Simulation Of Synchronized Controls in Circuit Breakers of Power Transformers and Operation of Reactive Compensation Banks

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Abstract. Alternative solutions to the problem of inrush currents when the power circuit breaker actuates were evaluated using SIMULINK with the VIZIMAX SynchroTeq Plus controlled switching device (CSD) with an opening and closing range of 0 to 0.038 seconds (s) respectively of two scenarios; high and low hydrology of the 138 and 230 kV patios, giving more impact to the high hydrology scenarios for the patios, giving as results for the energization of the capacitor bank for phase B in the time of 0.038 s an inrush current of; 3.452 in per unit (PU) at the generator terminals, and 3.833e-16 ≈ 0 in PU in the capacitor bank without the CSD. After obtaining these results, the CSD was applied, resulting in; -6.263e-09 ≈ 0 in PU at the generator terminals, and -3.089e-25 ≈ 0 in PU in the capacitor bank within the opening and closing range of the CB. In the energization of the power transformer for phase B in a time of 0.0055 s, inrush currents of -5.643 were obtained in PU at the generator terminals corresponding to the primary side of the power transformer without the CSD. After obtaining these results, it was applied the CSD (between the generator and the transformer) giving as a result -1.108e-09 ≈ 0 in PU in the terminals of the generator corresponding to the primary side of the transformer, it is possible to identify that the use of the CSD in an Electrical Substation would be a great contribution for CELEC EP TRANSELECTRIC.

Keywords: Inrush Currents, Controlled Switching Device, Capacitor Bank and Power Transformer.

1 Introduction

[1] mentions that when the transformer is energized without load there is a peak in the magnetization inrush current wave due to the saturation of the iron core, which leads to a malfunction in PE devices such as relays. [2] ensures that there have been many serious accidents due to the inconvenience that power transformers present when energizing them, the zero-mode inrush current of high impedance transformers caused the backup PE to malfunction. [3] studied the characteristics of inrush currents in the zero sequence of converter transformers, including the relationship between the amplitude

and attenuation characteristic of such currents and their relationship with the system, remanence, and angle. closing. [4] state that the saturation of the EMCTs can cause a malfunction of the 87T due to the presence of the inrush current that occurs during the reactivation of a high voltage power transformer. [5] explain the situation that power transformers have when connected to the network, the inrush current increases substantially with a high value within the harmonic components, which leads to an increase in the amount of flux in the core, which causes the magnetic circuit to saturate for a long time of many cycles, this inconvenience causes the PE relays to malfunction. [6] used different techniques in order to minimize the impact of inrush currents in power transformers with at least 10 mitigation techniques to verify which are the parameters that directly affect the inrush current. [7] propose a tuning strategy for the overcurrent PE of the link transformers in order to suppress the excitation inrush current under the conditions of changing the closing time of the CB, the direct load of the generator or the auxiliary transformer. and subsequently accurately determines the PE of the CB setting. [8] mention that placing a power transformer in parallel when it is energized can cause an inrush current in the energized transformer, this current has high frequency harmonic components, which can cause saturation in the transformer core. and the malfunction of the PE relays in the SEP. [9] analyzed the design and construction of an automated test bench measurement and verification unit to identify the inrush current of transformers of different sizes and power. [10] studied the characteristics of the waveform that occurs when there is inrush current and internal fault current in power transformers applying the use of the sinusoidal degree of correlation and indicate that it is extremely important to distinguish these forms of waves to avoid problems with the transformer. In the commutation process, the CBs are the ones that experience this process in which the inrush currents are implemented, which could affect the CB in its contact resistance, which could break the CB [11]. [12] mentions that closing a capacitor in parallel will generate high inrush currents, which leads to a decrease in the useful life of these reactive compensation equipment, for which they propose a divided $\emptyset$ control strategy for vacuum CBs.

1.1 Problematic

The researchers [13] carried out various studies on electromagnetic transients referring to the energization of three-phase power transformers in different SE corresponding to the Paraguayan SIN, to reduce the overvoltage's in which all the power transformers are subjected in each one of the SE applying ATP engineering software. [14] analyzed the effects of energizing the power transformers of SE San Francisco and LT, which present problems of overvoltage's and overcurrent's that in one way or another affect the power system, reducing the useful life of the network, implements as data the maximum demand of July 2016 considering the information from CENACE, they used computer programs such as ATP and MATLAB®. [15] used the ATP/EMTP engineering software to identify the difference between the magnitudes of the inrush and fault currents, since they come to have similar values and with this makes the 87T act in an ineffective manner, causing low reliability in the electrical system. [16] developed mathematical models in state space to obtain simulations of the various incipient faults found inside a single-phase transformer, he used various saturation and hysteresis characteristics in the mathematical models to better represent the behavior of a real single-phase transformer. [17] developed a graphical interface by means of MATLAB® software on a mathematical model in which they focused on the various operations of the SEL 587 of a power transformer, the mathematical model consists of the equations that govern the 87T in initial conditions. and/or normal, with this study they help students in the area or career of electrical engineering to extend their knowledge with practical learning that is fundamental. [18] designed a power transformer by applying mathematical models with characteristics similar to that of a real power transformer using MATLAB® software, in one of the models he applied the saturation that is present in power transformers or autotransformers, as well as well as the variation of the mutual reactance, he made various subsystems in which they are able to adapt to the main model, one of the subsystems deals with the study and simulation of the inrush current that is present in the power transformers in order to obtain the behavior through characteristic graphs of this phenomenon, and indicates that for a real power transformer the behavior of the inrush current is approximately between ten to twenty times the nominal current at high and extra high voltage levels, several aspects also influence such as ; core material, opening and closing of the CB and among others. [19] were able to demonstrate through mathematical modeling the behavior of two banks of three-phase transformers connected in parallel, with different types of connection, starting from DY N1 to N11, the mathematical model is based on several differential equations of different order, the variables are based on in the results to be obtained from the analysis, and they focused on the line current for the delta and star connection considering a purely resistive load, as well as the inrush magnetization current that occurs in the transformer core, part of the constants that were needed were obtained based on various experimental tests carried out on several single-phase transformers, once the differential equations were obtained, they used the MATLAB® software with the GUIDE tool in order to show the theoretical and graphic results of the different currents presented. In the study of the mathematical model, for the validation of their results they applied a margin of error which was an acceptable percentage. The authors [20] applied CS to their automatic CBs in the Hydro-Québec network, since the switching of reactive components in an HVAC CB generates a high number of transients that are injected into the electrical network, giving a deficiency in the quality of energy, for this they successfully implemented and validated the CS, being effective and reliable for controlled energization with power transformers and capacitor banks.

2 Methods

2.1 Methodology

The study of the inrush current both for the energization of the capacitor bank and power transformer with the CSD are the materials implemented, and the different CS strategies are the methods applied in this work.

Study of the Inrush Current in the Capacitor Bank.

For the study of the inrush current when the switching is carried out in the CB at the time of energizing the capacitor banks, the equations provided by the regulations [21], in session 4.3.2, are considered. individual capacitor banks containing the equations (1) peak inrush current in switching capacitors and (2) the frequency present in the inrush current.

$$I_{peak} = \sqrt{2} \cdot \sqrt{I_{SC} \cdot i_1} \quad (1) \qquad f_i = f_s \cdot \sqrt{\frac{I_{SC}}{i_1}} \quad (2)$$

Where; f_s: It is the network frequency in Hz, I_{SC}: It is the short-circuit current of the source in A RMS, i_1: It is the current through the bank of capacitors C1, in A RMS.

CS Equipment for the Elimination of Inrush Currents in the Energization of Capacitor Banks.

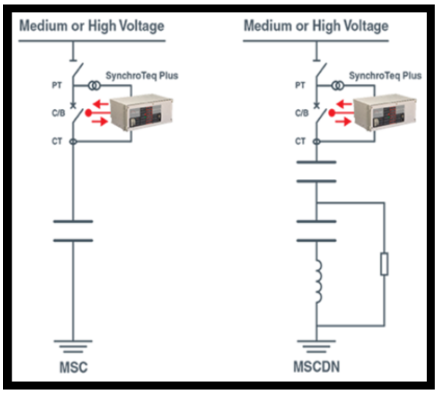

Fig. 1. Installation for AV and MV of SynchroTeq Plus, [22].

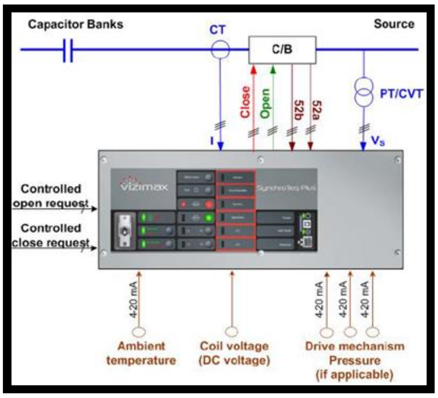

Fig. 2. Variables used in SynchroTeq Plus, [22].

The banks of capacitors are used in SE of AV and MV with the objective of compensating the Q, controlling the voltage and improving the PF, for this CB of AV and MV are used and at the moment of carrying out the opening and closing maneuver it is presented an uncontrolled commutation in the capacitor banks and this causes transient currents and voltage disturbances which causes direct damage to the CB and yard equipment such as measurement around it, there is equipment called SynchroTeq Plus which is a CSD (see figures 1 and 2), which aims to prevent CB operation problems at the optimal time to avoid transient currents and voltage disturbances when some maneuver is carried out in the capacitor banks, the CSD reduces equipment failures, improving reliability and system stability [22].

System Voltage Zero Crossing Strategy on Capacitor Bank Energization.

One of the strategies of the CS is the energization of the banks of capacitors when it is done at the zero-voltage crossing [23], since the capacitors inherently oppose the various voltage variations, this would avoid transients in the system. and even the inrush currents, however, due to the RDDS and the ±X°, the worst of the results can occur when the energization occurs at the peak of the system voltage, therefore, the closing angle calculated by the CSD uses a ShitfC° [20], as shown in equation (3).

$$Shift_C^{\circ} = \frac{360^{\circ}}{2\pi} \cdot \frac{RDDS_{1_{PU}}}{RDDS} \cdot \left| \frac{V_{peak}}{V_{peak\_nominal}} \right| \cdot sin(|X°|) \qquad (3)$$

Where; $RDDS_{1_{PU}}$: It corresponds to the slope calculated by the crossing by zero system voltages under normal conditions in PU, $RDDS$: Decrease rate of dielectric strength in PU, V_{peak}: Peak voltage in kV, $V_{peak\_nominal}$: Rated peak voltage or ∅ voltage in kV, $|X°|$: Dispersion of ±3σ in °.

Study of the Inrush Current in the Power Transformer.

For the study of the inrush current when switching is carried out in the CBs when energizing the set of power transformers, there are no defined equations to determine the value or behavior of this transient, as it can be identified in the regulations [24], but there are various switching techniques that have been implemented as they did in [20].

CS Equipment for the Elimination of Inrush Currents in the Energization of Power Transformers.

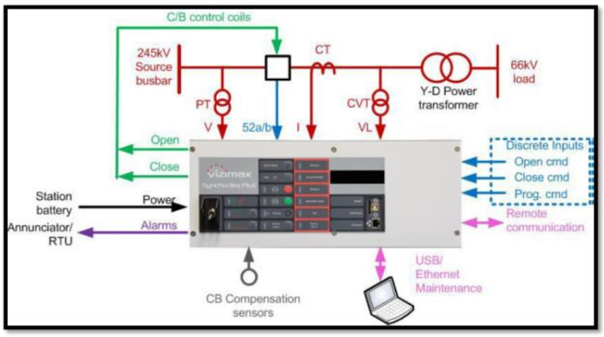

Fig. 3. Connection of the CSD for the Energization of a Power Transformer, [25].

The power transformers reduce or increase the voltage levels, the CB at the time of energizing these transformers cause energizing currents called inrush currents that become very high due to a transient of electromagnetic origin that is present in the core of transformers, this produces a high voltage drop and is maintained for several cycles, which causes electrical risk in any element that makes up the SEP, there is a CSD called SynchroTeq Plus from VIZIMAX (see Fig. 3), whose function is main to prevent CB operation problems when energizing a power transformer, [25] carried out the installation of the equipment and its connection, both digital and analog signals.

Controlled Closing Strategy with respect to Φr in Power Transformer Energizing.

Applying CS's strategy with respect to Φr is the most efficient technique since ∅ must be closed when Φr is the largest, in the first instance the point of the instantaneous voltage wave is equal to the peak voltage times the sinusoidal product of α, this angle is detailed in equation (4), and the values of Φr are mainly derived from the various voltage measurements of the transformer when it is de-energized, the CBs that present classification capacitors, show a fair significant coupling voltage in the bushings of the transformer that is de-energized, it is there where a ΔΦr is produced, and it is detailed in equation (5) [20].

$$\alpha = arcos \cdot \left(\frac{\Phi_r \pm \Delta\Phi_r}{V \cdot \sqrt{2}} / \omega \right) \qquad (4) \qquad \Delta\Phi_r = \frac{V_{coupling\ peak}}{\omega} \cdot sin(\beta) \qquad (5)$$

Where; Φ_r: Absolute value of Φr in Wb, $\omega = 2 \cdot \pi \cdot f$: Angular velocity in rad/s, V: System RMS voltage at V, β: Angle formed between the change of ∅ between the system voltage and the coupling voltage in °.

3 Results

To carry out the simulation with the CB CSD, the reference indicated by the regulations [26] was taken as a reference with an opening time of 0 to 0.038 s, a tentative value used by the different CB manufacturers found in the 230 yards. and 138 kV of the SE Pascuales of CELEC EP TRANSELECTRIC, in order to perform the simulation of the energization of a power transformer and the capacitor bank with a simulation time of 0.25 s, the parameters of the EP will be loaded in files MATLAB® editor that must be previously executed before the SIMULINK files, it should be noted that the colors used in this document are referenced as follows; yellow color for ∅ A, blue color for ∅ B and red color for ∅ C, both for currents, fluxes and voltages respectively.

3.1 Simulation of the Energization of the Capacitor Bank with the High Hydrology Scenario in the Study Area

Figure 4 shows a sketch of the SEP of the SE Pascuales patio 230 kV of CELEC EP TRANSELECTRIC, which shows the energization of the reactive compensation banks with the high hydrology scenario in the study area and how the transient phenomenon of the inrush current, will be analyzed with two sections; one with the CSD and one without the CSD and how the voltage and current curves behave respectively.

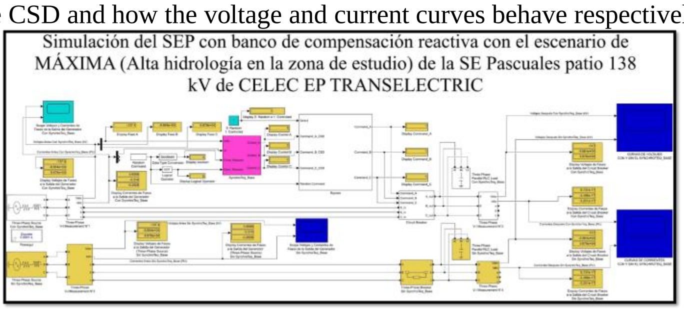

Fig. 4. Simulation of the Energization of the Capacitor Bank with the High Hydrology Scenario in the Study Area.

Currents in the Capacitor Bank with and without the CSD of the High Hydrology Scenario in the Study Area.

Figure 5 at the bottom shows the range when the CSD is not applied, in this case the ∅ B presence of the inrush current with a value of 3.833e-16 PU at a time of 0.039 s, and at the top the scope that the CSD has when solving the transient of the inrush current is displayed, giving a value in ∅ A of 1.289e-16 PU in a time of 0.051 s.

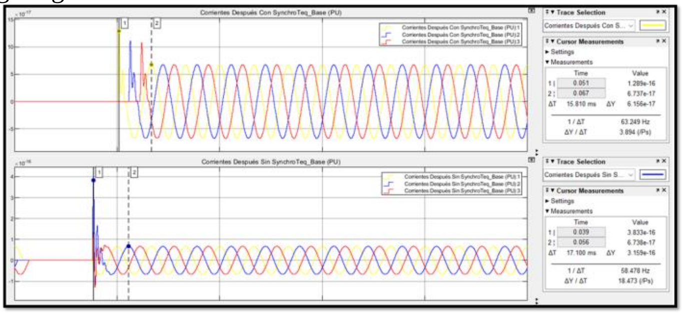

Fig. 5. Current Curves with and without the CSD During the Energization of the Capacitor Bank with The High Hydrology Scenario in the Study Area.

3.2 Simulation of the CSD During the Energization of the Power Transformer with the High Hydrology Scenario in the Study Area

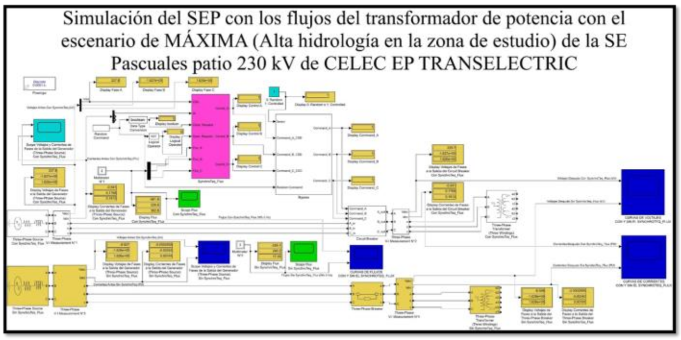

Fig. 6. Simulation of the Energization of the Power Transformer with the High Hydrology Scenario in the Study Area.

Figure 6 shows a sketch of the SEP of the SE Pascuales patio 230 kV of CELEC EP TRANSELECTRIC, which shows the energization of the power transformer with the high hydrology scenario in the study area and how the transient phenomenon behaves. of the inrush current, will be analyzed with two sections; one with the CSD and one without the CSD and how the curves behave; currents, flows and voltages respectively.

Currents Between the CB and the Primary Side of the Power Transformer with and without the CSD of the High Hydrology Scenario in the Study Area.

Figure 7 at the bottom shows the range when the CSD is not applied, in this case the ∅ B presence of the inrush current with a value of -5.643 PU at a time of 0.0055 s, and at the top it shows the scope that the CSD has when solving the transient of the inrush current, giving a value in ∅ A of -0.6793 PU in the time of 0.050 s.

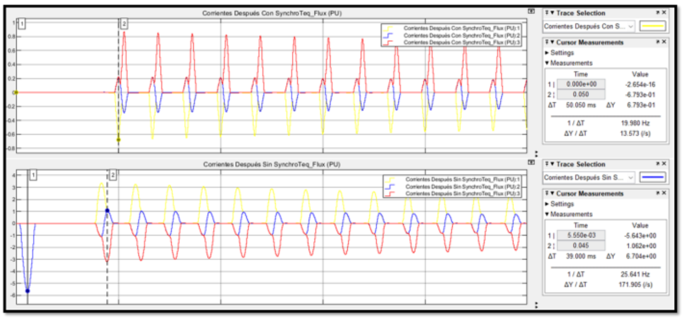

Fig. 7. Current Curves with and without the CSD During the Energization of the Power Transformer with the High Hydrology Scenario in the Study Area.

4 Discussion

In various countries, controls synchronized with CS have been installed to increase the reliability and quality of a SEP in order to solve the damage caused by the transient of the inrush current when the CB is opened and closed, there are several software that are sophisticated for carry out simulations of the inrush current transient and there are different methods and strategies to correct this phenomenon caused by the opening and closing of the CB when banks of capacitors or the power transformer are energized.

5 Conclusions

This article presents the use of SIMULINK, in which it was possible to solve the problem caused by the inrush current transient through the application of commands synchronized with SynchroTeq Plus libraries from the VIZIMAX company, two types of scenarios were evaluated when energize; the capacitor bank and the power transformer with two different scenarios which were; high and low hydrology in the study area, and it is verified that during the period where the CB opens and closes there are inrush currents, and the scenario that presents the most impact is that of high hydrology both for the energization of the capacitor bank and that of the power transformer.

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