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LABORATORY SESSIONS FOR TRAINING FUTURE ELECTRICAL PROTECTION ENGINEERS

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Abstract: In this paper, laboratory sessions for the learning of protective relaying are presented. The objective is that the students assimilate in a practical fashion, the concepts of protection systems by setting up the relays and applying voltage and current signals to serve to simulate real faults in the electrical networks. Several laboratory sessions are presented as a practical component in an undergraduate course. The sessions involve modern training test equipment and high technology protective devices used in industry nowadays. Synchrophasors technology is also included.

Keywords: Protective relaying, Laboratory tests, Testing equipment for protective relaying, Protections setting, PMU.

1. INTRODUCTION

The electrical industry is at present undergoing important challenges, as it is a requirement to involve reliability and economical aspects. Environmental requirements have to be fulfilled as well. A recent comprehensive work about the concepts and skills that a protection engineer would handle is presented in (Brahma *et al.*, 2009). In that reference, the laboratory sessions are recommended for a success in protective relaying training. This was validated after accompanying digital training with real equipment in some universities that include advanced courses on power system protection (Shahnia *et al.*, 2014; Oza and Brahma, 2005; and Sachdev and Sidhu, 1996).

In projects developed by Universidad Pontificia Bolivariana, UPB, laboratory training sessions have been proposed. Cubicle construction to accompany the theoretical lectures have been developed as well. This is really conceived as a basic strategy for proper protective relaying concepts (García and Henao, 1988; Cardona y Cardona, 1999; Cardenas and Cadavid, 2011). Something to highlight about these works is that protective equipment with proper technology was used. Important donations from the well-known company SEL (Schweitzer Engineering Laboratories www.selinc.com) have permitted the UPB to provide strong basis fundamentals for students of protective relaying. The SEL relays and systems also permit a first contact of students with the true industry of protection systems.

In the mentioned works, laboratory sessions were achieved involving real perturbations in electrical equipment and sometimes producing circuit breakers reclosing (Cardona y Cardona, 1999). Nevertheless, to avoid permanent failures in laboratory equipment, only light overloads were induced. This can be understood as a prior sensitivity on electrical components malfunctions and basic protection actions. To solve the restriction in low values of, *e.g.*, overcurrent, in (Cardenas y Cadavid, 2011) it was suggested to compliment laboratory practices by using a relay testing equipment. With such a device, high current faults could be simulated or applied. In

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addition, the measuring of relays trip operation times could be accurately measured in the order of milliseconds.

In this work, laboratory sessions involving relay testing equipment is presented. Some types of protection principles are set up and tested with this equipment. It is concluded that undergraduate students will benefit with this laboratory already implemented at UPB.

As a laboratory work, students also have to identify safety prescriptions against electrical accidents during testing. It is obvious that there is a risk when dealing with current injection systems for protective relay testing.

The paper is organized as follows: Section 2 presents a session concerned with relay testing equipment, Section 3 is related to relay communications, Section 4 deals with phase overcurrent protection, Section 5 with voltage protection and Section 6 with syncrophasors technology. Finally, conclusions are presented in Section 7.

2. RELAY TESTING EQUIPMENT

The equipment used is a SVERKER 780 (Megger, 2009). This is a simple single phase testing device. This testing resource involves as much good accuracy as flexibility and robustness. The interface of the device is user friendly. It is also easily portable, see Fig. 1.

Fig. 1. Relay testing equipment SVERKER 780 at UPB laboratory.

There is a special laboratory session dedicated to using this secondary injection device. The goal is to learn the basic operation and identify its main components by achieving measurements and basic tests with external conventional meters, see Fig. 2. For the case of producing and measuring the activation time of external relays, the value of the applied voltage, frequency or current used for the test must exceed the trip limit with a good margin (*e.g.*, as a rule of thumb, it is often used for the current a range between: 1.2-1.5 times the limit commissioning value). To prevent overheating, injecting a high current through the protective equipment should take place during the shortest possible time.

During the development of the laboratory guides, the student will be indicated steps for the proper management of the SVERKER. Nevertheless, the student or trainee is responsible to follow important security conditions listed in the session guide.

Fig. 2. Comparisons of values obtained with the SVERKER and with external measuring devices.

The Fig. 3 shows the interconnection of the relay and the SVERKER. The upper part corresponds to the rear view of the relay wiring connections.

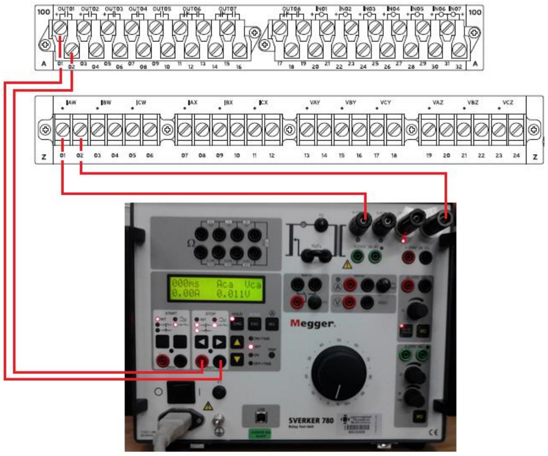


Fig. 3. SEL 421 IED and SVERKER connection.

3. VIA ETHERNET COMMUNICATION WITH 421 SEL IED

The SEL 421 relay or IED as an abbreviation of Intelligent Electronical Device, an acronym of standard IEC 61850 (Yang *et.al.,* 2010), communicates with a computer in order to establish its settings and informs its present status. The communication is possible using a dedicated software for SEL relays known as AcSELerator QuickSet (2014).

Once the settings are calculated, via the AcSELerator QuickSet it is possible to program the IED with those settings.

The SEL 421 relay (SEL, 2010) is available in several factory configurations depending on the number and type of inputs, outputs and analog inputs and control settings. See Fig. 4.

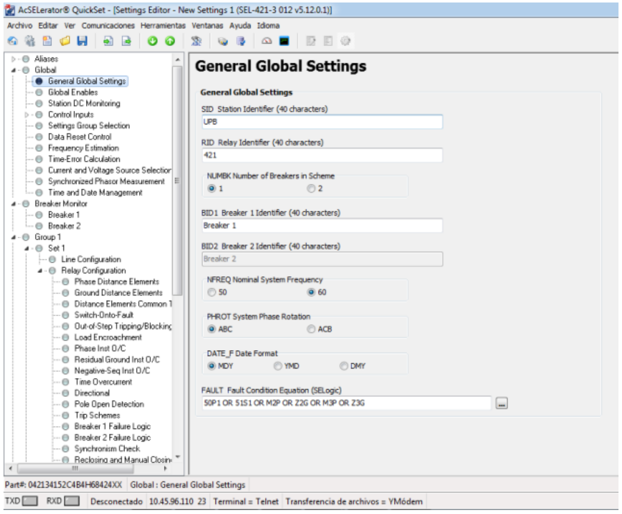
Fig. 4. SEL 421 IED (Schweitzer Engineering Laboratories).

Students learn how to obtain, manipulate and interact with the relay and the AcSELerator QuickSet. The IED is connected with the computer via ETHERNET.

When finished loading the relay data, one interface showing the parameters and functions appears. See Fig 5.

Now the relay will be parameterized and will be used as a "measuring instrument" to verify its correct operation and sensing. Voltage and current will be injected and measurements will be verified in the screen of the relay.

With the purpose of using a known power network data as an example, the industrial radial network of the IEC 60909-4 standard (IEC, 2000) was selected. Parameters and variables calculations are presented in the laboratory guides.



General Global Settings

SID Station Identifier (40 characters): UPB

RID Relay Identifier (40 characters): 421

NUMBK Number of Breakers in Scheme: ● 1 ○ 2

BID1 Breaker 1 Identifier (40 characters): Breaker 1

BID2 Breaker 2 Identifier (40 characters): Breaker 2

NFREQ Nominal System Frequency: ○ 50 ● 60

PHROT System Phase Rotation: ● ABC ○ ACB

DATE_F Date Format: ● MDY ○ YMD ○ DMY

FAULT Fault Condition Equation (SELogic): 50P1 OR 51S1 OR M2P OR Z2G OR M3P OR Z3G

Part#: 042134152C4B4H68424XX | Global : General Global Settings

TXD RXD | Desconectado | 10.45.96.110 23 | Terminal = Telnet | Transferencia de archivos = YMódem

Fig. 5. AcSELerator QuickSet interface for SEL 421 communicating to computer.

The student prepares the data for the location of the IED and inserts it in the relay via the AcSELerator software. See Fig. 5. Now, it is also possible to configure current and potential transducers.

4. PHASE OVERCURRENT PROTECTION

The objective is to establish communication between the SEL 421 and the computer via Ethernet, so that it can be parameterized the phase overcurrent function using acSELerator QuickSet.

Another objective is to analyze the operation of the phase overcurrent function and graph the actual operating curve. Applications of distance settings are not included in this paper.

The phase overcurrent function allows to clear faults with a time delay that depends on the magnitude of the current flowing. This function is asserted when the pick-up setting is exceeded.

The trip action can be given instantly, delayed by a fixed time or with a delay set inversely proportional to the magnitude of the current. There are standards that define the equations for each of the time vs. current characteristics (IEEE, 1996) and (IEC, 2014). The curves have been normalized according to IEC as follows:

- Definite time, DT or TD
- Inverse time, I
- Moderate inverse time, MI

- Very Inverse Time, VI
- Extremely inverse time, EI

See Fig. 6 as an example of the inverse time characteristics.

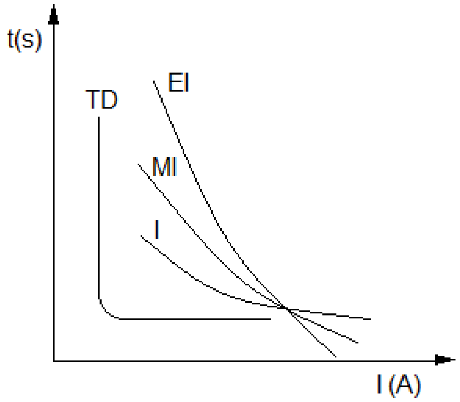


Fig. 6. Example of inverse and definite time characteristics.

In this session, the student is required to set the relay as in the previous session and inject currents of a selected curve with the objective of tracing a graph in the time vs. current axis, according to the pick-up current obtained for the relay network location. The students should have previously traced the expected curve using the respective equation, e.g., DT, I, MI, etc.

Using the scheme of Fig. 3, the selection of the value of the fault current is adjusted in the SVERKER. Variations will be between 1.5 - 20 times the setting current. The student should take at least five points so that the curve can be correctly traced. Now the simulated failure is injected and the SVERKER proceeds to register the closing time of the trip contact located on the relay output.

5. OVER/UNDER VOLTAGE PROTECTION

The variations of voltage in a power system can be caused by different events including asymmetrical faults, over-compensation, Ferranti effect, faulty generator excitation controllers, etc.

The over and under voltage detection is used to protect all types of equipment and loads of a power system. Parameterization depends on the equipment required to protect. For example, in the case of generators, they are usually designed for continuous operation at a minimum voltage of 95% of the rated voltage. This is because lower voltages may produce undesired effects such as reduced stability limit and in general, malfunction of equipment associated with the generator.

For setting the low voltage function, it is sometimes recommended to use two time-defined elements. One instantaneous for values below 60% of rated voltage, and a delayed unit to give alarm or trip at detecting voltages between 60% and 90% of the rated voltage. The IEEE Std C37.102-2006 (2006) recommends the implementation of special schemes. Delayed operation times range the values 2 s to 15 s.

Generators are usually designed to operate at a maximum voltage of 105% of the rated voltage. A generator operating at a voltage exceeding the allowable limit can produce an excessive overflow and electrical stress on the insulations.

For setting the function of overvoltage, it is normally recommended to use two elements of defined time, one instantaneous for voltages between 130% and 150% of the rated voltage, and a tight delayed at 110% of rated voltage. Operation times range from 10 s to 15 s.

In this practice, the relay SEL 751 will be used (SEL, 2010b). This will familiarize students with a feeder protection relay.

Once configured the relay by using the AcSELerator QuickSet, faults are simulated with the SVERKER 780. Operation times will also be recorded with this testing equipment.

6. PHASOR MEASUREMENT UNIT FUNCTION SETTING

This chapter shall allow the applicability of Synchrophasors, or phasor measurement units known as Phasor Measurement Units, PMU. Some of the IEDs owned by UPB have Synchrophasors function.

PMUs allow precise measurements and can be identified by a label of time, allowing the comparison of two quantities in real time and thus provide reliable information on the state system, unaffected by communication.

The PMU is integrated into a monitoring system or Wide Area Measurement System, WAMS. WAMS involve advanced digital processing algorithms and infrastructure that enable monitoring and control of power systems in real time. By integrating, the information provided by WAMS systems with established SCADA systems, precision and consistency of SCADA systems is improved, allowing the overall implementation of the PMUs.

PMUs basically measure bus voltages, angles and currents using the IEEE C37.118 standard (IEEE, 2011) and sends the data with a time tag to a phasor data concentrator, PDC.

For this practice, it is additionally needed a SEL-2407 Satellite-Synchronized Clock (SEL, 2008) and a GPS antenna. The student is oriented on the techniques to put the system in service including antenna, clock, relay, communication software and network.

With the objective of obtaining current and voltage phasors exposing important angle shifts, an inductive circuit is used. See Fig. 7.

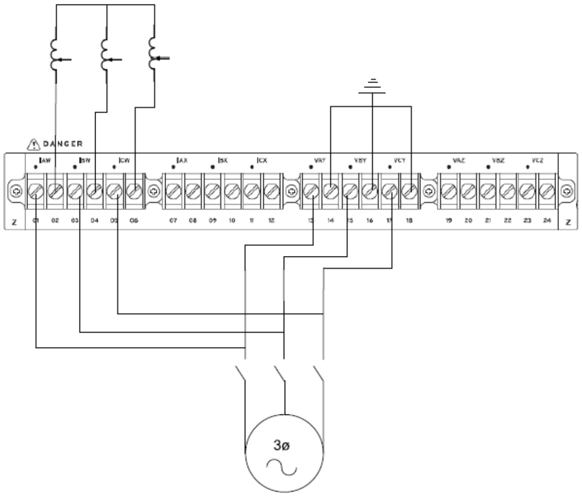
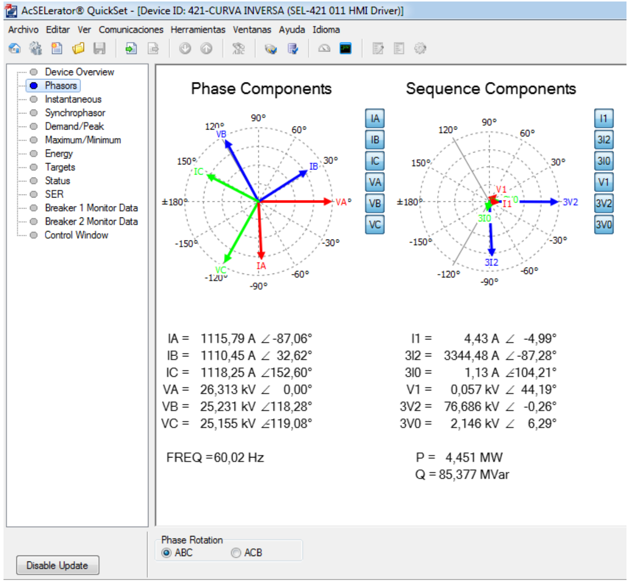


Fig. 7. Circuit to study PMU of SEL 421.

The inductive load drives to the results presented in Fig. 8. Current is lagging voltage by almost 90°.

The student is required to select "Synchrophasor" option, which displays the data of voltage and current, but in this case taking as reference the satellite clock. Fig 9 presents the output window of this option.



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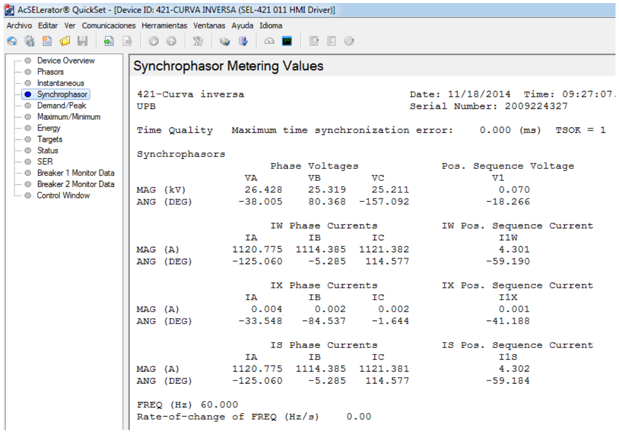
IA =  1115,79 A ∠-87,06°        I1 =     4,43 A ∠  -4,99°
IB =  1110,45 A ∠ 32,62°       3I2 =  3344,48 A ∠-87,28°
IC =  1118,25 A ∠152,60°       3I0 =     1,13 A ∠104,21°
VA =  26,313 kV ∠  0,00°        V1 =   0,057 kV ∠ 44,19°
VB =  25,231 kV ∠118,28°       3V2 =  76,686 kV ∠  -0,26°
VC =  25,155 kV ∠119,08°       3V0 =   2,146 kV ∠   6,29°

FREQ =60,02 Hz                  P =  4,451 MW
                                Q = 85,377 MVar
```

Phase Rotation
◉ ABC ○ ACB

Fig. 8. Circuit to study PMU of SEL 421 relay.



Synchrophasor Metering Values

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421-Curva inversa                         Date: 11/18/2014  Time: 09:27:07.
UPB                                       Serial Number: 2009224327

Time Quality   Maximum time synchronization error:    0.000 (ms)  TSOK = 1

Synchrophasors
                   Phase Voltages               Pos. Sequence Voltage
                VA        VB        VC                 V1
MAG (kV)      26.428    25.319    25.211              0.070
ANG (DEG)    -38.005    80.368  -157.092            -18.266

                   IW Phase Currents            IW Pos. Sequence Current
                IA        IB        IC                 I1W
MAG (A)     1120.775  1114.385  1121.382              4.301
ANG (DEG)   -125.060    -5.285   114.577            -59.190

                   IX Phase Currents            IX Pos. Sequence Current
                IA        IB        IC                 I1X
MAG (A)        0.004     0.002     0.002              0.001
ANG (DEG)    -33.548   -84.537    -1.644            -41.188

                   IS Phase Currents            IS Pos. Sequence Current
                IA        IB        IC                 I1S
MAG (A)     1120.775  1114.385  1121.381              4.302
ANG (DEG)   -125.060    -5.285   114.577            -59.184

FREQ (Hz) 60.000
Rate-of-change of FREQ (Hz/s)    0.00
```

Fig. 9. PMU measures in SEL 421 relay.

Now the student should vary the inductance to obtain a change in the angle between current and voltage. The student must obtain at least five considerable variations and make a written and photographic record.

7. CONCLUSIONS

Laboratory sessions for the learning of protective relaying were presented. Relaying equipment was received as a donation from SEL Company. The students can now assimilate in a practical fashion, the concepts of protection systems by setting up modern relays and applying voltage and current signals to serve to simulate real faults in the electrical networks. Several laboratory sessions were specified as a practical component in an undergraduate course. The sessions involved modern training test equipment and high technology protective devices used in industry nowadays. Synchrophasors technology was also included.

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