Available online at www.sciencedirect.com
ScienceDirect
Electric Power Systems Research 77 (2007) 93–98
ELECTRIC POWER SYSTEMS RESEARCH
www.elsevier.com/locate/epsr

A new method for real time computation of power quality indices based on instantaneous space phasors

Dalgerti L. Milanez [a,*], Rade M. Ciric [b]

[a] *UNESP-Universidade Estadual Paulista "Julio de Mesquita Filho", Departamento de Engenharia Elétrica, Av. Brasil Centro 56, 15385-000 Ilha Solteira, SP, Brazil*
[b] *University of the West of England Bristol, Engineering and Mathematical Sciences, School of Electrical and Computer Engineering, Frenchay Campus, Coldharbour Lane, Bristol BS16 1QY, UK*

Received 8 April 2005; received in revised form 31 January 2006; accepted 1 February 2006
Available online 20 March 2006

Abstract

One of the important issues about using renewable energy is the integration of dispersed generation in the distribution networks. Previous experience has shown that the integration of dispersed generation can improve voltage profile in the network, decrease loss, etc. but can create safety and technical problems as well. This work report the application of the instantaneous space phasors and the instantaneous complex power in observing performances of the distribution networks with dispersed generators in steady state. New IEEE apparent power definition, the so-called Buchholz–Goodhue effective apparent power, as well as new proposed power quality (oscillation) index in the three-phase distribution systems with unbalanced loads and dispersed generators, are applied. Results obtained from several case studies using IEEE 34 nodes test network are presented and discussed.

Keywords: Instantaneous space phasors; Instantaneous complex power; Buchholz–Goodhue effective apparent power; Power definitions; Unbalance; Dispersed generators

1. Introduction

One of the important issues about using renewable energy is the integration of dispersed generation (DG) in the distribution networks (DNs). Various investigations showed that DGs integrated into utilities' DNs could affect the host DNs in number of ways. Previous experience has shown that the integration of DGs into DNs could create safety and technical problems. They may contribute to fault currents, cause voltage flickers, interfere with the process of voltage control, increase losses, etc. Actually, overall model of the distribution system should be renewed, since the impact of DGs on the DNs planning and operation is significant.

Therefore, the main question here is: "What is the impact of the DGs on the overall system performance of the distribution system?" In this paper an investigation of the integration aspects of DGs in the three-phase DNs with unbalanced loads is presented. This work reports the application of instantaneous space phasors and the instantaneous complex power in observing performances of the DNs with DGs in steady state. New IEEE apparent power definition, the so-called Buchholz–Goodhue apparent power, as well as new proposed power quality indice in the three-phase distribution systems with unbalanced loads and DGs, are applied. It is shown that new proposed indices together with the existing indices are efficient tool for observing performance of the distribution systems with DGs. Results obtained from several case studies using IEEE 34 nodes test network are presented and discussed.

This paper consists of seven parts. In the second part handling PV and PQ nodes in the power flow analysis of distribution systems with DGs is shortly explained. In the third part the basis of the instantaneous complex power theory is presented. The fourth part contains the Buchholz-Goodhue effective apparent power definition, new power quality (oscillation) index and the three-phase power factor definition for unbalanced sinusoidal condition. In the fifth part application of the instantaneous complex power theory on the IEEE test feeder with DGs is presented.

* Corresponding author. Tel.: +55 18 3743 1227; fax: +55 18 3743 1163.
E-mail addresses: dalgerti@dee.feis.unesp.br (D.L. Milanez), rciric@netscape.net (R.M. Ciric).

0378-7796/$ – see front matter © 2006 Elsevier B.V. All rights reserved.
doi:10.1016/j.epsr.2006.02.001

The conclusion is in the sixth part and the final part contains the list of references.

2. Power flow

Efficient and robust power flow for large-scale real-life DNs with DGs is the basic tool in Distribution Management System (DMS) today. Besides, power flow analysis is essential for investigating the impact of the DGs in the DNs. Depending on the contract and control status of the generator, it may be operated in one of the following modes: (1) in parallel operation with the feeder where DG is located near and designated to supply a large load with fixed real and reactive power output; (2) to output power at a specified power factor; (3) to output power at a specified terminal voltage.

Considering power flow, the DG node in the first two cases can be represented as a PQ node. It requires just a little modification in the power flow algorithm, actually the current is injected into the bus. In the third case where the source controls the voltage magnitude at the corresponding node, the node is referred to as a PV node. If the computed reactive power generation is out of the reactive generation limits, then the reactive power generation is set to that limit and the unit acts as a PQ node. Some dispersed storage units may also act as a constant current but for purposes of the power flow the PQ model is adequate. In last decade, different procedures for handling PV nodes have been proposed. Special single-phase and three-phase power flow methods have been developed for radial and weakly meshed network analysis. Experience showed that very good results in handling PV nodes in the large-scale DNs are obtained using the backward/forward procedures. These methods may be classified as follows: current summation methods, power summation methods and admittance summation methods. In the proposed methodology for determining the impact of DGs on the distribution system performance, efficient and robust compensation-based method proposed in [1] is applied. In this method, PV node sensitivity matrix is used to eliminate voltage magnitude mismatch for all PV nodes. The problem of compensating PV node voltage magnitude is transferred to the determining reactive current injection for each PV node, so that the voltage magnitude of this node is equal to the scheduled value. Since the relation between reactive current and voltage magnitude of the DG is non-linear, desired reactive current of the DG is determined iteratively.

3. Background

In the Instantaneous Complex Power Theory complex variables may be used to represent currents and voltages in three-phase, three-wire circuits, operating on any conditions. For this purpose they are related to phase variables through the transformations [2–4]:

$$\tilde{V} = \tfrac{2}{3}(v_\mathrm{a} + a v_\mathrm{b} + a^2 v_\mathrm{c}), \tag{1}$$

$$\tilde{I} = \tfrac{2}{3}(i_\mathrm{a} + a i_\mathrm{b} + a^2 i_\mathrm{c}), \tag{2}$$

where $a = \mathrm{e}^{\mathrm{j}(2\pi/3)}$ is a unity complex operator.

These phasors are known as instantaneous space phasors (ISPs) and may be expressed as

$$\tilde{V} = V\,\mathrm{e}^{\mathrm{j}\phi_\mathrm{V}}, \qquad \tilde{I} = I\,\mathrm{e}^{\mathrm{j}\phi_\mathrm{I}}. \tag{3}$$

For transient or non-sinusoidal and/or unbalanced conditions, the amplitude and the argument of these phasors are time variables.

However, when dealing with sinusoidal and symmetrical voltages and currents, (3) yields to the well-known expressions:

$$\tilde{V} = \hat{V}\,\mathrm{e}^{\mathrm{j}(\omega t + \alpha_\mathrm{V})}, \qquad \tilde{I} = \hat{I}\,\mathrm{e}^{j(\omega t + \alpha_\mathrm{I})}, \tag{4}$$

i.e., rotating phasors which rotate counterclockwise at constant angular velocity for positive sequence.

The complex product of the voltage and the current instantaneous space phasors defines the instantaneous complex power [4]:

$$\tilde{S} = \tfrac{3}{2}(\tilde{V}\tilde{I}^*) = \tfrac{3}{2}VI\,\mathrm{e}^{\mathrm{j}(\phi_\mathrm{V}-\phi_\mathrm{I})} = S(\cos\theta + \mathrm{j}\sin\theta) = p + \mathrm{j}q \tag{5}$$

where $\theta = \phi_\mathrm{V} - \phi_\mathrm{I}$ and $p = \Re e(\tilde{S})$ is the real power and $q = \Im m(\tilde{S})$ is the imaginary power.

4. The Buchholz-Goodhue effective apparent power and the power quality indice

In the past, two main proposals were presented for the three-phase apparent power definition.

The arithmetic apparent power, as the sum of the single-phase apparent powers

$$S_\mathrm{A} = S_\mathrm{a} + S_\mathrm{b} + S_\mathrm{c}, \tag{6}$$

and the vector apparent power, the vector sum of those powers

$$S_\mathrm{V} = \sqrt{P^2 + Q^2}, \tag{7}$$

$$P = P_\mathrm{a} + P_\mathrm{b} + P_\mathrm{c}, \tag{8}$$

$$Q = Q_\mathrm{a} + Q_\mathrm{b} + Q_\mathrm{c}, \tag{9}$$

which may be expressed in terms of positive and negative sequence powers

$$S_\mathrm{V} = |P^+ + P^- + P^0 + \mathrm{j}(Q^+ + Q^- + Q^0)|. \tag{10}$$

These definitions do not lead to the same results and both of them have a lack of meaning regarding to their physical interpretation when considering the power losses in power systems under unbalanced and/or non-sinusoidal conditions.

However, the apparent power definition presented in the IEEE-Standard 1459-2000 [5], termed effective apparent power, fulfill the physical meaning above mentioned.

This effective apparent power for an unbalanced and/or non-sinusoidal three-phase, four-wire system is equivalent to the conventional apparent power for an equivalent balanced and sinusoidal system that transmits the same active power and causes the same power losses.