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Knee-Point Voltage Determination for Current Transformer Functional Identification

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Abstract:- A set of four 2000/1A current transformers (C.T.s) were earmarked for a substation power transformer protection requirement. It was necessary to investigate the characteristics of these transducers with a view to confirming whether or not they were protection C.T.s. In this paper the author discusses the open-circuit laboratory test carried out for the generation of voltage and current data relevant for the production of their magnetization curves to that effect. MATLAB was used in plotting the magnetization curves. The knee-point voltage (KVP) of the C.T.s was 1000V as determined from the curves. The C.T.s being observed to possess such a high value of KVP in each case, were thus confirmed as protection C.T.s. being clearly different from metering C.T.s whose KVP values are generally within 60 to 120V.

Keywords:- Current Transformer, Knee-point Voltage, Functional Identification.

I. INTRODUCTION

A. Definition, Ratings, General Functional Requirements and Classifications

Current transformers (C.T.s) are electromagnetic devices used in power system installations to reproduce a primary circuit current at a much reduced level for the supply of the current circuits of indicating instruments and protective relays or for the monitoring/control of a transmission network operation as in the books in [1], [2]. They usually have primary windings rated at 5 to 15,000A to supply a rated secondary current of 1 or 5A according to the books in [3], [4]. Generally, they are required: 1) To produce the primary current conditions at a much lower level so that the current can be carried by the small cross-sectional area cables associated with panel wiring and relays; and 2) To provide an insulating barrier so that relays which are being used to protect high voltage equipment need only be insulated for a nominal 600V as in [1]. It should be added that the performance of a C.T. is determined by the highest current that can be reproduced without saturation to cause large errors according to the book in [5].

Industries produce indoor and outdoor C.T.s for voltages up to 750kV in various design versions as regards the method of mounting, purpose and service such as: a) platform C.T.s, for mounting on platforms and other supports; b) built-in C.T.s, where the primary serves as an input circuit of an electrical device; c) bushing C.T.s, intended for use as input transformer; d) busbar C.T.s, in which the primary is the busbar of a distribution device; e) clip-on C.T.s, which are portable detachable split-electromagnet instruments without a primary, where the magnetic circuit can be split up and then clipped on the conductor to measure the current as in [3]. However, the current transformers considered in this work were to serve as bushing current transformers.

B. Electrical Connection Method and Vital Precautionary Measure

A current transformer is otherwise referred to as a series transformer according to the dictionary in [6]. Thus, the primary winding of a C.T. is usually connected in series with the load to be measured or controlled, and this load determines the current flowing through it; whilst, the secondary winding is loaded with a constant impedance, for any given set of conditions as in [6] and according to the manual in [7].

Due to the high turn ratio usually encountered in a C.T., it is possible to obtain an unsafe high voltage across the secondary terminals of the C.T. The voltage regulation of C.T.s, however, is designed so that the voltage drops very rapidly as soon as the burden is connected to it. For safety reasons, therefore, the terminals of the C.T. should always be short-circuited when instruments are not connected to it; the instruments should first be connected before the short-circuit strap is removed as in the books in [2], [8]. Indeed, for this reason, the secondary circuit of a current transformer (as well as that of a potential transformer) should always be earthed according to the book in [9].

C. Specific Functional Requirements and Vital Determinant

Current transformers are often used for the dual duty of measurement and protection as stated in the book in [10]. The functional requirements of a protective C.T. are quite different from those of a metering C.T. A current transformer designed for measuring purposes operates over a range of current up to a specific rated value, which usually corresponds to the circuit normal rating, and has specified errors at that value. On the other hand, a protection current transformer is required to operate over a range of current many times (10 to 20 times) the circuit rating and is frequently subjected to conditions greatly exceeding those which it would be subjected to as a measuring or metering current transformer in accordance with the books in [1], [5], [11].

Since the operation of measuring devices and protective relays is to a large extent dependent upon the magnitude and balance of currents, the performance requirements of C.T.s are frequently specified in terms of the knee-point voltage of their excitation characteristics as in the manual in [12]. The knee-point voltage of the excitation characteristics of a C.T. is defined as the point at which a further increase of 10% of secondary e.m.f would require an increment of exciting current of 50% as in [10], [12]. The knee-point voltage indicates that voltage above which the C.T. enters into saturation and the exciting current increases rapidly with a very little increase in voltage as in [10], [12].

According to the book in [11], the knee-point voltage of a metering C.T. is generally around 60 to 120V and is kept low so as to protect meters; whereas, the knee-point voltage of protective C.T.s are generally quite high varying from 200 to 1900V depending upon the requirements of the relay. The upper limit of 1900V is specified because the secondary cables from a C.T. are generally rated to withstand 2kV for 1 or 3 minutes and 660V to 1100V continuously.

II. OPEN-CIRCUIT LABORATORY EXPERIMENT

Figure 1 shows the arrangement of the experimental apparatus. Traces of possible residual magnetism were removed from the C.T. by having the adjustable auto-transformer (or variac) raised until current approached secondary winding rating of 1A and steadily reducing the same to zero; this being done ten (10) times as stated in the manual in [13].

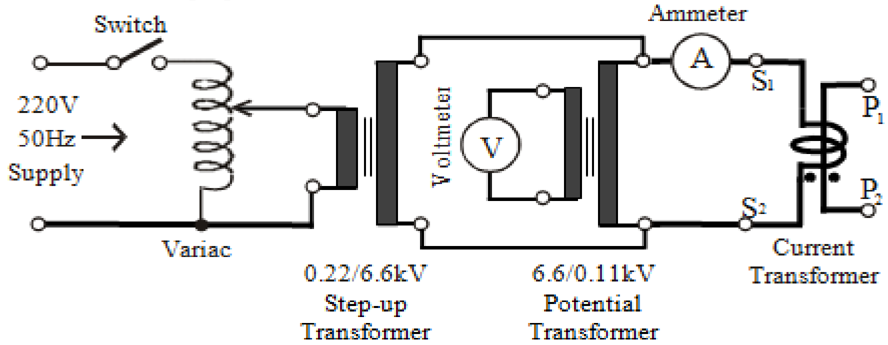


Fig. 1: Apparatus as set-up for Open-circuit Test of a Current Transformer

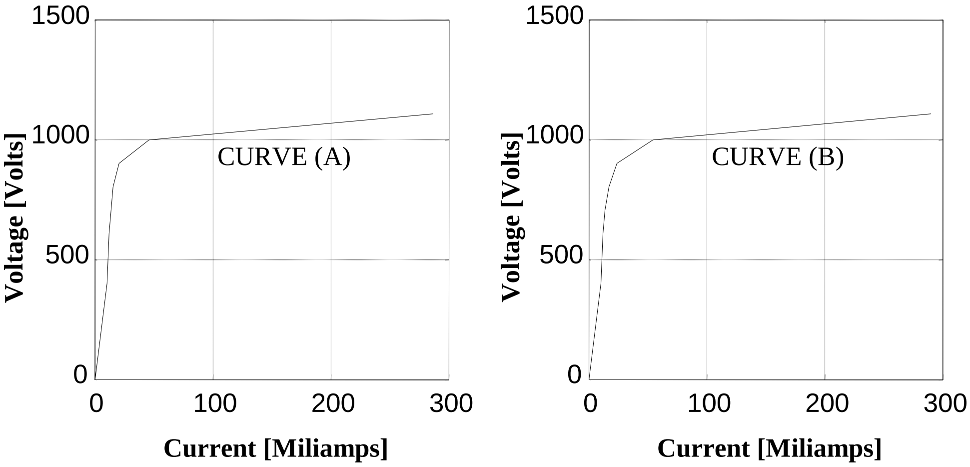
Care was also exercised when taking the voltage and current readings not to turn the variac backwards (for any reason) while in the upward direction of adjusting it for increase of exciting voltage. This was to avoid the introduction of errors in the readings obtained sequel to hysteresis effect, which reflects the lack of retraceability function in the C.T. core as a ferromagnetic material according to the book in [14]. The results of the experiment were as given in Table 1.

Table 1: Results of the Open-circuit Tests carried out on the C.T.s

C.T. Labelling	C.T.1		C.T.2		C.T.3		C.T.4	
Voltage and Current Readings Obtained	V	mA	V	mA	V	mA	V	mA
	0	0	0	0	0	0	0	0
	400	11	400	11	400	11	400	5
	600	13	600	13	600	14	600	10
	700	15	700	15	700	15	700	12
	800	16.5	800	17	800	17	800	15
	900	21.5	900	24	900	21	900	22
	1000	47	1000	55	1000	52	1000	36
	1100	288	1100	290	1100	290	1100	230

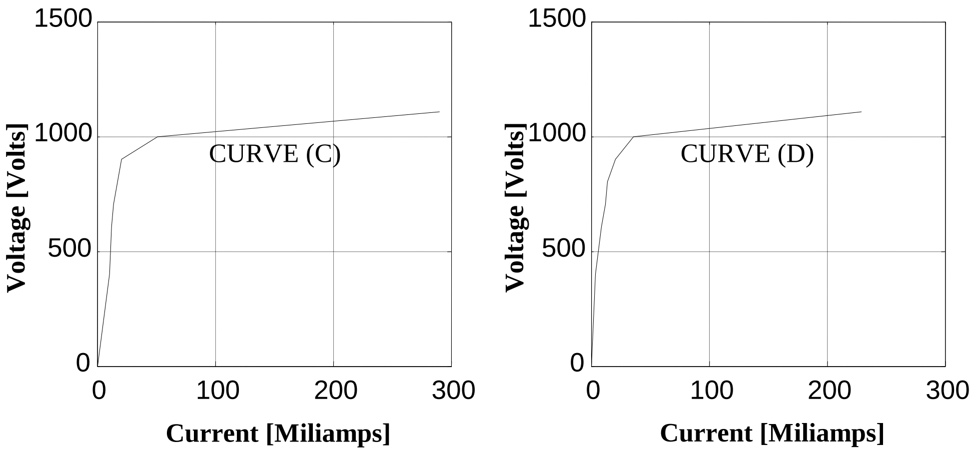
III. MAGNETIZATION CURVE PRODUCTION

Using MATLAB, the magnetization curves shown in Fig. 1 & 2 were plotted from the voltage and current readings presented in Table 1.



(a) **(b)**

Fig. 1a) & b): MATLAB Generated Magnetization Curves A & B for C.T. 1 & 2, respectively.



(c) **(d)**

Fig. 2a) & b): MATLAB Generated Magnetization Curves C & D for C.T. 3 & 4, respectively.

MATLAB is an acronym for Matrix Laboratory developed by Math Works Inc. as stated in the books in [15], [16]. This is a software package for high performance and visualization, combining capabilities, flexibilities, reliability and powerful graphics, hence, suitable for engineers and scientists as found in the journals in [17], [18] as well as the institutional compilation in [19]. The most important feature of MATLAB is its programming capability, which is relatively easy to learn and to use, and which allows user-developed functions as stated in the journal in [20].

IV. DISCUSSION AND CONCLUSION

A close study of the magnetization curves in Fig. 1 & 2 reveals that the four current transformers, C.T.1, 2, 3 and 4, do possess the same knee-point voltage of value 1000V. This is because just after the 1000V point on the curves one observes the exciting current increasing rapidly with a very little increase in voltage as earlier stipulated in the introductory part of this work (see 'Specific Functional Requirements and Vital Determinant').

Going by such a high value of knee-point voltage (falling between 200V and 1900V clearly), it is conclusive that the C.T.s were actually protective current transformers.

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