negative component equivalent to the negative component absorbed by the unbalanced load. In phase amounts, the compensator determines a redistribution of active and reactive power between the phases, fact that which can be obtained only by a delta connection of its elements.

It's clear that the compensator can intervene also on the positive sequence, for the symmetrical compensation of the reactive power in order to power factor correction or voltage control. The condition of total compensation of reactive power absorbed by the load can be analytical put in the form of imaginary part annulations of the positive component of the current on the load phases.

Putting together the three conditions presented above, the following relations for the susceptances of the compensator are obtained [9]:

$$\begin{aligned}
B_{12\,C} &= -B_{12\,load} + \frac{1}{\sqrt{3}}(G_{23\,load} - G_{31\,load}) \\
B_{23\,C} &= -B_{23\,load} + \frac{1}{\sqrt{3}}(G_{31\,load} - G_{12\,load}) \qquad (1) \\
B_{31\,C} &= -B_{31\,load} + \frac{1}{\sqrt{3}}(G_{12\,load} - G_{23\,load})
\end{aligned}$$

where $B_{12\,C}$, $B_{23\,C}$, $B_{31\,C}$ are the equivalent susceptances of the compensator, and $B_{12\,load}$, $B_{23\,load}$, $B_{31\,load}$, $G_{12\,load}$, $G_{23\,load}$, $G_{31\,load}$ the equivalent susceptances respective conductances corresponding to a delta connection of the three-phase load (Fig. 1).

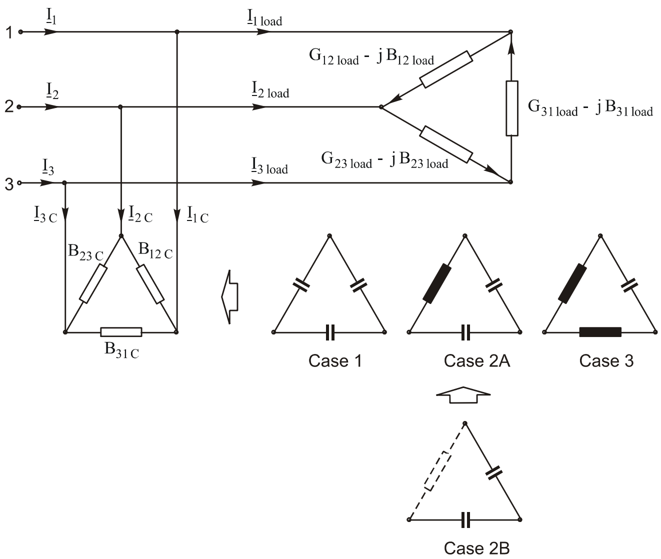

Fig. 1. The equivalent electrical schema of the load and the balancing compensator.

As we know, the transversal capacitive compensation, used in fact like an instrument for the reactive power flow control,

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A Numerical Analysis of the Harmonic Impedance Seen Along a Transmission Overhead Line

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***Abstract* – This paper presents general relations for calculation of harmonic impedance seen along an AC transmission overhead line. This is modeled by a chain of two symmetrical passive quadripoles corresponding to the segments that are on either side of the section of interest. Chain matrices of the two quadripoles are written by considering uniformly distributed line parameters and on their base, the expressions for the input impedances of the two quadripoles fed in the common section are obtained. The equivalent impedance seen in the section of the line, obtained by placing in parallel the two impedances mentioned above, depends on both the position along the line and the frequency. The expression for its calculation is applied to the numerical study realized for overhead lines having a nominal voltage of 220 kV. The results allow the identification of line areas and the frequencies where the risk of parallel resonance occurrence is greatest.**

***Index Terms* -- Transmission lines, Frequency response, Power system harmonics**

I. INTRODUCTION

Theoretical and experimental study of the frequency response of an AC electric network for transmission or distribution of electricity is necessary both for the analysis of the steady state [8], [9] and transient operating conditions [3], [4]. For steady state operating conditions the need for this operation appears under the presence of harmonic pollution in order to determine the frequencies values corresponding to series and parallel resonance and then establish ways and means to mitigate or avoid adverse effects thereof. The most commonly used instrument for this analysis is the impedance seen in the section of interest of the network, which is a function of frequency.

II. PUTTING THE PROBLEM

It is known that permanent operating regimes of the electricity transmission grids are affected by harmonic pollution becoming more pronounced, resulting from the distribution networks that feed and where are located most of the sources of pollution. At the same time, electrical wires of overhead power lines are instead expressions of corona discharges modeled by distributed sources of harmonic currents [4], [5], [7].

The presence of high equivalent natural capacitances and equivalent inductance of the network can lead to the occurrence of parallel resonance on the frequencies of harmonic currents flowing in the network and thus amplify the harmonic conditions both for current and voltage. The negative effects of voltage distortion amplification occur mainly through insulation overstressing which endanger the safe operation of the system.

Therefore, the study of the harmonic impedance seen along a transmission line is needed to identify the section, respectively the frequencies at which the risk of harmonic parallel resonance is highest.

The problem is similar to that caused by the effects of electric locomotives inverters in power supply networks, where, due to harmonic resonances parallel, there is a marked increase of the harmonic currents and voltages. In references [1], [2], [3], [6], [7] the distorted receiver (the locomotive) is modeled as a source of harmonic current which travels along the electrical contact, the impedance seen at the feeding point of the harmonic being dependent on the position of the source along the line.

In this paper are presented the expressions of computing and numerical study results of harmonic impedance seen along a high-voltage power line, found in a particular case that transfer energy between an equivalent source (upstream power system) and equivalent load (downstream distribution network). Figure 1 shows the simplified single line diagram, and the equivalent quadripolar diagram, respectively.

III. THE MATHEMATICAL MODEL USED

Assuming that the system elements involved have a symmetrical design and balanced operation, quadripolar single-phase equivalent circuit diagram will be used, which will include positive sequence equivalent parameters. The determination of these parameters is done by known methods, for which, in the following we will give brief explanations on identifying quantities that occur in mathematical expressions.

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Identify Resonant Frequencies In AC Distribution Networks – A Numerical Example Part I – Harmonic Nodal Admittance Matrix Method

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Abstract

The subject of the paper is part of the general issue, particularly complex, establishing the means and methods of intervention for maintaining an appropriate quality of power supplied to consumers connected to existing distribution networks, which are subject to more pronounced harmonic pollution. In this context, the analysis in the frequency domain of the normal operating regimes of electrical distribution networks is a mandatory operation, the main instrument being the harmonic impedance seen in the network buses nodes. A typical application of this tool of analysis refers to reactive power compensation in distribution network harmonic polluted, operation that may lead to increased non-sinusoidal regime and consequently to increased negative effects on the operating of installations belonging to the supplier or consumers. Avoidance of harmonic resonances is possible only by knowing the frequency response of the network, more exactly the change of harmonic impedance seen in the network buses. This paper presents, in two parts, the numerical examples carried out on the same area of a real distribution network, two analytical methods: harmonic nodal admittance matrix method, respectively state matrix method. The results are analyzed and compared with the values obtained by the two methods.

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Keywords: Electrical distribution network, harmonic impedance, harmonic resonance, nodal admittance matrix.

1. Introduction

Electrical distribution networks and utility are built mostly like alternative current systems. Currently there is a

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Identify Resonant Frequencies In AC Distribution Networks – A Numerical Example Part II – The State Matrix Method

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Abstract

One of the most important issues regarding the operation of electrical distribution networks which is harmonic polluted is to avoid parallel resonance frequencies of relatively high harmonic currents, that are present in the network. For this is absolutely necessary to know the frequency response of the network or its harmonic impedance, more exactly, the frequencies which can produce parallel harmonic resonance. This article is the second part of the paper which presents two methods of calculating the parallel resonance frequencies corresponding to peaks (poles) harmonic impedance seen in the buses: harmonic nodal admittance matrix method (in the first part), respectively that state matrix method (in the second part). The results obtained by the two methods are compared and a qualitative and quantitative analysis is done.

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Keywords: paralel, matrix , article

1. Introduction

To avoid parallel harmonic resonances that may occur in a network harmonic polluted, it is necessary to know the network status, namely the operating conditions, including knowledge of the frequency for which harmonic resonance phenomena may occur in the network (Dugan et al., 2002; Arrillaga & Watson, 2003). Solving the problem of determining the resonance frequencies in a network can be done by classical methods and modern analytical techniques or artificial intelligence (Wang et al., 2004; Bergen & Vittal, 2000). In the first part of the paper, the application of the classical method based on harmonic nodal admittance matrix construction was presented. The

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Numerical evaluation of the effects of phase admittances asymmetry at HVAC overhead lines

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Abstract — **The paper offers an answer to the question: a high voltage overhead line, operating in no load conditions, "generates" active power (energy)? In order to justify the answer, a case study on an untransposed 110 kV single circuit overhead line was used, for which the no load operating condition has been studied using phase amounts. For this goal, applying the modified Carson's equations and the Kron's method of reduction, were determined the equivalent phase impedances and admittances matrices. Numerical analysis of stationary no load operating conditions, demonstrates that on two of the phases the overhead line takes active power from the network, that delivers back to the network on the third phase. On the whole three phases the sum of the active powers at the beginning of the line results of a value much smaller than the phase active power being actually consumed power, corresponding to line losses. Actually the line doesn't generate active power, but its measurement system indicates a negative value for the sum of the active powers redistributed by the line between the network phases, due to the asymmetry of the measurement errors of the elements installed on different phases. Of these elements, the most presumably are the current transformers, known that at low values of the currents have large measurement errors for both rms and angle.**

Keywords — **HV overhead lines, phase impedances, phase admittances, asymmetry, unbalance.**

I. INTRODUCTION

Voltage unbalances of power system buses have their origin from a load unbalance and/or equivalent impedance of the system components asymmetry. Among the elements of the power system, which determines the most important of impedance asymmetry are overhead lines, which are even higher as their length is greater. Transposition of the phases for these lines is performed only if their lengths exceeding the limit values set by regulations. This operation reduces the asymmetry for normal operating conditions, but not that for transitory or non-sinusoidal steady state operating conditions.

Most of the high-voltage overhead lines are not transposed so that for their normal operating conditions the impedance asymmetry effect can be determined by using a three phase modeling, based on the determination of the phase series impedances matrix respectively phase shunt admittances matrix. The accuracy of the power flow calculation in normal unbalanced conditions depends on the accuracy of phase impedance and admittance determination [1-4].

II. THREE PHASE MODELING OF ELECTRICAL OVERHEAD LINES

Because most high-voltage lines have lengths smaller than the quarter wavelength of the electromagnetic wave that propagates along them, modeling them by equivalent nominal electrical circuit with concentrated parameters is sufficiently precise. The correct establishing of the expressions for the series or shunt, self or mutual, equivalent parameters is difficult because each conductor lies in both its electric and magnetic fields and electric and magnetic fields of the other conductors, the full set of conductors being close to the ground, whose potential is zero.

A. *Primitive impedance matrix and phase impedance matrix for overhead lines*

The calculation of self and mutual primitive impedances for an overhead line having any number of conductors is done taking into account that each conductor is placed in its own variable magnetic field and in the variable magnetic fields of the other conductors. The Carson's equations are often used in practice [1-4]. These were deducted based on a technique based on the conductor images, using the simplifying assumptions that the ground is a solid uniform, infinite size, with a uniform surface perfectly flat on the outside and whose electrical resistivity is constant. Also the end effect which is introduced by grounding the neutral conductor is reduced for the frequencies that are found in the network and can therefore be neglected. Some additional mathematical simplifications led to modified Carson's equations, which proved to be sufficiently accurate and is therefore widely used in the modeling of both the overhead and underground lines [4].

The modified Carson's equations for self and mutual primitive impedance calculation for overhead lines are:

$$\underline{z}_{ii}^{p} = r_i + k_1 \cdot f + j \cdot k_2 \cdot f \left(\ln \frac{1}{GMR_i} + k_3 + \frac{1}{2} \ln \frac{\rho}{f} \right) \qquad (1)$$

$$\underline{z}_{ij}^{p} = k_1 \cdot f + j \cdot k_2 \cdot f \left(\ln \frac{1}{D_{ij}} + k_3 + \frac{1}{2} \ln \frac{\rho}{f} \right) \qquad (2)$$

where:

$\underline{z}_{ii}^{p}$ is the self impedance of conductor *i* in Ω/mile,

$\underline{z}_{ij}^{p}$ - mutual impedance between conductors *i* and *j* in Ω/mile,

r_i - resistance of conductor *i* in Ω/mile,

f - frequency in Hz,

D_{ij} - distance between conductor *i* and conductor *n* in ft.,

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Article

From the Balancing Reactive Compensator to the Balancing Capacitive Compensator

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Abstract: Nowadays, improving the power quality at the Point of Common Coupling (PCC) between the consumers' installations and the distribution system operators' installations depends more and more on the use of specialized equipment, able to intervene in the network to eliminate or diminish the disturbances. The reactive power compensators remain valid solutions for applications in consumer and electricity distribution, in those situations when the criterion regarding the costs of installing and operating the equipment is more important than the ones related to the reaction speed or the control accuracy. This is also the case of the equipment for power factor improvement and load balancing in a three-phase distribution network. The two functions can be achieved simultaneously by using an unbalanced static var compensator, known as an adaptive balancing compensator, achieved by adjusting the equivalent parameters of circuits containing single-phase coils and capacitor banks. The paper presents the mathematical model for the sizing and operation of a balancing reactive compensator for a three-phase four-wire network and then presents some resizing methods to convert it into a balancing capacitive compensator, having the same functions. The mathematical model is then validated by a numerical application, modelling with a specialized software tool, and by experimental laboratory determinations. The paper contains strong arguments to support the idea that a balancing capacitive compensator becomes a very advantageous solution in many industrial applications.

Keywords: electrical power quality; reactive power compensator; static var compensator; Adaptive balancing reactive compensator; adaptive balancing capacitive compensator; symmetrical component method

1. Introduction

The Electric Power Distribution Systems face the problems caused by poor power quality, the most important of which being the high reactive power load, the pronounced load unbalance, the unsymmetrical voltages, nonsinusoidal current and voltage waveforms, a high rms value and highly deformed current flowing on the neutral conductor [1–3].

The asymmetry of the three-phase voltage set is primarily due to unbalanced loads, so the methods and means used to limit this asymmetry are directed to preventing or limiting the load unbalance. The measures aimed at preventing the effects of the load unbalance include those that achieve their natural balance. Here are two main methods [1–3]:

- the balanced repartition of single-phase or two-phase loads on the phases of the three-phase network;
- connection of unbalanced loads to a higher voltage level, which usually corresponds to the solution of increasing the short-circuit power at their terminals. This is the case of industrial consumers of large power (from hundreds of kVA to tens of MVA) in which power is supplied

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Article

Iterative Method for Determining the Values of the Susceptances of a Balancing Capacitive Compensator

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Abstract: To increase the electrical power quality, in the last decades, an intense development in the last decades of high-performance equipment built as advanced power electronics applications, such as the compensators from Switching Power Converter category, has taken place. For all that, Reactive Power Compensators (RPC) based on passive circuit elements, such as Static var Compensators (SVCs), still occupy a wide range of applications in customer and installations of the distribution system installations. The functions of power factor (PF) improvement and load balancing in a three-phase distribution network can be achieved with an unbalanced SVC, known as the Adaptive Balancing Reactive Compensator (ABRC). Presenting first the mathematical model of the initial sizing and the working mechanism of a Balancing Reactive Compensator (BRC) for a three-phase four-wire network, this article develops a compensator resizing algorithm through an iterative change of the initial sizing to transform the compensator into a Balancing Capacitive Compensator (BCC), which keeps the same functions. By using two computational and modeling software tools, a case study on the application of the method was carried out, demonstrating the availability of the sizing problem solution and validating the unbalanced capacitive compensation as an efficient way to PF improving and load balancing in a PCC (Point of Common Coupling).

Keywords: electrical power quality; reactive power compensator; Static var Compensator; adaptive balancing reactive compensator; balancing capacitive compensator; symmetrical component method

1. Introduction

Excessive reactive power load and three-phase voltage set asymmetry are two of the most important problems to be solved to ensure a high level of power quality in a PCC [1–3].

The most known means of mitigating/eliminating the three-phase network load unbalances are reactive power compensators (RPCs) containing passive circuit elements [4–28]. These have been developed especially in the last 3–4 decades, starting from the Steinmetz's balancing scheme, conceived over 100 years ago [4]. To be used efficiently for variable loads, PRCs have been designed to allow the adjustment of equivalent compensator circuit parameter values, thus obtaining static reactive power compensators (SVCs) [17–23].

Using units type *Thyristor Controlled Reactor* (TCR) and *Thyristor Switched Capacitor* (TSC), SVCs allow switching and parameter setting, respectively, of reactive passive circuit elements [5–8,12–15]. The most efficient applications of SVCs, for which they have proved to be fast and accurate enough, are intended for PF correction, load balancing, voltage regulation, and flicker mitigation [22].

At present, the second-generation of static compensators, type SPC, is being developed, which is based on high-power switching elements: *Insulated Gate Bipolar Transistors* (IGBT) or *Thyristor Integrated Gate Commutated Thyristors* (IGCT), belonging to the so-called *Solid-State Devices* (SSD) [29–34]. Found