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Solid-state tap-changer of transformers: Design, control and implementation

Jawad Faiz *, Behzad Siahkolah

Center of Excellence on Applied Electromagnetic Systems, School of Electrical and Computer Engineering, University of Tehran, Tehran 1439957131, Iran

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ABSTRACT

This paper presents the implementation of a prototype electronic tap-changer of transformer. Mechanical tap-changer has many problems such as low operating speed, short lifetime and heavy size. In order to solve these problems a fully solid-state tap-changer with a new control strategy and optimal configuration is proposed. The design of tap-changer is discussed and bi-directional solid-state power electronics switches are implemented. Following the realization of the tap-changer controller, developed software for such precise control is introduced. To verify the design procedure and optimal configuration and apply the developed software, a prototype low-power tap-changer has been built and tested.

1. Introduction

Normally the main objective of a tap-changer is to regulate and adjust the output voltage of transformer [1]. The voltage fluctuation springs from the load changes. Sometimes tap-changer in power transformer is used to shift the phase angle [2,3]. An on-load tap-changer (OLTC) enables to change the taps under load and it is utilized where a short period of time is required for such changes. In an OLTC impedance is added to circuit in order to prevent the short circuit during the tap-changing process while the load current passes the load when tap-changer operates.

The main advantage of a reactive OLTC is that the reactor stands continuous load current. However, this type of tap-changer has some disadvantages including low operating speed, large arcs, shorter lifetime and heavy size [4]. Therefore, it is obsolete now. Due to the above-mentioned drawbacks, reactive tap-changers are almost replaced by resistive tap-changers. In spite of progress made in the structure of mechanical OLTC, they have some limitations and considerable drawbacks, as such that major fault in power transformers springs from the tap-changer fault [5]. Some limitations and drawbacks of mechanical OLTC include arc in contacts, high cost of maintenance, low speed of operation and high losses [6]. The main function of the controller in the tap-changer system is to minimize the fluctuations (rising and falling) of the voltage amplitude in comparison with the reference voltage at the point called the regulation bus. The regulation bus may be far from the secondary of transformer. In the other words, the main objective of the controller is to keep the amplitude of the bus voltage within a defined range [7]. Of course, in addition to the main function, the tap-changer controller may control the tap-changer during critical cases such as over-loads, output short-circuits, transient over-voltages of input and tap-changer damage. In order to preserve power system integrity in emergency conditions, the taps of transformer can be moved and locked to predetermined position or voltage set-point [8]. The controller may also make the necessary decision to protect the tap-changer system and its loads. To remove these limitations and drawbacks, new circuits and structures for OLTC have been so far suggested [16]. They are categorized into two main groups:

1. Electronically assisted OLTC [9–12].
2. Solid-state OLTC [13–22].

In the 1st group, solid-state power switches have been employed beside mechanical switches in order to reduce the arc. In the 2nd group, there are no mechanical parts and they have been totally built by solid-state power switches. The advantages of the latter group of OLTC are very low maintenance cost, high operating speed, and possibility of tap jumping and high performance.

Although several ideas have been so far introduced to realize the totally solid-state tap-changer, there is no any versatility in these ideas. It is not clear that which ideas is suitable for a define application. Basically which structures are optimal or what is an optimal configuration. The above-mentioned functions for the tap-changer controller are expected for any mechanical and electronic tap-changer. However, it is noted that there are fundamental differences between the capabilities and characteristics of mechanical and electronics tap-changers [23,24]. So, if the same conventional controller of a mechanical tap-changer is used for an electronic tap-changer system, many capabilities and features of the electronic tap-changer will not be realized.

* Corresponding author. Tel.: +98 21 88003330; fax: +98 21 88633029.
E-mail address: jfaiz@ut.ac.ir (J. Faiz).

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