A New Technique for Improvement Differential Relay Performance in Power Transformers

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***Abstract*—Transformer protection devices are often used to identify internal or external transformer problems and act to either prevent damage or unnecessarily disconnect power transformers. This study proposes a new differential element that combines harmonic restraint, security, and reliability with harmonic blocking speed to improve the relay performance in a power transformer. Under high load, a negative-sequence differential element adds more sensitivity for internal turn-to-turn failures. External fault detection monitoring enhances security in an external problem involving current transformer (CT) saturation. Furthermore, overcurrent elements may be configured to vary dynamically in operation is provided. This element enhances protection coordination for various operating conditions without requiring modifications to the transformer group settings. The balance of the paper discusses the use of an under-load tap changer using a time-synchronized phasor monitoring system to reduce loop current and losses in parallel transformer applications.**

Keywords— percentage differential relays, harmonics, power transformer, internal and external faults.

I. INTRODUCTION

An important consideration is whether or not a relay can detect internal faults during times of high inrush currents when used to protect a transformer[1]. A traditional differential protection system with common harmonic blocking can detect these problems when the inrush current harmonic content is less than the relay harmonic blocking threshold. This may be achieved in a few cycles[2]. However, due to the extended time duration of inrush currents, more damage to the transformer occurs, increasing the repair costs and posing a severe risk to personnel and equipment. Due to the decreased tripping time, differential elements with separate harmonic constraints may identify faults under inrush conditions in merely two cycles.

Whenever faults occur without the presence of inrush currents, the common harmonic blocking element responds faster than the independent harmonic restraint element. The technique presented combines these components to achieve quick fault clearing times in any working condition[3]. Detecting problems involving just a few revolutions when the transformer is under high load is a challenge because of the relay's sensitivity. Unbalanced faults significantly impact the sensitivity of the negative-sequence differential element. Under laboratory conditions, a 2% defect in transformer windings was detected using this differential element. All the advantages may be achieved under CT saturation, inrush currents conditions, and overexcitation while preserving relay security for external faults. Inverse-time overcurrent elements that are configured for dynamic operation adapt to changing system conditions. For example, in parallel transformer applications, these overcurrent components may enhance relay coordination with feeder relays[4]. Overcurrent element settings for two transformers are different from those for a single transformer to obtain the best coordination possible. Thus, the relay does not have to alter configuration groups when using the proposed dynamically configurable overcurrent element since it changes settings based on changing system circumstances. It's possible that a user entering erroneous values into a new setting group may cause settings problems in other parts of the relay that aren't directly connected to it.

Modern numerical relays and synchrophasor processors include time-synchronized measurements and bespoke logic that may be used to create sophisticated controls. For example, we can reduce circulating currents in transformer applications for parallel operation by measuring the current flowing through the transformers[5]. Transformer losses and overheating are reduced when circulating currents are minimized. It is feasible to use a tap changer method for regulating bus voltage while reducing circulating current based on the angle difference between the currents passing through transformers and the bus voltage information[6].

II. IMPROVED RELIABILITY AND SPEED DIFFERENTIAL ELEMENT

A. Operating principle of the differential element

Figure 1 shows a two-winding transformer differential element connection. Again, a percentage difference components can be used, and a running current is compared to a scaled or biased restraining current[5].

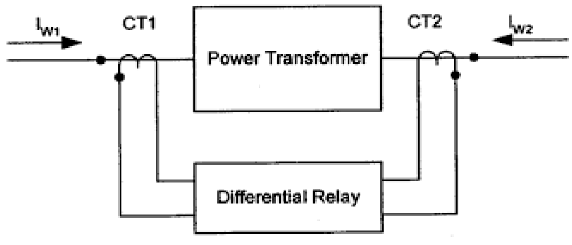

Fig. 1. Typical differential connection[7]..

The differential element uses the primary current (Iw1) and secondary current (Iw2) to compute the operating current and the restraining current with two-winding transformers. Under other operating (ideal) conditions, the Operating Current(IOP) of a device with an internal defect is zero[6]. When using equation (1.) to calculate the restraining current, the absolute values of the additional windings currents may be added to make it work with more than two windings.

Where: $I_o = \left[I_{w1} + I_{w2} \right]$ (1)

The relay monitors and records the voltage and current entering the transformer through each terminal[8].

Where: $I_{RT} = k\left(I_{w1} + I_{w2}\right)$ (2)

The scaling factor k is often equal to 1 or 0.5. The operating current (IOP) and the restraining current (IRT) is used in the single-slope operating characteristic illustrated in Fig. 2. This feature is shown by a straight line with a slope equal to SLP and a horizontal straight line showing the element's minimum Pickup Current (IPU). The working area is on top of the characteristic, while the restraint zone is on the base[9].

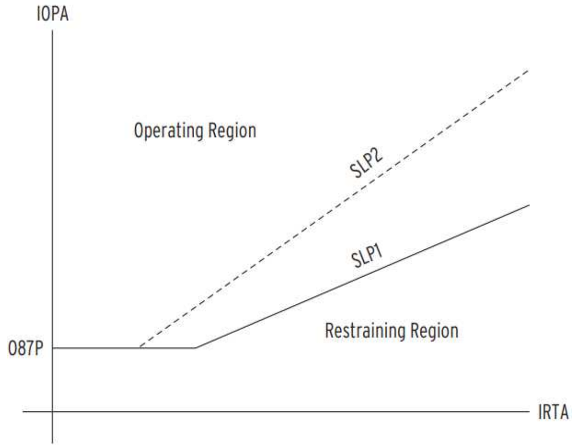

Fig. 2. Percentage of slopes with a dual element[1].

Where feasible, the differential element's operating point should be inside the differential element protection zone, which is determined by the placement of CTs. The differential element is not utilized when a problem occurs outside of this zone or during normal operation. The differential element will not work until the CTs correctly duplicate the main currents [7]. External faults will cause it to fail. While this is unlikely, if one or more CTs are saturated, the resulting operating current may lead to unacceptably high differential element conditions.

Some protection from CT saturation is provided by the slope feature of the percentage difference element. The relay's resilience to high-current external faults may be improved with a variable percentage or double differential function. A dashed line in Figure 2 depicts this characteristic[10]. Overexcitation and inrush present themselves as undesired operating currents, which may jeopardize the differential element's safety. Inrush, overexcitation situations, and exterior defects with CT saturation all have a harmonic component that distinguishes between internal and external issues. When it comes to transformer differential elements, harmonics may be used to either limit or completely block the differential element[11]

B. *Differential Element with Harmonic Blocking*

With the logic shown in Figure 3, it is impossible to utilize the differential element. This is because the fundamental component of the differential current differs from a particular harmonic component by more than the required value. An external fault with CT saturation may be blocked using the differential element's scaled second- and fourth-harmonic component differential current to prevent operation in rush situations. A more technical name for this kind of action is "common harmonic blocking" (or cross harmonic blocking[5].

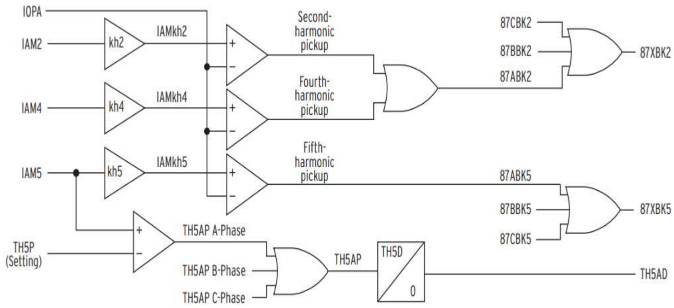

Fig. 3. Differential element with harmonic blocking logic[7].

Relay tripping needs 1(3) and 1(4), not 1(5) and 1(6).

$$I_{OP} > I_{PU} \tag{3}$$

$$I_{OP} > S_{LP} I_{RT} \tag{4}$$

$$K_2 I_2 > I_{OP} \tag{5}$$

$$K_4 I_4 > I_{OP} \tag{6}$$

where I_{OP}=Operating current, the restraining current is I_{RT}, I_{PU} stands for minimum pickup current, and S_{LP} stands for slope. Furthermore, I_2 and I_4 are the differential current's second and fourth harmonic components. Lastly, K_2 and K_4 are constants.

C. *Differential Element with Harmonic Restraint*

Figure 4 further restricts the differential element by using the second and fourth harmonics of the differential current. Inrush situations and external faults with CT saturation are minimized with these even harmonics without compromising the reliability of internal faults with CT saturation. In order for the differential restraint feature to work correctly, (87WB)[12] must be strictly complied with.

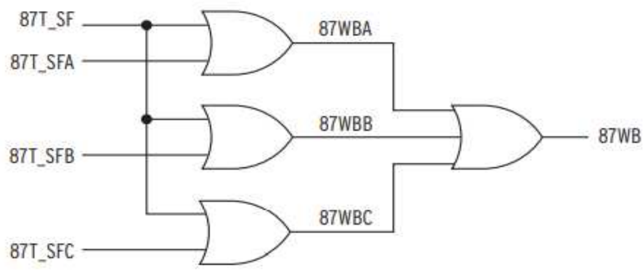

Fig. 4. Harmonic Restriction on Defferential Element[13].

D. *Harmonic Restraint and Harmonic Blocking are Combined in an Improved Differential Element.*

It combines a differential element for harmonic constraint with a differential element for common harmonic blocking. In Fig. 5 (, we can see how these two parts operate together in harmony. Transformers with internal faults have a faster restraint differential element than a blocking differential element when powered up and then de-energized. We also demonstrate that the blocking element outperforms the restraint element when a failure develops in the differential

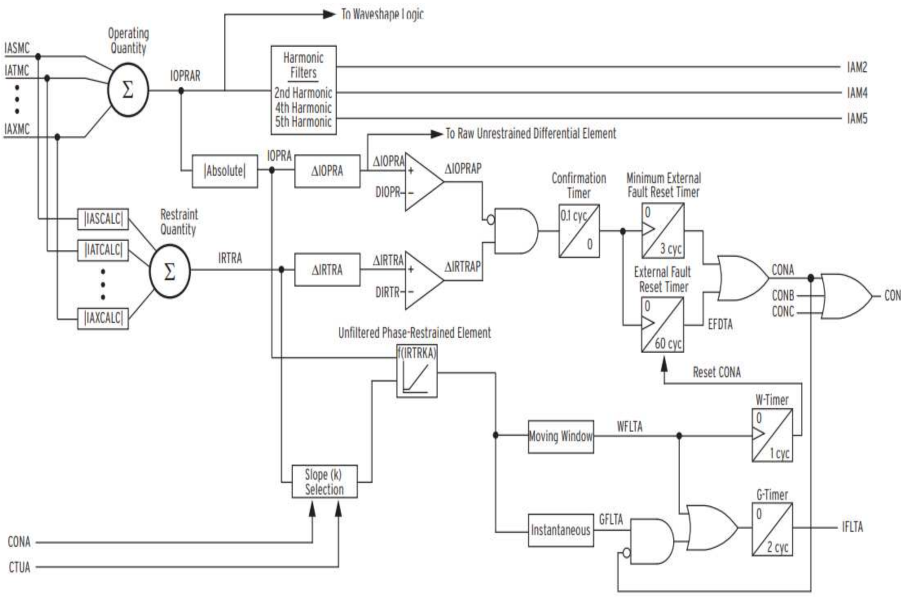

Fig. 5. Combination of Harmonic restraint and Harmonic blocking[15].

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zone while the transformer is not running. Internal fault speed may be enhanced while inrush; both components working together protect external faults with CT saturation and overexcitation [14].

E. *Internal Fault Performance of the Modified Differential Element*

In order to assess the combined differential element during transformer energization, we used a power system simulation model. A high-voltage A-phase-to-ground failure triggered a 20 MVA transformer. The winding connection modification eliminates the zero-squence current on the high and low sides of the transformer. After the transformer is connected, the harmonic constraint element output 87HR1 asserts the provision of appropriate cycles. a second harmonic substance may block the harmonic blocking element. To utilize the 87HB1 output, the harmonic content of the differential current must be lower than the set harmonic blocking percent of the relay. During this time, there is no assertion from the 87HB1 output. Because it works more quickly than the harmonic blocking element, the harmonic constraint element reduces transformer damage[14].

F. *Blocking Logic Harmonic Logic Inrush and Overexcitation*

The differential current's second-and fourth-harmonic content is used to prevent misoperation during inrush conditions by blocking the differential (harmonic-blocking method) or boosting the restraining signal (harmonic-restraint method). In contrast, the fifth-harmonic differential current prevents misoperation during transformer overexcitation. The filter function block shown in Fig. 6 is where the relay calculates the various harmonic magnitudes of the differential current[16].

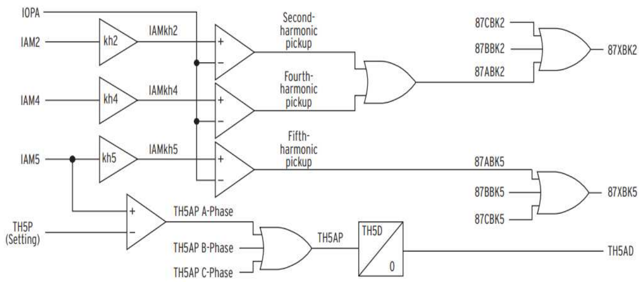

Fig. 6. Blocking Logic Harmonic Logic Inrush and Overexcitation[13].

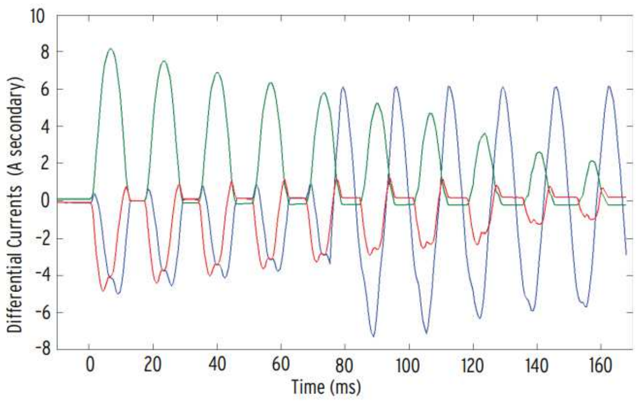

Fig. 7. Differential currents for internal transformer faults.

The differential currents for an internal transformer fault that occurs during transformer energization are shown in Fig 7. The first section of the picture illustrates the unipolar behavior of differential currents under inrush conditions. When an internal fault occurs on a single phase, the resultant waveform is bipolar, as shown in blue[17].

There are two thresholds in Fig. 8 where the incorrect phase differential current is overlaid. Note that the current is negative during inrush circumstances (the first 72 milliseconds) and continually exceeds the negative barrier (the dashed blue line in Fig. 8).

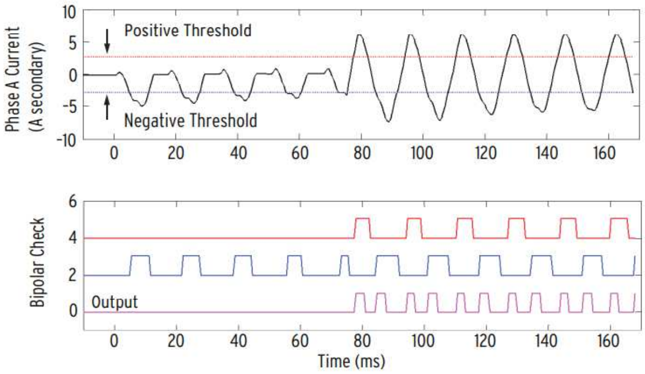

Fig. 8. Faulty phase differential current.

During this time, the current does not exceed the symmetrically set positive threshold (the dashed red line). When an internal fault develops, the current exceeds the negative threshold and quickly returns to the positive. We create a pair of bipolar differential overcurrent elements using this information: a low-set element for unblocking the relay's inrush blocking functions and a high-set element for uncontrolled differential protection. Due to the bipolar nature of the elements, we may set the thresholds rather conservatively while still ensuring security under inrush situations. The relay classifies the current as symmetrical rather than inrush if it occurs. The negative polarity is covered by mirrored logic. The magenta line in Fig. 8 is the output of the bipolar low-set overcurrent element, denoted by the symbol 87T B1A in Fig. 8[18].

G. Differential element with a sensitive and secure negative sequence

The traditional phase differential element cannot detect defects near the transformer's neutral, such as turn-to-turn and phase-to-ground failures. It is possible to employ a restricted earth fault (REF) element to detect a phase-to-ground fault close to the neutral transformer. The conventional phase differential element has an unusual problem when dealing with a turn-to-turn failure since the load current from the transformer may obscure the fault current. Phase-difference and negative-sequence differential elements are almost equivalent in sensitivity when the transformer is hardly loaded. Phase differential element is less sensitive as transformer load rises, while negative sequence differential element is constant in its sensitivity. Figure 9 depicts how a current differential element with a negative series of values works.

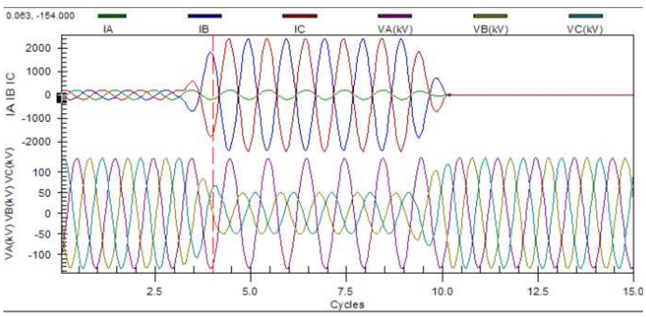

Fig. 9. Typical differential element.

Negative-sequence current flows to the fault site when a transformer develops an imbalanced fault, such as a turn-to-turn or interwinding fault. One way to detect an internal transformer breakdown is to measure negative-sequence currents[19].

III. CONCLUSION

When a fault occurs during an inrush, differential elements with harmonic blocking elements, which use the harmonic content of all phase currents to block the differential element, are quicker at identifying transformer failures. When a defect develops without generating inrush currents, the differential element with common harmonic blocking detects transformer failures faster than the harmonic restraint differential element. Using two differential elements is slower than using a differential relay with one of each. Using differential components in tandem with CT saturation and transformer energization, it is possible to improve operating speed while maintaining security against external failures. The imbalanced fault sensitivity of the negative-sequence differential element is higher than that of the normal differential element while operating under high load. Due to its enhanced sensitivity, the relay can identify problems with only a few turns of the key. For example, transformer safety relays that use time-synchronized readings may set tap changer limits on circulating currents and reduce overheating and transformer losses when used in tandem with transformers. Additional gadgets aren't required to achieve this functionality. Inverse-time components that change their characteristics according to the power system's operation do not affect the availability of relays. Due to this element's adaptability, parallel transformers may benefit from better operating time coordination.

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