Implementation of Test Automation System for Protection Relays using IEC 60870-5-103 Communication Protocol

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Abstract - *Protection relays and other protection equipment controls and protects primary assets during both normal operation and fault conditions, making them vital to network reliability. Reliability of relay protection devices is determined by its quality and performance check both in debugging and in field operation. These checks are done on a regular basis using various software tools generating currents and voltages to diagnose Protection relays. As utilities have end number of relay units, and hence Test Automation plays an important role in today's world. Automating the testing process speeds up the testing with more accuracy with less errors and less human intervention covering a greater number of test cases scenario. The project aim is to automate the relay testing process. DevOps concept relies automating every possible test case based on effective software tooling. DevOps is a combination of Development and Operations which is a three-step process i.e. Build, Test and Release. The aim of DevOps is to develop the application and release it to the customer as fast as possible. After this, application can be upgraded as per the user requirement and can be released in less amount of time. The project deals with automating the testing process of device by capturing real time data from device by making use of IEC-60870-5-103 Communication protocol during the protection functions operation in power system.*

Key Words: DevOps, Protection Relay, IEC-60870-5-103, Omicron Control Centre (OCC).

1. INTRODUCTION

The fundamental objective of any power protection devices is to isolate a part of the system, or the equipment, that are under fault condition, from the remaining part of electrical system. The basic aim is to protect the equipment from getting damaged or from failing permanently. A power outage or power cut can be short-term or a long-term loss of the electric power due to many reasons and results in various types of faults. Examples of these causes include faults at power stations, damage to transmission lines, or other parts of the distribution system, a short circuit, cascading failure, fuse or failure in circuit breaker operation. Hence Protection devices are installed with the aims of ensuring continued supply of energy.

The main Protection devices include:

- Current Transformer (CT) or Potential Transformer (VT)
- Relays
- Circuit breaker

CT and VT transformers are used to step down signals as per the relay requirement. Protection relays are the most important part of power system which helps to sense the faulty part from the entire electrical system. It continuously measures the current and voltages in line and compares with set values. If it exceeds the set value, the it gives trip signal to Circuit Breaker. Circuit Breaker is mechanical device that disconnects the faulty circuit from the rest of the electrical system.

Protection relay is equipped with various protection functions. American National Standards Institute (ANSI) has defined ANSI function numbers for each protection functions to identify characteristic of various protection functions. A single protection relay may correspond to only one function number or may have many function numbers associated with it, such as a multifunctional protection relay. ANSI 50/51 Phase overcurrent, ANSI 50N/51N or ANSI 50G/51G Earth fault or sensitive earth fault are some examples of protection functions.

SCADA is a Supervisory Control and Data Acquisition System used for acquiring data from remote sites. For controlling and monitoring the real-time digital information of substation automation, the SCADA system is used which gathers the data and displays it on HMI (Human Machine Interface), so that operator sitting in control room can monitor the process of substation. SCADA makes use of various communication protocols to carry out communication between remote devices and control station, either via Ethernet or by serial transmission. Communication Protocols are standard which defines rules and procedures to carry out communication between two or more electronic devices. Modbus, Profibus, DNP3, IEC-60870-5 are some of the protocols used in electrical utility industries for communication.

The routine testing of protection relays is more important from development stage to production to periodical maintenance of device. Manual Testing is time consuming and continuous human intervention is required. The manual testing is done using various software tools and manually verifying the results. The aim is to replace the manual testing by automating the test process by making use of software tools to automate the test cases. It helps in testing more number of test cases and hence efficiency, Accuracy and reduces human intervention and errors. More importantly it can playback the prerecorded and predefined action end number of times. This saves a lot of testing time in an organization and makes the tester's life a bit easier.

The protection testing of relay is fully automated and is carried out by Omicron Control Centre (OCC) scripts. This paper highlights the design and development of an Automated Communication Test setup to carry out the Communication protocol testing of relay by validating the IEC 60870-5-103 protocol simultaneously with Protection function testing. This will avoid separate communication testing of relays.

2. SYSTEM BLOCK DIAGRAM

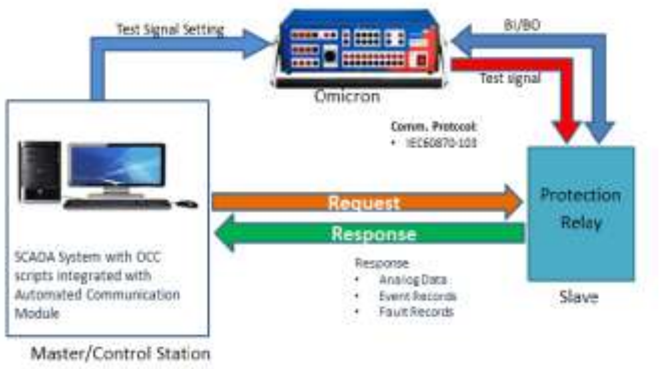

Fig1: Communications between DUT and Master/ Control Station

Figure 1 show the system block diagram, wherein the relay communicates with the Master Control station using IEC60870-5-103 protocol. SCADA system consists of Computer that acts as Master and relay act as a Slave device. The master station or a computer is interfaced with slave using RS485 standard serial transmission. Omicron is Current/Voltage Injection device and provides various test signals to relay as per user requirement. The Master send queries to the slave device by sending Request commands. Slave responds back to master by sending Response frames.

2.1 HARDWARE MODULE

1. Protection Relay

A protection relay is a switchgear device and is designed to detect the faults in the electrical circuits and initiate the operation of Circuit breaker. It constantly measures the electrical quantities which are different under Fault condition and Normal conditions. Once the fault is detected, relay operates to close the trip of circuit and results in opening of Circuit breaker and disconnection of faulty part. The protective relaying is used to give an alarm for the removal of any element of the power system when that element behaves abnormally. It also indicates the location and type of the fault.

Communication plays a vital role in protection power control system and automation. Themain role of communication is to collect the utility data and transmit these data to master station for further control and monitoring purpose. Communication protocol testing is carried out by different software tools such as TMW Test Harness, ASE2000 Communication test set etc.

2. Omicron

The Omicron CMC 356/ CMC 256 is the universal solution for testing all generations and types of protection relays and other test equipment in industries. Its powerful current sources make the unit capable of testing high-burden electromechanical relays. It consists of four voltage outputs, six current outputs, four binary outputs (BO), ten multifunctional binary inputs (dry/wet BI), etc. It provides three phase mode up to 64A/860 VA per channel.

The Test Universe is software that has been designed by Omicron for testing protection devices and other measurement equipment. It consists of various modules like CM Engine, State sequencer, overcurrent, harmonic etc. In order to test different functions of digital devices, the OMICRON Control Center (OCC) allows the combination of individual testing functions into an overall test plan. Each test function will be executed sequentially and an overall test report including the results of each test function tested is created automatically. It allows the user to create their own test cases as per requirement and to include various types of file extension and are linked using Object Linking Embedded (OLE). OCC scripts carry out the Protection function testing of relays.

2.2 SOFTWARE MODULE

1. Reydisp Evolution simulator

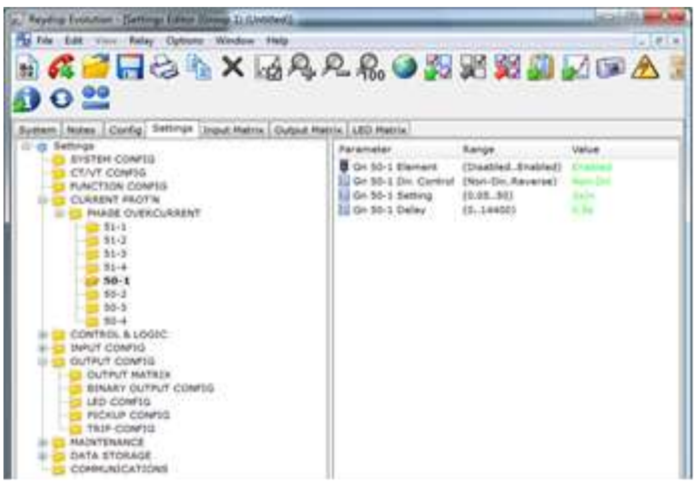

Fig2: Reydisp Evolution Master Simulator for relay configuration

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Reydisp Evolution is Microsoft Windows based software for the Reyrolle brand of protection relays consisting of the Informative Communications Interface. It allows the viewing and editing of relay settings, viewing fault information, system information, Events and waveform records, IDMT curves and communication data points. The following features are provided in Reydisp Evolution:

1. Download specific/all Settings, getting Event, Faults Record, waveform record, System Information etc.
2. Settings Manipulation: Edit Settings, upload specific/all Settings, etc.
3. Waveform Manipulations: View Waveform recorder with Values and Timings.
4. Device Control: Login/Logout, Trigger & Reset Waveforms, Reset Events, Reset Flags, Automatic Polling of devices etc.

2. IEC60870-5-103

IEC 60870-5-103 (IEC103) is an International standard protocol which is developed by IEC Technical Committee 57 specifically for the informative interface of protection equipment. It enables interoperability between protection equipment and other devices in substation.

It follows the Enhanced Performance Architecture (EPA), which makes use of Physical, Data Link and Application layer of OSI model. It uses FT1.2 frame format having variable length and fixed length frames like IEC 101. An unbalanced or balanced transmission mode can be used for data transmission. It maintains a specified Application Service Data Unit (ASDUs) format for the application layer as shown in figure 3.

Data unit	Name	Function
Start Frame	Start Character	Indicates start of Frame
	Length Field (*2)	Total length of Frame
	Start Character (repeat)	Repeat provided for reliability
	Control Field	Indicates control functions like message direction
	Link Address (1 or 2)	Normally used as the device / station address
Data Unit Identifier	Type Identifier	Defines the data type which contains specific format of information objects
	Variable Structure Qualifier	Indicates whether type contains multiple information objects or not
	COT	Indicates causes of data transmissions like spontaneous or cyclic
	ASDU Address	Denotes separate segments and its address inside a device
Information Object	Function Type	Provides function type of the protection equipment used
	Information Number	Defines the information number within a given function type
	Information Elements (n)	Contains details of the information element depending on the type
Stop Frame	Checksum	Used for Error checks
	Stop Char	Indicates end of a frame

Fig3: IEC60870-5-103 Frame Format, variable length.

IEC 103 Frame Formats:

The only change in frame format of IEC 103 and IEC 101 is Information object address which is split into Function code (FUN) and Information number (INF) in IEC 103 and each frame can have only single information object whereas IEC 101 can have multiple information objects. Time tagged frames are used to return Events with timestamp and General Command Responses. The type of information being returned can be determined by checking the cause of transmission (COT) octet; the supplementary information octet is dependent on the COT as shown in figure 4.

Description	COT	Supplementary Information
Spontaneous Events	1	0
General Interrogation	9	GI Scan Number from GI Initialisation Message
Command Acknowledgement Positive	20	Return Information Identifier from Command Message
Command Acknowledgement Negative	21	Return Information Identifier from Command Message

Fig4: Supplementary information octet in IEC60870-5-103.

3. TMW Test Harness

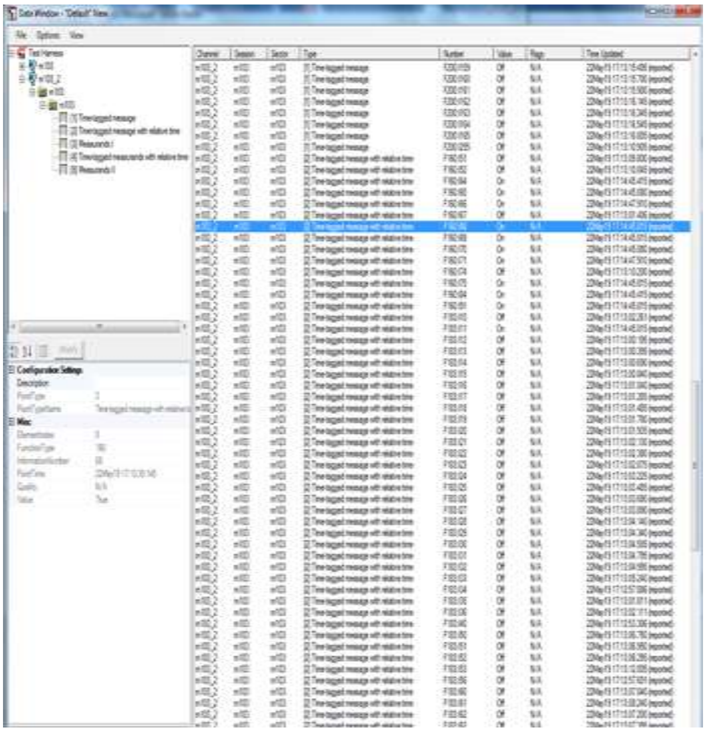

Fig5: Data window of TMW Test Harness software

The Test Harness is a powerful tool for testing communication protocols like DNP3, IEC 60870-5, and Modbus in industrial organization. It can be used to test and validate devices and networks and performs the official Conformance Test Procedures published by the Technical Committees of each protocol. It simulates master or slave devices and multiple Slave sessions can be active at one time. When simulating a Master device, command windows allow commands to be sent once or repeated at desired repetition intervals.

Data window provides graphical view of database points and values as shown in figure 5. It creates custom views of data by displaying required data and user-defined point descriptions and is saved in a workspace file.

3. DESIGN AND IMPLEMENTATION

In order to carry out automated relay testing, a separate Automated communication module is been created using C-Sharp programming language. The reason behind choosing C-Sharp is, its flexibility and faster execution is possible so that polling the master can be done at faster scan rate. It produces efficient programs and can be compiled on various computer platform. The communication module is designed to get all Events and Fault records using IEC60870-5-103 communication protocol. It continuously scans for database points of protection function to get the status. Here the automated communication module acts as master and relay as slave device. The communication between master and slave is carried out using RS485 standard for serial transmission. RS485 defines the electrical and mechanical characteristics of drivers and receivers used in serial transmission. It takes user input such as Device name, Communication protocol, COM port, Baud Rate, Parity and Address of slave device as shown in figure 8. Once OK button is clicked next window appears as shown in figure 9.

The figure 6 shows step wise communication between master sending requests to slave and slave responding back with acknowledge (ACK) and response messages.

1. Master continuously polls for the "General trip" register at a scan rate of 100 milliseconds until the response is Success.
2. When General trip is SET, all events during protection function operation is stored in slave device. Master then polls to get the fault records.
3. Master then queries to get all spontaneous events raised during the protection function operation.

The same is depicted in system flowchart diagram as shown in figure 7.

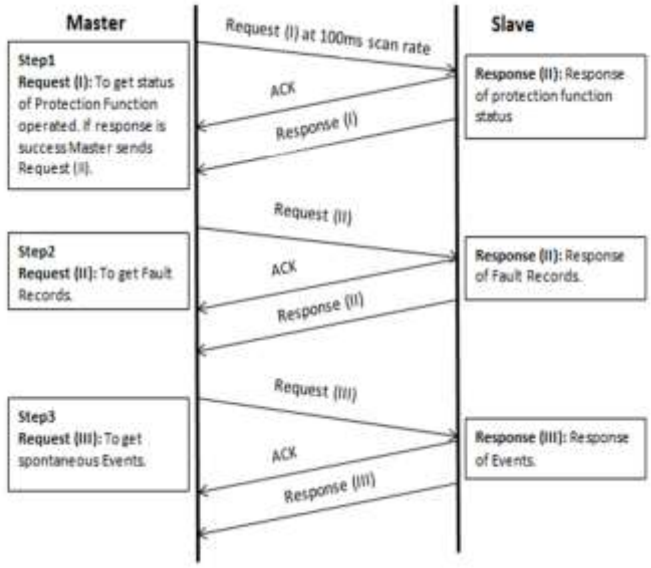

Fig6 Steps showing communication between Master and Slave.

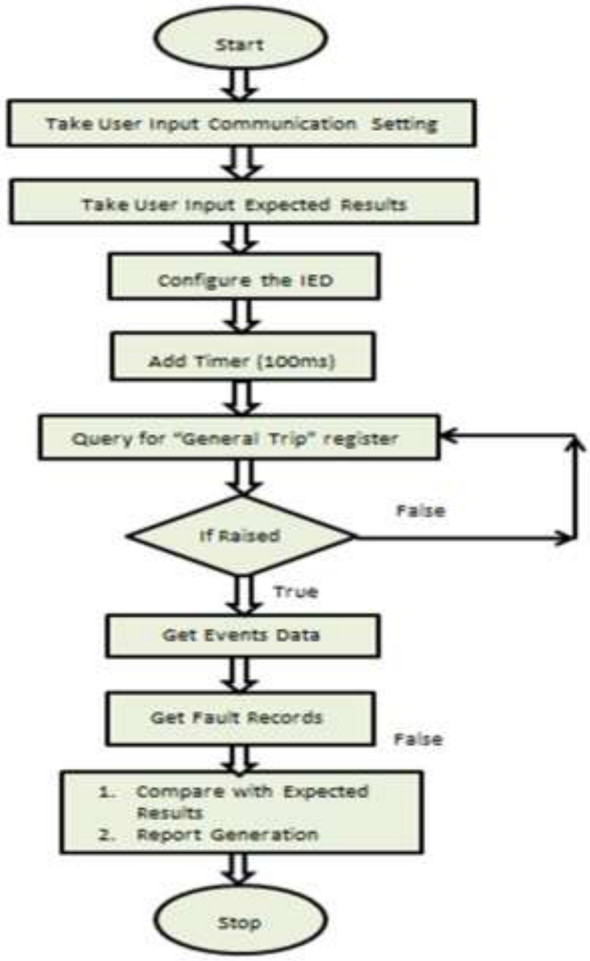

Fig7: System Flowchart

The output of Automated Communication module using IEC 60870-5-103 protocol is shown in figure 9 with actual operated protection function, Events with timestamp, Fault records and Expected records. Once the communication setting is done master polls the device.

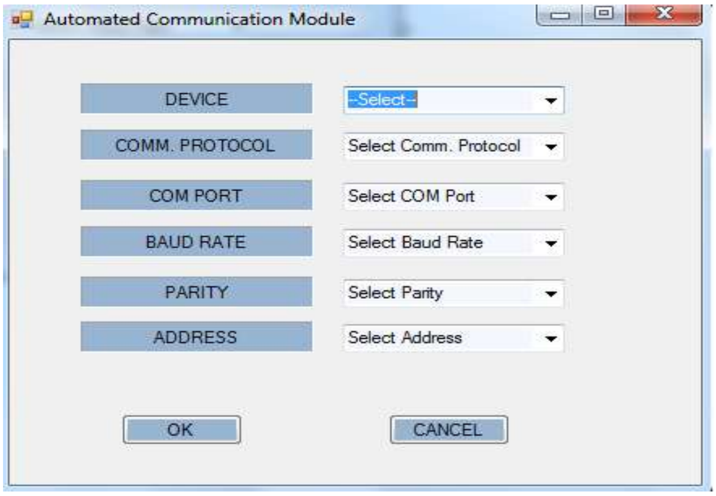

Fig8: Communication Settings.

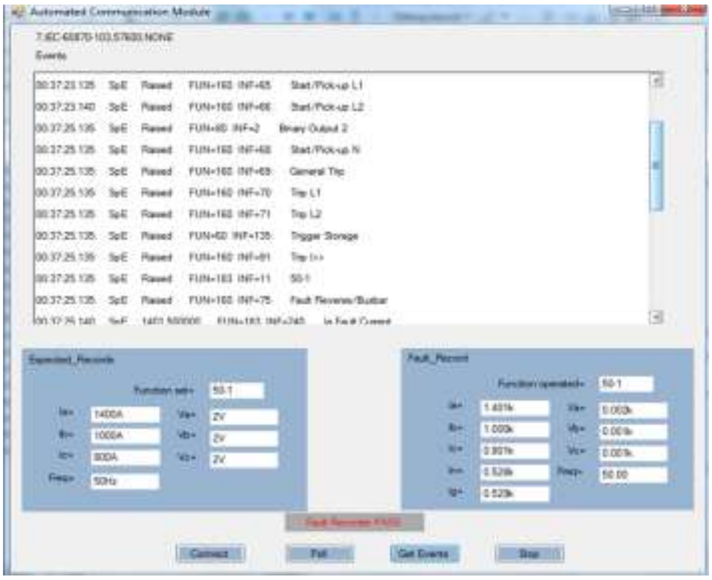

Fig9: Automated module for IEC 60870-5-103 protocol.

In IEC60870-5-103 (IEC 103), master continuously polls for the time-stamped messages at a scan rate of 100 milliseconds. Master queries for frame type 1 with Cause of Transmission (COT) as 1 i.e. for spontaneous events. It basically requests for Data Class1 messages. When any spontaneous events are generated, master checks if FUN and INF of "General Trip" register is Raised or not. For Fault records, master polls for fault recorder, which is stored in device. Relay can store up to 15 fault records. Fault records provide the relay status at the time of trip, i.e. elements that issued the trip, any elements that were picked up, the fault type, LED indications, date and time, status of BI/BO etc.

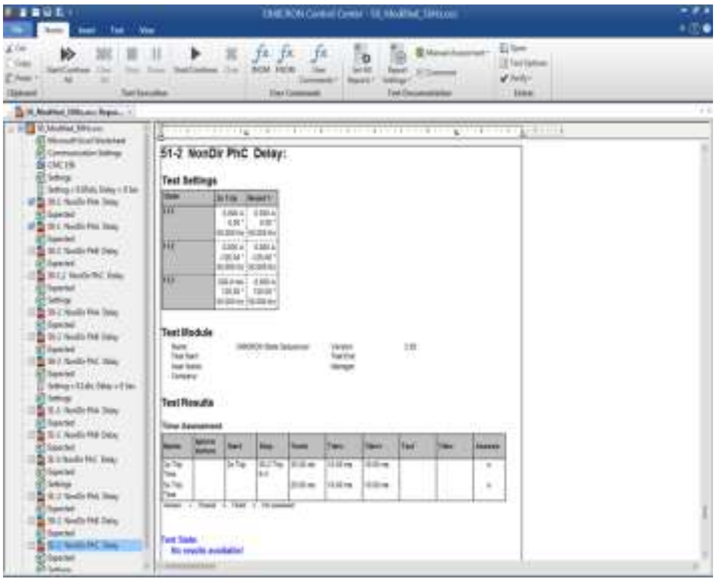

Fig10: Automated Communication module integrated with OCC Scripts.

This Automated module is then integrated with OCC scripts as shown in figure 10. Protection function testing of relay is carried out using OCC scripts which run in sequential manner. The communication settings for both Front port and Rear port is entered in "Communication setting" excel file. Front port for relay is used for setting configuration and back port to capture events and fault data. Communication setting includes relays COM Port, Baud Rate, Parity, Slave Address, Protocol and Device name.

The Expected data which includes expected Protection function to be operated, three phase currents, three phase voltages, frequency etc. is then entered in "Expected Setting" excel file in OCC. The Captured Fault Data is then stored in same excel file where Expected results were entered by user. Where it is compared with the Expected results. The comparison is based on 10% tolerance band range. Based on the comparison test displays PASS or FAIL inside OCC script in excel file as shown in figure 11.

Fig11: Captured Fault Records and Events and test showing Pass or Fail.

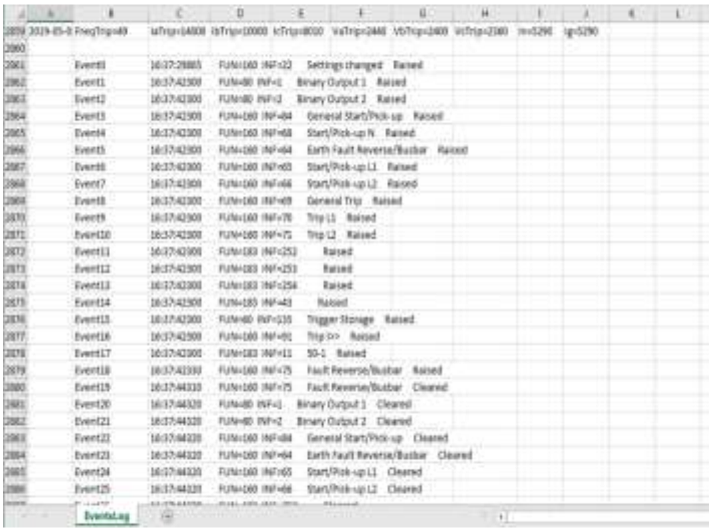

Fig12: Events stored in CSV file.

4. OBSERVATION AND RESULTS

4.1 OBSERVATIONS

Implementation of Automated communication module started with getting the instantaneous data from relay slightly before fault occurrence, i.e. after pickup current level is set. The term Pickup Current is defined as the minimum value of current that causes the relay to close its contact based on user set time. The idea was not to take any expected data from user but to get these data from relay after Pickup current level is set. But it takes more time to get instantaneous data from relay and fetch it to master. This requires that the test signal should retain for longer period of time after Pickup current is set so that master can capture all the required amount of data from relay before fault occurs. But the protection function operation takes place within milliseconds of time interval, i.e. approx. 35 milliseconds as shown in figure 13. Within this time interval, it is difficult to get all instantaneous data (three-phase currents I1, I2, I3, three-phase voltages V1, V2, V3, frequency, etc.) from relay and transmit it to master over serial transmission.

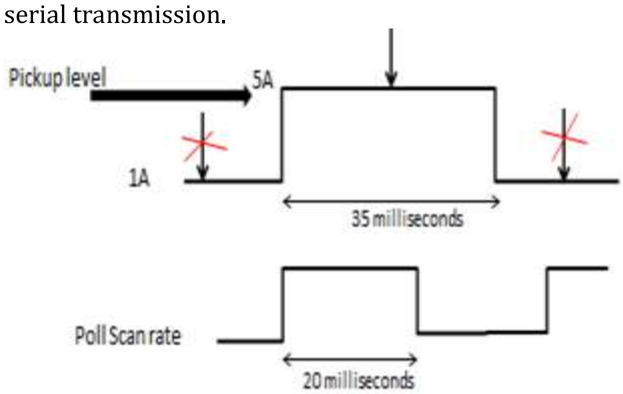

Fig13: Timing diagram when Pickup Current level is reached.

This is mainly due to the following reasons

1. Relay design structure. It is designed in a way that protection function and fault recorder stamping will not happen at the same time interval. Fault recorder stamping will happen only after the protection function is operated and updating of this data in database itself is taking some delay.
2. Serial transmission: Transmission and Reception of the data over serial communication is taking delay as per the selection of Baud rate. Higher the Baud Rate faster is the transmission of data. Also based on payload, the number of bytes increases as per number of registers which adds additional delay.
3. Software Implementation: Operating system is taking time to send the response back to master. Communication protocol Libraries which are used internally does General interrogation to get the status of separate point index numbers.

4.2 RESULTS

In OCC scripts when protection function is operated, communication module operates simultaneously and captures Fault and event data. The Event and Fault records are stored in Comma Separated Value (.CSV) format, with timestamps. It will also store communication settings such as COM port, Protocol selected, Baud Rate and Parity. The Events includes the data of operated protection function and other raised function with timestamp, Function code (FUN), Information Number (INF) and its description as per IEC 60870-5-103 standard.

5. CONCLUSION

As seen from the results, real time information is captured by automated communication module after the protection function is operated and is transmitted to Control station using IEC60870-5-103 Serial communication protocol. Hence it can be concluded that the protocol testing can be obtained simultaneously during the protection function operation. The integration of Communication operation along with Protection operation function saves a lot of time during testing process of relay in Industrial organization and automating this process increases the coverage of test cases as well as reduces the human intervention.

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