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Auto-balancing transformer based on power electronics

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ABSTRACT

An auto-balancing transformer based on power electronics is designed and proposed to prevent voltage or/and current unbalances arising on the primary side system from infecting the secondary side system, or in reverse. The multilevel converters and interleaving parallel connection technology are adopted in the transformer design to match the demand of power automatically balancing and high-voltage and high-power application. The operating principle is analyzed in detail and an effective control scheme is developed. To verify the new features of the proposed design, a detailed computer simulation model is established using Matlab\Simulink and typical simulations are carried out. And the experimental verification is also presented. All show satisfactory results.

1. Introduction

Transformers are used widely in power transmission and distribution systems to step up or down the voltage. Conventional transformers are inexpensive, efficient, and reliable. However, with non-linear loads and sensitive loads increasing, the disadvantages of the conventional transformer, such as sensitivity to harmonics, dc-offset, voltage drop under load, and so on, become obvious and serious. To resolve these problems, power electronics based transformers have been widely discussed in the literatures [1–9]. Power electronics based transformer is also named electronic power transformer (EPT), solid-state transformer (SST), electronic transformer (ET), and power electronic transformer (PET). It utilizes power electronic converters along with a high-frequency transformer to obtain overall size and cost ascendancies over a conventional transformer [10] and/or achieve the functions of flexible AC transmission systems (FACTS) or DFACTS [6,9,11].

Ref. [1] first introduced the electronic transformer concept based on a high-frequency AC–AC link. Ref. [2] discussed the implementation of the electronic transformer and Ref. [3] developed an optimal control for it. This topology has the advantage of reducing the transformer size and weight. Nevertheless, neither its power rating nor voltage level fits for the fact of power distribution systems. Another drawback of this approach is that it does not provide any benefits in terms of control or power factor improvement [4]. Refs. [10,12] discussed the application of the high-frequency AC–AC link based electronic transformer as an automatic voltage regulator and presented some interesting results.

Ref. [4] described a single-phase power electronic-based transformer with three-part design (an input stage, an isolation stage, and an output stage). Its input stage and isolation stage consisted of multiple low-voltage modules with series connection to reach high-voltage level. However, this transformer can only provide unidirectional power flow, and the input reactive power or power factor cannot be controlled smartly. Ref. [5] described another three-stage power electronics based transformer which is realized using single-phase and three-phase voltage source converters (VSCs). However, this scheme was only outlined in principle and no numerical simulations or experimentations were done to verify its feasibility and performance. Furthermore, the isolation transformer in its DC–DC module is very complicated.

Although many topologies of power electronics based transformer have been discussed to satisfy the voltage level and power rating of distribution systems, little attention was paid to how the power electronics based transformer fit three-phase system unbalanced operation. And the topologies proposed in Refs. [4–7] did not provide any benefits in terms of relieving three-phase system unbalance. That is, unbalanced current, voltage, and power can transmit through the transformer from one side system to the other side system. Unfortunately, there are lots of asymmetric loads in distribution systems and unbalanced operating state arises frequently.

In this paper, a novel power electronics based transformer, named as auto-balancing electronic power transformer (A-EPT), is proposed. It can not only reach high-voltage level, but also prevent

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