TENAGA NASIONAL BERHAD
Experience on Protection System Analysis Utilizing Fault Recorders and Numerical Relay Recordings

Allen Tan Sean Chun and Sazali P. Abdul Karim

***Abstract*— Over the recent years, power systems have evolved and matured into bigger and more dense systems. The demand for a more reliable and higher quality power system is more apparent in this decade as technology advances further compounded by the increase in demand for electricity supply. Due to the complexity of the present and future power systems, evaluation and analysis of system disturbances have become more complex and time-consuming. This paper describes field experience on utilizing fault recorders and numerical relay recordings to analyze system disturbances correctly and more accurately. Typically new numerical-type protection and control relays are equipped with built-in recorders. Advancements in relay recording give the already-proven disturbance recorders more insight into a system fault or disturbance incident. This approach has helped Tenaga Nasional Berhad (TNB) to improve on the quality of fault and disturbance analysis and detection of faulty equipment or scheme, resulting in a quicker and more precise decision-making, particularly during major disturbances.**

***Index Terms*— fault and disturbance analysis, fault recorders, numerical relay recording.**

I. Introduction

Power systems are constantly evolving into more and more complex systems to meet the ever increasing demand for more reliable electrical power supply. This is more apparent in developing countries. Loss of electrical power supply almost always has cost implications to the power utilities. Thus power utilities' will usually incur financial losses due to power system fault/disturbance. Therefore it is important to analyze quickly and accurately each system disturbance to reduce down time and to allow for faster system restoration time.

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II. Application of Fault/Disturbance Recorders in TNB System

Since the late 90's, TNB has installed and tested numerous types of fault and disturbance recorders in several of the critical 275kV substations via stand-alone recorders and a few 132kV substations via portable recorders. These recorders were installed to retrieve information that is useful for fault analysis, validation of power system simulation models, and testing of new protection relays[1]. These recorders have been a pinnacle tool in numerous fault and disturbance recording analysis.

III. Fault/Disturbance recorders versus Numerical Relay Recording

A. Benefits of Fault/Disturbance Recorder

Fault/Disturbance recorders utilizing analog sensor and digital sensor inputs, high and slow speed-recording, have facilitated protection engineers in the following areas[4]:

- To examine protection system behaviors during power system faults and disturbances
- Locate and determine root cause of faults through waveform analysis
- Continuous monitoring of power system parameters (i.e. Voltage, Current, Frequency)
- Reduce down time of faulty equipment by providing fast and accurate system information
- Planning of maintenance of power system equipment
- Control of power system

These recorders, utilizing high capacity digital storage devices, are capable of storing much more fault records and monitoring more system parameters.

B. Advancement in Relays

Power system protection relays have undergone numerous developments from the primitive, but effectively proven electro-mechanical relays to the latest state-of-the-art numerical relays. In the era of microprocessors and advancement in semiconductor technology, many of the new power system protection relays are microprocessor-based. This means that we are no longer restricted to a one-function-to-one-unit protection relay. Relays now come with multi protection functions and flexible scheme implementation through programmable logics. These new numerical type relays contain memory capability, thus enabling these relays to store and record measurements and waveforms. These new relays are also known as Intelligent Electronic Devices (IEDs).

C. Limitations of Implementing Disturbance Recorders

Even though stand-alone disturbance/fault recorders or portable recorders can be installed and applied in generation, transmission, and distribution systems, the recorders are primarily located at strategic locations in a power system. It is generally not financially feasible to install these recorders at all substations in a particular power system.

D. Numerical Relays in TNB Power System

TNB Transmission power system has in the recent years acquired new substation and transmission lines to further enhance and provide more dependable power to the ever-increasing demand of power supply. These new substations are fitted with the latest state-of-the-art protection relays as the older electro-mechanical relays are no longer available for purchase from relay manufacturers. Also, when the existing electro-mechanical and older electronic type relays become faulty and beyond repair, these relays will be replaced with the newer numerical type protection relays. Hence, more and more numerical relays are located throughout the TNB Transmission power system.

IV. Experience on Fault Analysis Utilizing Both Fault/Disturbance Recorders and Numerical Relay Data

In the recent years, TNB has experienced several complicated system faults and system operations. Almost all the faults were successfully analyzed and investigated using Fault and Disturbance Recorders. This paper will elaborate more on one of such faults to prove the intimate relationship in utilizing both the Fault/Disturbance Recorders and Numerical Relay Recordings to successfully carry out a more detailed analysis and investigation.

On 9th August 2008 at 1808H, a power supply interruption at Chuping substation had occurred due to a yellow phase fault initiated by a broken pin insulator at tower no. 105 for the overhead line to Pauh substation at the remote end. Following are the sequence of events from the first inception of the first fault and two subsequent fault events.

A. Sequence of Events

1. First Fault

Time		**Events**
Absolute *	**Relative**	
18:08:50.404	0.000 s	Fault inception at CPNG-PAUH due to a broken pin insulator at tower no. 105 (yellow phase)
18:08:50.425	0.021 s	CPNG 405 Distance Protection 7SA511 zone 1 operated (Y-N)
18:08:50.445	0.041 s	PAUH 405 Distance Protection 7SA511 zone 1 operated (Y-N)
18:08:50.484	0.080 s	CPNG 405 CB opened
18:08:50.485	0.081 s	PAUH 405 CB opened
18:08:53.542	3.138 s	CPNG 405 Autoreclose attempted
18:08:53.671	3.267 s	CPNG 405 CB closed onto a permanent fault
18:08:53.693	3.289 s	CPNG 405 Distance Protection 7SA511 zone 1 operated (Y-N)
18:08:53.708	3.304 s	CPNG 405 Autoreclose Lockout
18:08:53.820	3.416 s	CPNG 405 CB opened

2. Second Fault

Time		Events
Absolute *	**Relative**	
18:30:34.412	0.000 s	CPNG 405 CB closed manually
18:30:34.460	0.048 s	CPNG 405 Distance Protection 7SA511 SOTF operated (Y-N)
18:30:34.564	0.152 s	CPNG 405 CB opened

3. Third Fault

Time		Events
Absolute *	**Relative**	
18:30:34.761	0.000 s	CPNG 405 CB closed manually
18:30:34.806	0.045 s	CPNG 405 Distance Protection 7SA511 SOTF operated (Y-N)
18:30:35.833	1.072 s	PLPS M10 and M20 CBs opened
18:30:35.867	1.106 s	CPNG 405 O/C operated
18:30:37.447	2.686 s	CPNG 130 O/C operated
18:30:37.476	2.715 s	CPNG 130 CB opened
18:30:38.348	3.587 s	BKHM 905 Distance Protection 7SA511 Fault Detection Zone operated (Y-N)
18:30:38.388	3.627 s	BKHM 905 CB opened
18:30:39.162	4.401 s	BKTR 405 Distance Protection 7SA511 Fault Detection Zone operated (Y-N)
18:30:39.170	4.409 s	KGAR 205 Distance Protection 7SA511 Fault Detection Zone operated (Y-N)
18:30:39.210	4.449 s	KGAR 205 CB opened
18:30:39.284	4.523 s	BKTR 405 CB opened
18:30:40.056	5.295 s	CPNG 405 CB opened

* Time taken from Digital Fault Recorder at CPNG s/s

Note: Please Refer to Appendix 1 For Circuit Breaker Reference Number

B. Disturbance Analysis

The fault occurrence was captured by the fault recorder at CPNG 275kV and 132kV respectively. The yellow phase fault (*Appendix 2*) was caused by a broken pin insulator at tower number 105. The fault current was approximately 5.6kA observed in the distance relay (7SA511). A voltage dip of 30.7% was also recorded at CPNG Substation.

The fault was detected by Distance Protection and isolated accordingly by opening of circuit breakers 405 at both substations. Auto reclose was initiated at CPNG substation and re-tripped due to a permanent fault (*Appendix 3*). PAUH end did not attempt to reclose because the Auto Reclose setting was set to Live-Line, Dead Bus (LLDB) condition. PAUH substation is in a spur network configuration.

Approximately 20 minutes after the isolation of the first fault, the National Load Dispatch Centre (NLDC) decided to re-energize the faulted line in a bid to restore supply to PAUH. The restoration involves manual reclosing of the line from CPNG substation (*Appendix 4*).

In the process of reenergizing the line, it was observed through the recordings (*Fig. 1*) that two successive closing pulses were sent to the circuit breaker (the duration between the two successive closing attempts was 0.349s). The circuit breaker re-tripped 0.152s after the first closing pulse was received. However, it successfully closed after receiving the second closing pulse but only re-tripped after 5.295s. This would explain the behaviour observed in the second and third events.

The protection relay correctly operated for the Switch On To Fault Condition during the attempt to re-energize the line via manual closing at CPNG. However from recordings, the circuit breaker CB405 in the attempts to re-tripped after the second manual closing did not operate within the expected normal operating time of 50ms[2].

The delay in the circuit breaker operation allowed sufficient time for the Overcurrent Relay (CDG36) at the 132kV CPNG 405 and CPNG 130 (Bus Coupler) to operate and subsequently tripped CPNG 130. As a result of splitting the 132kV busbar, the in-feed from the 275kV system through the SGT1 is no longer feeding to the fault. At the time of the fault, SGT2 on the reserve busbar was on outage.

After the 132kV busbar separation, the remaining 3 overhead line feeders connected to the reserve busbar were still feeding to the fault. All 3 remote-end distance relays (7SA511 at BKHM, BKTR and KGAR) operated on fault detection element and tripped their respective breakers.

Even with the isolation of the three overhead line feeders on the reserve busbar, the fault was still being fed from the 132kV main busbar through the paralleled

132/11kV T1 and T2 transformers. The final operation observed was the opening of CPNG 405 after 5.295s.

C. Summary of Protection Operations[3]

Index	Expression …	Defined as …
No. of Success Operations	n1 = 21	Number of protection operated successfully per terminal
No. of Failure Operations	n2 = 0	Number of protection failed to operate per terminal
No. of Unnecessary Operations	n3 = 0	Number of protection operated unnecessarily per terminal
Dependability Factor	N1/(n1+n2) = 21/(21+0) = 1.0	Number of success protection operation over total number of success and failed operations
Effectiveness Index	n1/(n1+n2+n3) = 21/(21+0+0) = 1.0	Number of success protection operation over total number of all operations.
Unnecessary Operation Ratio	n3/(n1+n2+n3) = 0/(21+0+0) = 0.0	Number of unnecessary protection operation over total number of all operations.

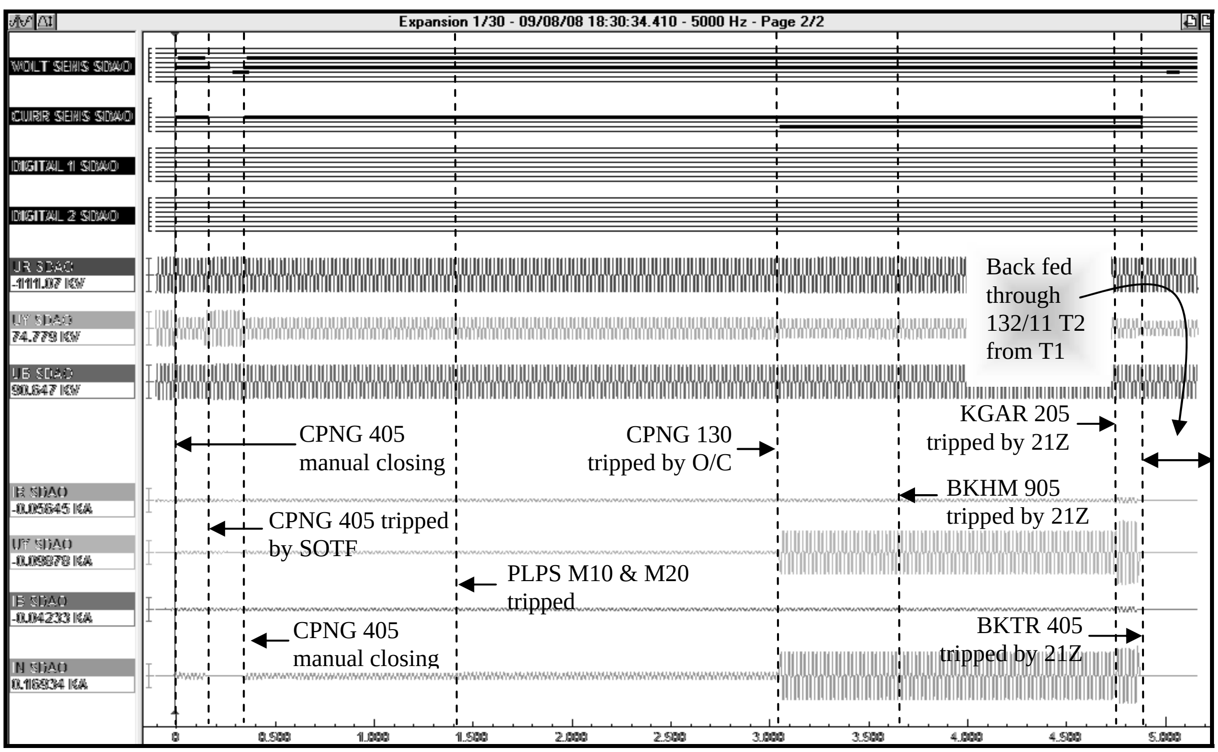


Figure 1: Fault Record Captured by Digital Fault Recorder at CPNG 132kV for BKTR/SADAO

D. *Findings & Recommendations*

From this analysis, the following conclusions and recommendations were made:

- All the protection systems operated correctly during all the three faults. However, it was observed that the manual closing did not check through the master trip contact to avoid second closing after a SOTF operation[2] (*Appendix 5*).
- The CB 405 at CPNG did not operate within the expected normal operating time of 50ms[2] for the second and third faults.
- The slow operation of the Circuit Breaker could be caused by the inherent design of the CB. Most of the CBs in service in TNB System consist of 3 operating cycles (C-O-C). Hence, subsequent opening of the CB will require some time for the CB operating mechanism to be recharged[5].

The following are the engineering recommendations:

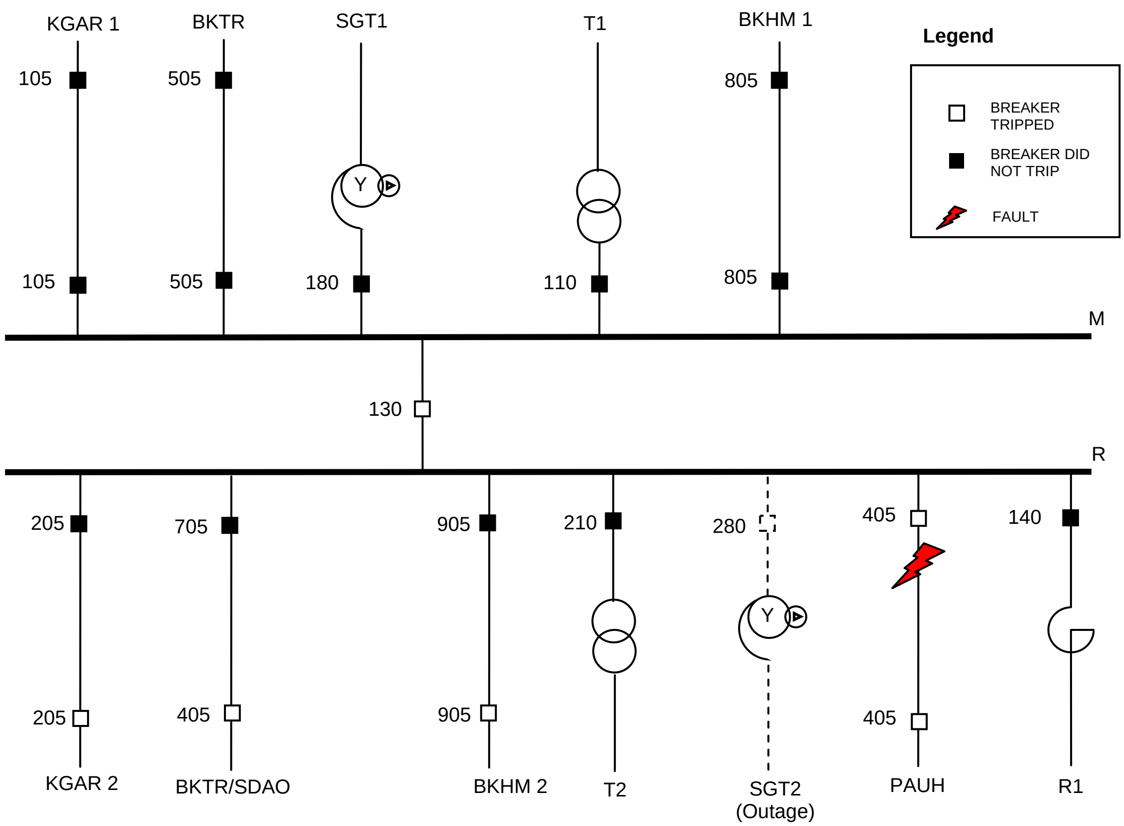
- To rectify the manual closing circuit design that check through the master trip contact in order to avoid another manual closing after a SOTF operation as shown in *Appendix 6*.
- To check the delayed operation of CB 405 at CPNG.

V. CONCLUSION

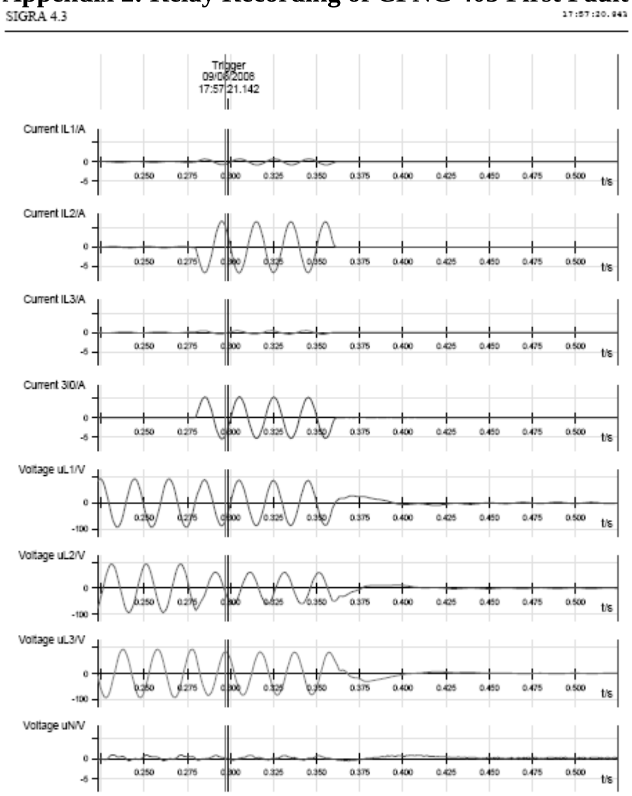
With the example given above, it is evident that analysis of power system disturbance utilizing only records from disturbance recorders may not be sufficient. Therefore recordings from numerical relays at the affected zone of protection can be used to supplement the power system disturbance analysis for a more effective and detailed analysis. On top of disturbance analysis, TNB was able to detect issues related to schemes and operational deviations through the more precise analysis.

APPENDIX

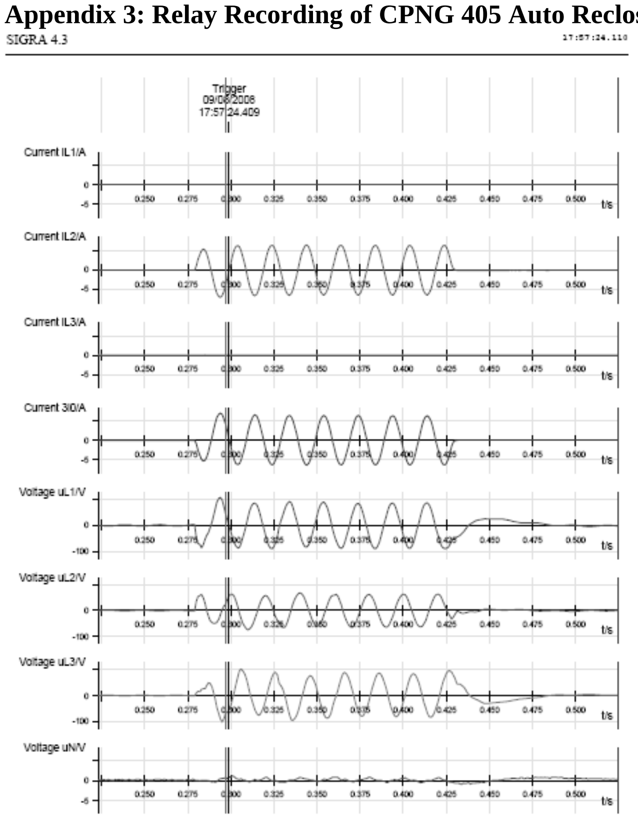
Appendix 1: Single Line Diagram of CPNG Substation



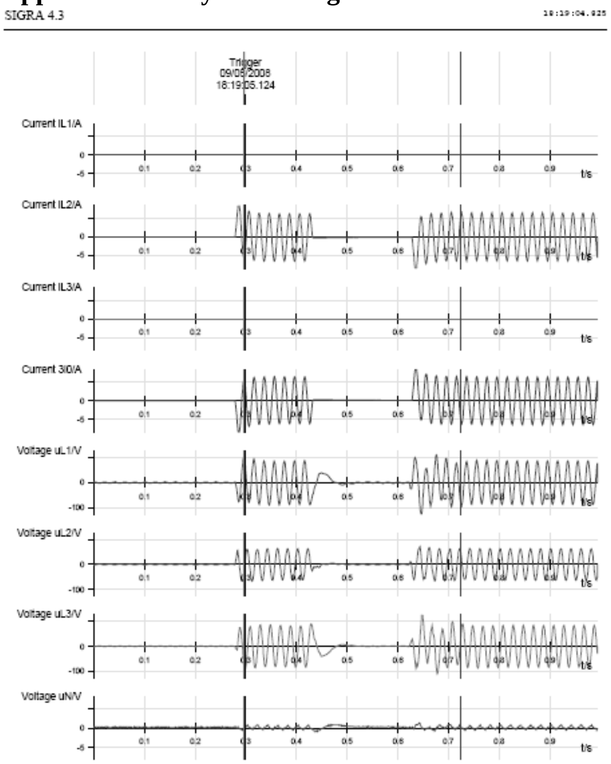
Appendix 2: Relay Recording of CPNG 405 First Fault



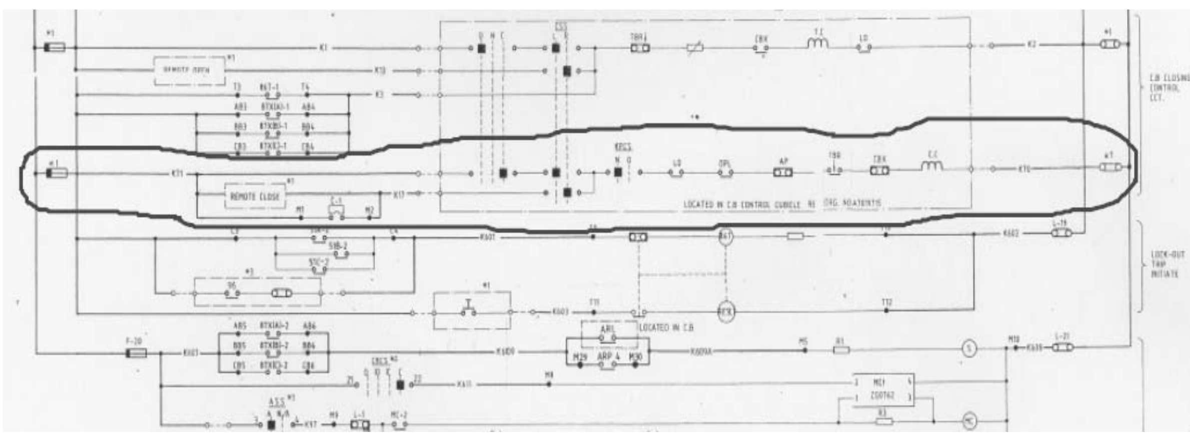
Appendix 3: Relay Recording of CPNG 405 Auto Reclose



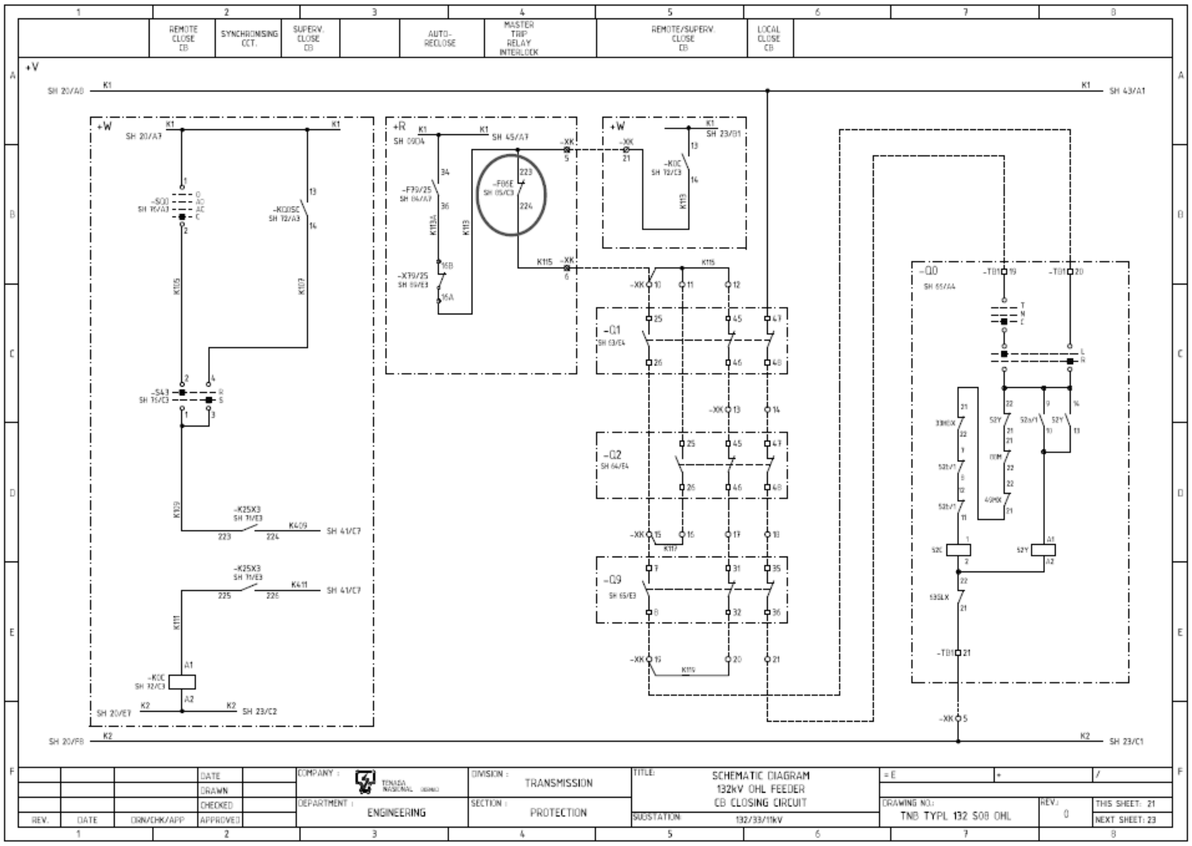
Appendix 4: Relay Recording of CPNG 405 First and Second Manual Closing



Appendix 5: Existing CB Closing Circuit at CPNG Substation



Appendix 6: The TNB Standard CB Closing Ciruit for 132kV OHL Feeder



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