www.ietdl.org

Published in IET Power Electronics
Received on 16th January 2014
Accepted on 4th March 2014
doi: 10.1049/iet-pel.2013.0973

ISSN 1755-4535

Individual-phase control of 3-phase 4-wire voltage–source converter

Seyed Mahdi Fazeli[1], *Hew Wooi Ping*[1], *Nasrudin Bin Abd Rahim*[1], *Boon Teck Ooi*[2]

[1]*UMPEDAC, University of Malaya, 50603 Kuala Lumpur, Malaysia*
[2]*Department of Electrical and Computer Engineering, McGill University 3480 University Street, Montreal, P.Q. Canada H3A 2A7*
E-mail: mahdifazeli2003@yahoo.com

Abstract: An innovative method of operating 3-phase, 4-wire voltage–source converters, based on decoupled P–Q control of individual phases, is presented. Individual-phase control has six independent degrees of control freedom to deal with both symmetrical and asymmetrical operating conditions. Experimental tests on a laboratory distribution static synchronous compensator (D-STATCOM) show that individual-phase control can simultaneously (i) support the voltages of unbalanced 3-phase loads against droop; (ii) equalise the complex powers at source-side of the transmission line; (iii) balance the voltage magnitudes and (iv) balance the angles of 'ac' voltages at the point-of-common-coupling.

1 Introduction

Voltage–source converters (VSCs) are the basic power electronic building blocks of motor drives, flexible ac transmission systems (FACTS) and high-voltage dc transmission (VSC-HVDC) [1–4]. As VSCs have a long history, most of the problems on symmetrical operation have already been solved. This leaves asymmetrical operation which requires mastering Charles L. Fortescue's symmetrical components combined with instantaneous active and reactive power analyses [5–9]. There is an extensive literature on applying symmetrical component methods and [10–16] are only a few samples.

1.1 State of art in decoupled P–Q control

Theoretical and hardware advances, in the past, have enabled VSCs to make use of 3-phase decoupled P–Q control. Theory relies on deriving the formulas $P^* = v_d i_d^*$, $Q^* = v_d i_q^*$ which requires a 3-phase phase-locked loop (PLL) to acquire [cosωt, sinωt], whereby current references i_d^* and i_q^* can be formed for injection to control active power P* and reactive power Q*. The symbol (*) is used to denote a control variable in this paper.

The operation of a PLL requires filtering of a double line frequency term. Historically, analogue filters of low frequencies (100 or 120 Hz) were cumbersome and expensive. This consideration has restricted engineering practice to 3-phase PLL where the sum term is eliminated by 3-phase balance.

1.2 Advance in filter technology

Owing to recent advances in digital filtering and filter theory, compact and reliable single-phase PLL (S-PLL) is now feasible. As in [17], the objective of the research of this paper is to apply the advance in filter technology to break out from the bondage of the past practices. The first step consists of applying S-PLL to define individual phase $P-Q$ controllers: (P_a^*, Q_a^*), (P_b^*, Q_b^*) and (P_c^*, Q_c^*) and proposing transducers [single-phase active power measurement (SPM)] to measure active powers. The six independent degrees of control freedom exceed the state-of-the art of combining 'positive sequence' $P-Q$ control and 'negative sequence' $P-Q$ control, which together constitute four control degrees of freedom [10–16]. The next step is to show that with individual-phase control, VSCs can tackle problems which have been avoided, for example, systems with zero-sequence. The justification for the existence of the individual-phase control is that it delivers more features than conventional 'three-phase' decoupled $P-Q$ control. One major selling point is that it can balance the unequal loads from the distribution substation so the transmission line powers are equal.

1.3 Symmetrical components

Invariably, symmetrical components are used to address asymmetrical problems. The introductory chapter of classical texts, such as by Wagner and Evans [18], invariably called attention to the limitations of the method. Symmetrical component approach is based on classifying transmission line faults (single-line-to-ground, two lines to ground, line-to-line etc.). Each classification has a solution based on combinations of series and/or parallel connected sequence impedances. As sequence impedances represent the portions of the network which are symmetrical, the asymmetry originates from the fault only.

In situations where the network is not symmetrical, it is necessary to convert the imbalance into 3-phase balanced