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A new control unit for electronic ferroresonance suppression circuit in capacitor voltage transformers

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ABSTRACT

Ferroresonance suppression circuit (FSC) as an important portion of capacitor voltage transformer (CVT) has a vital role in the prevention of overvoltages. There are three types of FSC: active, passive and electronic type. In this paper, a new control unit is proposed for electronic FSC (EFSC) to damp out oscillations and overvoltages of ferroresonance as quickly as possible. The proposed control unit is installed at the secondary side of the CVT and takes samples from the output voltage and then switches on the silicon-controlled rectifier (SCR) according to the overvoltages level. In the proposed control unit, the SCRs are switched off automatically after the disappearance of overvoltages. Thus, a separate command circuit is not required for generation of negative pulses to switch off SCRs. In addition, phase detector unit, firing circuit and separate source for SCRs triggering are omitted from the control unit. All simulation studies are conducted in the Multisim software environment. The obtained results show that the designed control unit has very fast response and desirable stability in different operation conditions. Moreover, frequency response and CVT transient response are not affected by the proposed electronic control unit.

1. Introduction

Ferroresonance is a complicated phenomenon which can occur when the non-linear inductance of saturated magnetic core of the intermediate voltage transformer (IVT) resonates with the existing series capacitor. The abrupt change of voltage due to the transient in a power system, can lead to IVT core saturation. In this condition, the IVT magnetizing current increases and the output voltage begins to fluctuate. According to the operating point of the saturated core, different steady-state responses may appear in the CVT output voltage known as: fundamental mode, sub-harmonic mode, the quasi-periodic mode and the chaotic mode. Since the CVT output voltage is utilized for measurement, control and protection purposes, the suppression of overvoltages and fluctuations is of great importance in the power system operation. On the other hand, if the CVT output is not a good replica of input voltage, some protective schemes such as transmission line protection may mal-operate during ferroresonance phenomenon [1–4].

The ferroresonance suppression circuit (FSC) can alleviate overvoltages and oscillations by imposing extra burden during appearance of the ferroresonance event. As shown in Fig. 1, FSCs are classified into three main groups: active, passive and electronic type [1]. Active ferroresonance suppression circuit (AFSC) has an undesirable effect on the CVT frequency response due to the large capacitor and inductance [5]. This type of FSC operates as a band-pass filter which has the highest impedance for nominal frequency while the FSC impedance is near zero for off-nominal frequencies. The passive ferroresonance suppression circuit (PFSC) includes a reactor in which its magnetic core is saturated when the output voltage exceeds the threshold value (typically 1.5 p.u.). In the saturation conditions, the inductance of FSC decreases significantly and additive burden is imposed through the series resistance. The PFSC has the lowest response rate among all types of FSCs. In contrast to electronic type, both AFSC and PFSC are always subjected to the secondary voltage which causes perpetual power losses [5–7]. The electronic type of FSC is equipped with two power electronic switches which are turned on after the appearance of overvoltages. These switches damp out overvoltages through a resistor connected to ground [8–10].

In this paper a new control unit is proposed for optimal firing of SCRs in an electronic FSC (EFSC). In the proposed method, the CVT output voltage is used as the input signal of the control unit. Then, in order to detect ferroresonance overvoltages, the control unit input is compared with a prespecified threshold value. If the voltage value is greater than the threshold, the control unit conducts SCRs. On the other hand, the control unit turns the SCRs off when the overvoltages disappear. In some proposed control units, IGBT and GTO have been used as power-electronic switches in the EFSC. Since these types of switches

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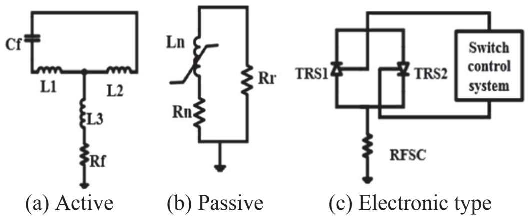

Fig. 1. Different types of FSC.

need positive and negative pulses to be turned on and off, two separate firing circuits are required in their control units [1,5,11]. In the proposed control unit, the thyristors of SCR type are used which are turned off by self-commutation. Thus, negative pulses are not needed in the SCR firing circuit. Unlike some previously designed EFSCs, the proposed control unit needs only one firing circuit to turn the SCRs on. Moreover, operation of the proposed EFSC depends only on the CVT secondary instantaneous voltage while in some approaches the SCRs are turned on for a preset duration time irrespective of overvoltages level [5,11].

2. Problem description

CVTs are widely used in substations at voltage level greater than 63 kV to reduce the input voltage to designated low voltage level through a capacitance voltage divider followed by an IVT. The CVT output voltage can be a main signal for protective relays. Therefore, the correct operation of the protection schemes depends heavily on the CVT precision. Since the CVT error is dependent on its frequency response, ferroresonance phenomenon as the most important event during transient conditions should be investigated comprehensively.

In order to study the ferroresonance phenomenon, the behavior of the depicted CVT in Fig. 2 has been investigated in transient conditions [3,12]. C1 and C2 are HV and MV capacitors which constitute the voltage divider circuit. RP and RS are the resistances of the IVT primary and secondary windings respectively. LP and LS are the leakage inductances of the IVT primary and secondary windings respectively. LM is the non-linear magnetizing inductance and RM denotes the equivalent resistance of the IVT core loss. RL is the rated ohmic CVT burden. The compensating series reactor for correction of phase shift caused by CVT capacitors is an autotransformer that connected to the primary side of IVT. The parameters of autotransformer model are RPR, LPR, RSR, LSR, LMR and RMR. The compensating reactor is tuned so that the sum of compensating reactor self-reactance and IVT leakage reactance is

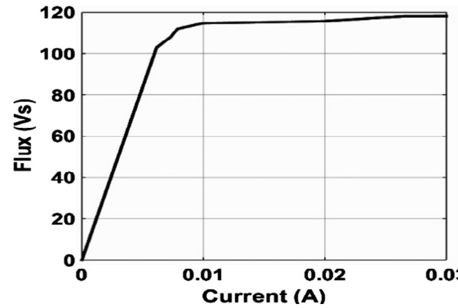

Fig. 3. Non-linear magnetization characteristics of IVT core.

equal to equivalent reactance of divider capacitors [13]. The resistance and leakage inductance of the compensating reactor are named RPR and LPR respectively. LD is the inductance of drain coil which is used in power line carrier (PLC) communications. The values of above mentioned elements are given in Table A.1 in Appendix A.

According to IEC 60044-5 standard, to establish ferroresonance conditions, the CVT secondary side is assumed to be shorted for 100 ms through switch ‘S’ (see Fig. 2) [14]. The magnetizing characteristics of the IVT core i.e. flux-current curve is shown in Fig. 3 [12].

All simulation have been implemented in Multisim software which is a powerful tool for advanced analysis and circuit design in industrial applications. At first, it is assumed that the FSC is out of the circuit and the CVT burden is 0.1 p.u. The ferroresonance condition is provided by applying a short circuit at secondary side for a duration of about 100 ms. The CVT output voltage is shown in Fig. 4(a) for this condition. It can be clearly seen that after removal of the short circuit, the fundamental mode appears due to saturation of IVT core. Indeed, the nonlinear core inductance and the equivalent series capacitor constitute a nonlinear resonance circuit which can lead to an operational point beyond knee point of core magnetizing characteristics. As depicted in Fig. 4(b), the magnetizing current includes abrupt peaks after the occurrence of ferroresonance. The frequency spectrum of the CVT output voltage shown in Fig. 4(c) consists of fundamental frequency of power system as well as odd harmonics specifically 3rd and 5th order components. In this condition, the overvoltages can rise up to about 5 p.u. which can result in severe damage to the CVT insulation.

3. Proposed control unit structure

Fig. 2 shows the CVT under study as well as the controlling unit. The

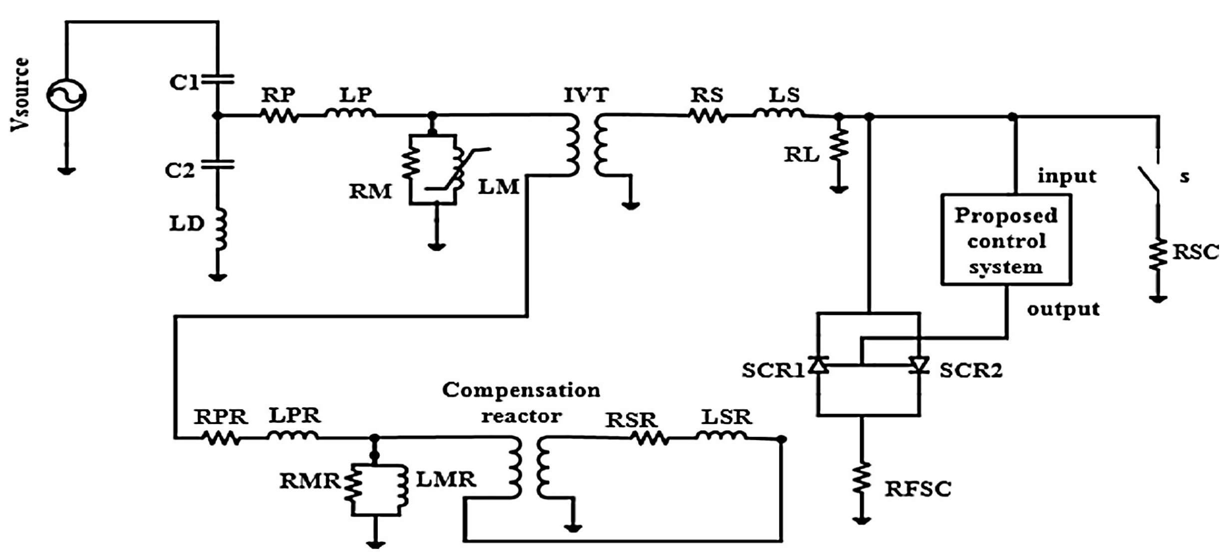

Fig. 2. CVT equivalent circuit as well as the proposed control unit.