Accuracy and Suitability of the CT Circuit in the Ref and Differential Relay Functions in the Digital Substation System

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ACCURACY AND SUITABILITY OF THE CT CIRCUIT IN THE REF AND DIFFERENTIAL RELAY FUNCTIONS IN THE DIGITAL SUBSTATION SYSTEM

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***Abstract*—The perturbation of Transformer #2 at Digital Substation System (DSS) Baturaja, which results in the operation of the Restricted Earth Fault (REF) LV, has resulted in numerous enhancements. One of these enhancements is the replacement of the neutral LV positioning of the current transformer (CT). This was initially located in SAM600-CT2 and has since been relocated to SMU615, which is located in the 20kV SAS Panel. The SAM600-CT2 processes data using a digital substation system-based standardization, specifically the IEC61850 Standard, which is a protocol for digital data exchange between devices and can process data in digital form. In this enhancement, it is necessary to evaluate the replacement of this position, either from the circuit or the position's accuracy. In order to guarantee this, a stability test was implemented. The CT differentiator and CT REF circuits were subjected to testing. It is assembled as required with AC system injection, and the anticipated outcomes are consistent. Stability testing is conducted on a 3-phase transformer with a capacity of 60 MVA in this journal. The transformer is connected to a digital substation system with a voltage of 150 kV/20 kV and an Alternate Current (AC) circuit. A process bus is present in one of the digital substation system architectures to facilitate the digitization process. In order to render the substation automation system measurable, flexible, and efficient, all analog values are converted to digital values. Digital values are directly derived from the digitally measured value data stream by protection relays.**

Keywords—Digital Substation System (DSS), Stablility, Differential, Restricted Earth Fault (REF), Current Transformer (CT), Earth Fault (EF), IEC61850.

I. INTRODUCTION

In my previous paper, I investigated the Transformer Fault Case Study on Digital Substation Systems and suggested a variety of improvements, one of which was the relocation of the CT [12]. This is done in order to more precisely define the operating area of each relay. In this discourse, we will investigate the sensitivity of the CT circuit to REF LV, as sensitivity is one of the prerequisites for a relay. On the secondary side, REF LV receives input from CT N; however, it should be more sensitive on the 20 kV side. This paper will evaluate the circuit's appropriateness and the results of current measurements on the differential relays and REF.

The process of digitalization in PLN has commenced to expand. In the same vein, the transition from conventional to highly integrated numerical contacts in the sphere of protection and control [2]. The research findings pertain to Indonesian digital substations, including those that are currently operational and those that are in the process of being constructed. These include the GI 150 kV Jakabaring, GI 150 kV Sukamerindu (Bengkulu), GI 150 kV Tanjung Api-Api (South Sumatra), GI 150 kV Tanjung Api-Api Extension (South Sumatra), GI 150 kV Teluk Naga II (Banten), GI 150 kV Sepatan II (Banten), and GI 150 kV Baturaja (South Sumatra).

Every change necessitates the examination and evaluation of novel elements to determine their appropriateness. One of them is the stability test conducted on the primary protection unit (MPU). In conventional substations, the physical wiring can be examined, whereas in the digital substation system, the current flowing into the MPU is already in digital form due to the conversion of analog data to digital through the SAM 600 CT device with the assistance of Ethernet fiber optics [1]. The system employs a process bus that adheres to the IEC 61869 and IEC 61850-9-2 standards to establish an interface for the interaction of primary and secondary apparatus. The transformer's measured values are converted into standard data packets through fiber optic Ethernet [1], [4].

Substation systems are automated to reduce the likelihood of errors caused by human error [1]. The system's operation is standardized according to the IEC6180 Standard, which has provided numerous advantages over the course of digitization history [2], [3], [4], [5]. One of the undesirable outcomes is the interruption of electricity distribution to customers as a result of widespread interference, as evidenced by the Baturaja Digital Substation System (DSS) on March 3, 2021. Operating errors are consistently averted.

The benefits of implementing a digital substation system include simplified substation maintenance, reduced cabling, and reduced building dimensions due to the use of Ethernet fiber optics for all distribution [2], [5]. The distribution was halted as a result of a fault current that reached the REF LV setting. The analysis concentrates on the neutral current transformer (CT) as the reader and input of REF LV. The unit protection function is the restricted earth fault protection, low impedance function REFPDIF. It safeguards the power transformer winding from earth-related defects. The function of the Restricted Earth defect (REF) is to safeguard the transformer in the event of a single-phase defect to the ground near the neutral point of the transformer. This relay operates similarly to a differential relay. REF is necessary on both the primary and secondary sides of the transformer, which is equipped with the YNyn group vector [15].

Current transformers (CT) are equipment that are utilized to measure the amount of current in primary power installations on a large scale. They do so by accurately and thoroughly transforming large current quantities into small current quantities for measurements and protection purposes. Consequently, the protection system is closely related to CT. At the time of the disturbance, adjustments were performed by swapping the position of CT IN LV for REF LV readings, which were all on the SAM600-CT 2. Additionally, SMU615, which was located in the 20 kV SAS Panel, was relocated [10].

This study examines the repositioning of current transformers at DSS Baturaja to improve the precision performance of the reference working slope in the aftermath of a transformer fault. The paper is divided into four sections: the first section provides an introduction to the system, followed by an analysis of the modifications made to the current transformer's position. The third section presents the results of the current transformer circuit's fitness evaluation following the position change, and the paper concludes with concluding remarks and suggestions for future research. In an endeavor to resolve actual incidents that occurred at DSS Baturaja in 2021, this document was submitted.

II. Theoretical Foundation

A. *Current Transformer in Modern Substation*

Modern substations use microcontroller-based devices that are often called Intelligent Electronic Devices (IEDs) [3], [5]. IED is an electronic device in the form of a processor that can receive or transmit data/control from or to other devices or systems [8]. Digital substation architecture is generally divided into three levels. At the station level, digital substation equipment includes gateways, servers, workstations and software (local HMI) as well as other equipment such as printers. Bay-level digital substations include BCU (controller) IEDs, Protection IEDs, and other IEDs such as AVR IEDs, kWh meter IEDs, etc. Finally, the process level includes combining units, Switchgear Control Units (SCU), Conventional Instrument Transformers (CIT), Non-Conventional Instrument Transformers (NCIT) and other equipment in the switchyard. Meanwhile, the bus in the digital substation is divided into two. The station bus includes an Ethernet network that connects existing equipment at the station level and at the room level. This Ethernet network is built using Ethernet switches. Status and measurement data contained in IEDs (bay level) are sent to servers and gateways (station level) via Ethernet with IEC 61850 protocol. Meanwhile, control is sent from the server or gateway (station level) to the IED (bay level) [8].

In a digital substation, primary signals such as current measurements on current transformers (CT) and voltage measurements on voltage transformers (VT) as well as status and control on equipment in the switchyard are digitized to protection and control devices using fiber optic baskets in accordance with IEC 61850 9-2 and IEC 61850 8-1 with communication between station-level devices using IEC 61850 GOOSE services [7], [8].

Digital substation system (DSS) architecture has several components including relays that depend on their respective functions, which are electronic devices that perform functions as control, protection, measurement and regulation [12]. Another component is time synchronization, which is very important in the digital substation architecture, especially when the sample value will be processed by the IED which will be forwarded to the protection relay [7]. From the importance of time synchronization, a Global Positioning System (GPS)-based time server was chosen. GPS supports two time synchronization mechanisms used in DSS applications, namely Precision Time Protocol (PTP) and Simple Network Time Protocol (SNTP) [12].

Protection systems in substations for transmission use differential line relays or distance relays, both of which are the main safeguards, both in conventional and digital substations [3].

Digital substations provide overall control and stability of the system and have a positive impact on protection systems and automation systems [6]. Until now, control communication between high voltage equipment in substations uses Supervisory Control Data and Data Acquisition (SCADA), Remote Terminal Unit (RTU) and Human machine interface (HMI) [4], [5].

Local Human Machine Interface (HMI) provides monitoring and control facilities of substation equipment to the operator. Gateway which is the interface between the substation and control center to shown for monitoring, remote control, and data acquisition [8].

One of the equipment located at the substation and is an important component in the substation protection system is the Current Transformer (CT) [13].The working principle of the current transformer is shown in Figure 1:

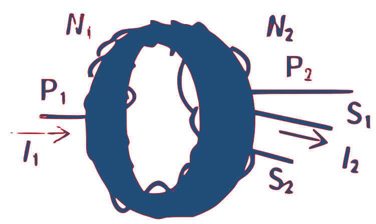

Fig. 1. Circuit on CT

For short-circuited transformers:

$$I_1 . N_1 = I_2 . N_2 \quad (1)$$

For transformers in an unloaded condition:

$$\frac{E_1}{E_2} = \frac{N_1}{N_2} \quad (2)$$

Where: $a = \frac{N_1}{N_2}$ (3)

$I_1 > I_2 \; than \; N_1 > N_2$

N_1 = number of primary turns, and

N_2 = number of secondary turns

The current and voltage phasor diagram of the current transformer (CT) is shown in Figure 2[13]

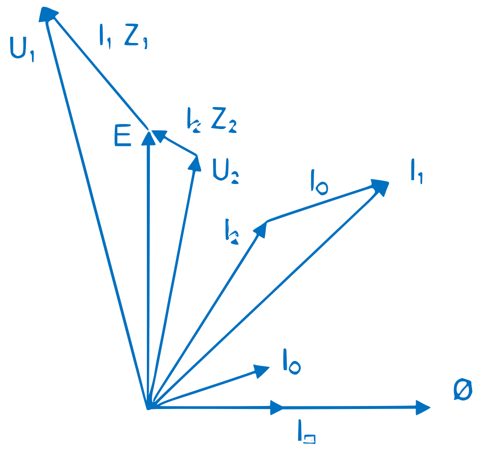

Fig. 2. Phasor diagram of current and voltage at transformer

The functions of the current transformer are:

- Convert current quantities in power systems from primary quantities to secondary quantities for metering and protection systems.
- Isolate the secondary circuit to the primary circuit, as a security against humans or operators taking measurements.
- Standardization of secondary quantities, for nominal currents of 1 Amp and 5 Amp.

In function, the current transformer can be divided into two:

- Measurement current transformer, for metering have high accuracy in the working area (rated area) of 5% - 120% of the nominal current depending on the class and a relatively low level of saturation compared to current transformers for protection. And use of measurement current transformers for Amperemeter, Watt-meter, VARh-meter, and cos φ meter.
- Protection current transformer, have high accuracy in the event of a fault where the current flowing is several times the rated current and the level of saturation is quite high. Use of protection current transformers for overcurrent relays (OCR and GFR), overload relays, differential relays, power relays and distance relays. The basic difference between measurement and protection current transformers is at the saturation point as shown shown in Figure 3.

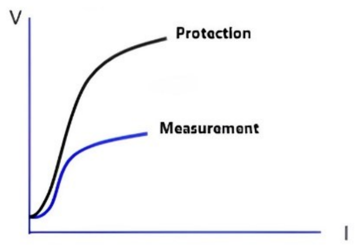

Fig. 3. CT saturation curve for measurement and protection

Current transformers for measurement are designed to saturate faster than protection current transformers so their construction has a smaller core cross-sectional area. It shown in Figure 4.

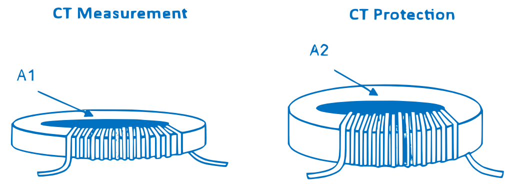

Fig. 4. Cross-sectional area of current transformer core

While based on the type of current transformer according to the type of construction and installation can be explained as follows:

Construction type:

- Type of window/ring
- Type of cast resin that is mounded
- Type of oil reservoir
- Current transformer of the bushing variety

Installation type:

- Installation within an indoor environment
- Installation in an outdoor environment

B. A method for determining whether the current transformer circuit is suitable for REF and differential relay operations.

Differential protection usually detects short circuits and ground faults in power transformer windings and internal terminals [9]. Transformer stability tests are conducted to ensure that the differential relay does not operate under normal conditions, despite high load currents and only operates when a fault occurs in its protection zone. The differential protection zone consists of transformers and cables between current transformers.

The differential stability test is to determine the soundness of the differential CT circuit, which protects the zone equipment from actual fault conditions and through fault conditions. The scheme is implemented to protect the equipment from faults inside the zone and to avoid false operation of the scheme due to faults outside the zone. This differential testing is mainly performed to ensure the correctness of CT selection and parameter settings during fault sensing. The differential relay monitors the magnitude and current vector of the primary and secondary side.

The differential stability method is shown on figure 5 and that's the explanation:

- Provide a 3-phase AC supply with a voltage rating of 380 VAC.
- Prepare the supply connector for the inlet side of the 150 kV primary CT.
- On the incoming 20 kV CT side (secondary side) after the CT output is temporarily jumpered.
- Make sure there is no local grounding, and during the circuit testing, it is safe that there is no other activity. If all the circuits are ready, turn on the AC supply.

- Monitoring the current flowing in the relay application and ensuring the iDiff value is smaller than iBias. Indicates that the primary CT to secondary CT series are in good and stable condition.

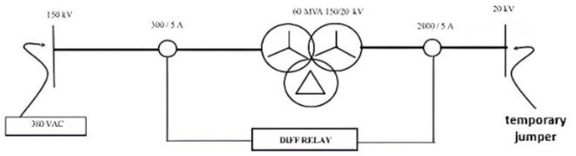

Fig. 5. Connection of stability Differential

The purpose of the REF stability test is to determine the health of the REF CT circuit protecting equipment. REF must remain stable under switching and fault conditions. The 220 VAC injection in front of the HV CT, with a temporary jumper on the Neutral Grounding Resistor (NGR) or bypassing the NGR and a temporary jumper on the LV CT side. It shown in Figure 6. And the method are:

- Provide AC supply with a voltage rating of 220 VAC.
- Prepare the supply connector for the inlet side of the 150 kV primary CT.
- On the incoming 20 kV CT side (secondary side) after the CT output is temporarily jumpered and ground.
- Bypass the NGR circuit. If all the circuits are ready, turn on the AC supply.
- Monitoring the current flowing in the relay application and ensuring the iRest (Ref Diff Current) value is smaller than iBias. Indicates that the primary CT to secondary CT series are in good and stable condition.

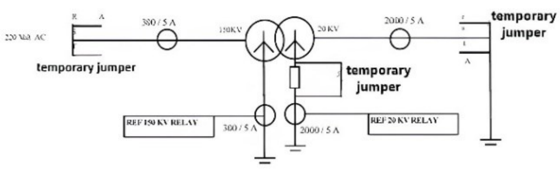

Fig. 6. Connection of syability REF

III. CT Circuit Repair and Stability Results

CT measurements were repositioned from the previous SAM CT-2 to SMU615. As a result of the repositioning, primary stability was performed to ensure the new cable condition was stable. Figure 7 shows the condition of CT REF LV before it changed position. CT REF LV is still in SAM CT-2 located in the 150kV switchyard.

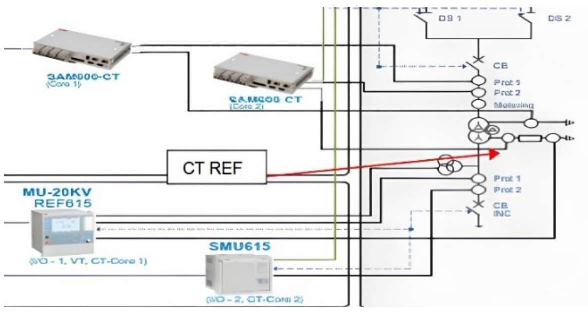

Fig. 7. Conditions before CT-REF LV removal on SAM600-CT2

The new position is now on the 20 kV cubical SAS control panel. It joins the LV side measurement on the SMU 615 device. Figure 8 shows the condition of CT REF LV before it changed position.

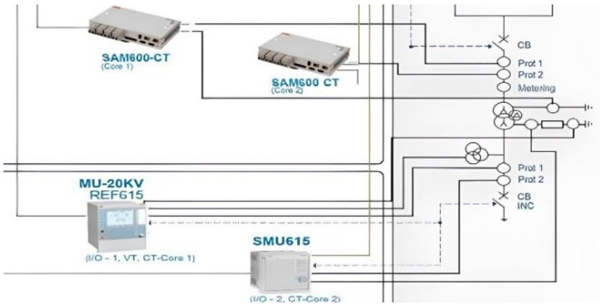

Fig. 8. Conditions after transferring CT-REF LV to SMU615 on a 20kV SAS panel

The retest after circuit improvement is shown in Figure 9, and the results of the Differential RET670 primary stability are shown in Table 1. The differential stability circuit is carried out with a 3 phase 380 VAC injection in front of the HV CT which has a ratio of 300/5 in DSS Baturaja transformer 2. Temporary jumpers on the LV CT side which has a ratio of 2000/1. Readings from relay applications with 6 A injection read 5.9 A on the HV side and 41 A on the LV side. While for I diff read 0.4 A with I bias 6 A which means the results are stable and connection in good condition.

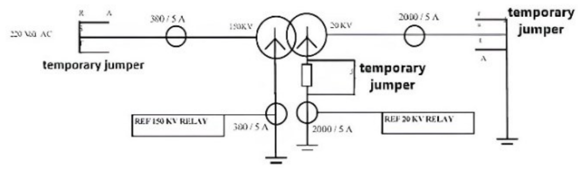

Fig. 9. Scheme diffenrential stability

TABLE I. STABLE CONDITION DIFFERENTIAL RET670

Phase	150 KV SIDE		20 KV SIDE		Diff Current (A) / I Bias	Remark
	Injection	*Measure (A)*	*Injection*	*Measure (A)*		
R	5.9 A	5.924 ∟0	41 A	41.257 ∟-179.85	0.445 A 5.983 A	/Stable
S	5.9 A	5.973 ∟-120.775	41 A	41.888 ∟58.866	0.404 A 5.983 A	/Stable
T	5.9 A	5.859 ∟118.872	41 A	40.747 ∟-61.264	0.419 A 5.983 A	/Stable

The REF stability circuit is shown in Figure 10. With the results read in Table 2. The REF injection circuit uses a 220 VAC voltage on the CT HV side with a temporary jumper on the NGR worth 40 ohms, this is so that the I Diff in the REF function is read. And just like the Differential stability, for the LV CT side it is also temporarily jumper but the difference is in the REF stability of the CT-LV side being grounded. The stability results show that the reading of I diff < I bias which means it is stable and the circuit is good.

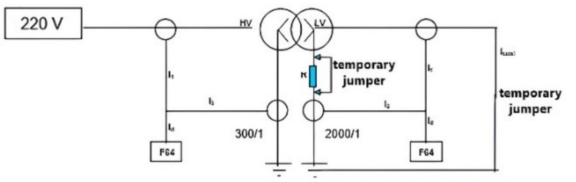

Fig. 10. Scheme REF stability

TABLE II. STABLE CONDITION REF LV RET670

Phase	150 KV SIDE		20 KV SIDE		REF Diff Current (A) / IBias	Remark
	Injection	*Measure (A)*	*Injection*	*Measure (A)*		
R,S,T	32 A	32.18	128 A	128.81	0.246 A 128.81 A	/STABLE

IV. CONCLUSION

Stability is essentially achieved by ensuring that the circuit is accurate. Regardless of whether it is implemented subsequent to maintenance or a disruption. The primary and secondary circuits on the CT are typically removed after maintenance. In the event of a disturbance, such as the current case, stability is restored through the displacement of the CTN LV circuit and the completion of repairs. The subsequent deductions may be made:

- In order to re-energize the Transformer in a safe manner, stability is necessary.
- The HV and LV circuits are installed correctly and efficiently.
- Differential and REF schemes undergo stability assessments. By employing 380 VAC injection for differential and 220VAC for the REF side.
- In the context of differential schemes, jumpers are implemented on the LV side CT or 20kV side, while jumpers to grounding are implemented on the CTN side and LV CT for REF schemes.

The author aspires to conduct additional research on the stability of the DSS bay transformer or bay line using the line current differential in the future.

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