INTRODUCTION

In this series of articles, we will be looking at each of the main stages of the electrical power system in turn. As you will recall from our Introduction to Electrical Power Systems, this can be broken down into five key areas:

- Generation
- Transformation
- Transmission
- Distribution
- Protection

Each article in this series will comprise a brief overview of the topic in question, and will focus on the learning objectives within that field. We will relate these to our individual Power System Laboratory modules, and detail the range and depth of the experimental scope, highlighting important concepts along the way.

Finally, we will discuss our Power System Trainer, and detail the added experimental scope that an integrated system will cover, and how this relates to some of the key issues in the power industry.

THE PROTECTION OF ELECTRICAL POWER SYSTEMS

As modern Electrical Power Systems become ever larger and more sophisticated, particularly as we transition from traditional branching networks into more Smart Grid–configured structures, the need for effective Protection systems becomes increasingly important.

Since the advent of electrical power systems in the late nineteenth century, various methods have been used to protect the network from damage, in addition to providing a safe environment for the people using it. At the same time, one of the key reasons for having an effective protection system is to keep the healthy parts of the power system network up and running.

For many decades, electromechanical relays were the predominant means to achieve this. As solid state technology developed in the second half of the twentieth century, this revolutionised...
protective devices, as indeed it revolutionised many other areas of modern society. Digital relays were the next major advance in the field, soon followed by the development of microprocessor-controlled programmable numerical relays, which are now used extensively around the world, and form the backbone of an effective protection system.

Numerical relays are used in all our PSL modules, and the PSS1 Power System Trainer, and experiments in protection techniques figure strongly in all these modules. In addition, our PSL50 Protection and Relay Test Set, introduces students to basic concepts of Protection, and enables them to familiarise themselves with the operation and behaviour of numerical relays.

In this article, we shall look at each of these products in turn and summarise the role that protection plays in each of the key stages of the power network.
THE TECQUIPMENT POWER SYSTEMS RANGE

TecQuipment manufactures a comprehensive range of trainers to cover all the aspects of an electrical power system, ranging from a suite of standalone Power Systems Laboratory trainers which look at each of the aspects of Power Systems in turn – Generation, Transformation, Transmission, Distribution and Protection, through to an all-encompassing Power Systems Trainer that combines all these elements in one unit, and allows for further investigations from an integrated systems standpoint.

The diagram shows how the different ranges support each other to create a complete Electrical Power System course.

In electrical power systems courses in universities and colleges, it is often easier for students to understand the principles involved with each of the elements of an electrical power system separately. Only then can students progress towards studies of more complex systems when several of these elements are interconnected and working together.
THE PSL PROTECTION RELAY TEST SET (PSL50)

The PSL50 is the individual Power Systems Laboratory module that focuses on the protection element. It allows the student to study the characteristics of a range of different relays, as well as study two relays side by side, allowing analysis of grading and discrimination under fault conditions.

The PSL50 acts as a test bed for the protection relays listed below, all of which are genuine industrial relays, not simulations, and each has been specially adapted by TecQuipment for educational use:

- Overcurrent and Earth Fault Relay (MiCOM P122) (PSA10)
- Differential Protection Relay (MiCOM P642) (PSA15)
- Directional/Non-Directional Overcurrent Relay (MiCOM P127) (PSA20)
- Feeder Management Relay (MiCOM P142) (PSA25)
- Distance Protection Relay (MiCOM P441) (PSA30)
DESCRIPTION OF THE PSL40 AND KEY EXPERIMENTS

The PSL50 is a free-standing, three phase-supplied console comprised of several components, and divided into two main sections:

- **A Lower Console which contains:**
  - 0-220 V Supply – a variable transformer used to adjust the incoming voltage
  - Set Test Current – a variable load used to adjust the test current
  - Fault Limiter 1 – a single variable resistor used to limit fault currents
  - Fault Limiter 2 – a single variable resistor used to limit fault currents
  - 3Φ Star Load – a variable three-phase load, star connected
  - 3Φ Delta Load – a variable three-phase load, delta connected
  - Main Supply 16 A MCB, activated by the Emergency Stop button

- **An Upper Console which contains:**
  - A Relay Test Area
  - A Configurable Transformer Test Circuit
  - A Transmission Line Model
  - Selection of Voltmeters and Ammeters

Selection of Current Transformers (CTs) and Voltage Transformers (VTs) to connect to the current and voltage inputs of the relays under test.

Circuit breakers at strategic locations on the console allow individual sections and circuits of the unit to be switched in and out, allowing a very wide and flexible range of network configurations to be set up during the tests.

The individual relays are connected to the back of the PSL50 using standard multicore cables which provide 24 VDC and 110 VAC to the relays, along with trip and reset control signals. Sockets at the front of the relays connect to the CTs and VTs and provide the fault signals that the relay is designed to detect.

The range of experiments begins with an investigation into the **Current Transformers** in the PSL50, and the student develops an appreciation of how CTs are an effective way to allow safe monitoring of high currents.

The student is then invited to perform investigations on relay modules themselves, and a number of different relay types are examined. All relays are supported by the manufacturer’s Technical Manuals, which detail the programming required for their effective operation. Relays are programmed either via the front panel, or by a PC running the MICOM software.
PSA10 - OVERCURRENT AND EARTH FAULT RELAY

The increasing complexity of modern power systems, and the associated increase in the level of fault currents, mean that existing methods of Current Grading are no longer sufficient on their own to provide an adequate level of protection. Inverse Time-Current Grading is therefore used in a system to minimise operating times of the relays.

By understanding the role and interplay of the three main relay settings: the Current Setting \( I_n \), the Time Delay Characteristic, and the Time Multiplier Setting, students learn the fundamental techniques of providing a properly graded protection scheme that provides effective Fault Discrimination on a Radial Power System.
As a consequence, students develop an understanding of the key factors involved in Protection Zoning.
PSA15 - DIFFERENTIAL PROTECTION RELAY

This relay is used for the protection of three phase transformers with two or three windings and provides differential and overcurrent functions.

With the PSA15, the student studies the concept of Unit Protection, where the relay characteristics are such that a very specific region of the network can be protected.

Zero Sequence Current Filtering is employed, and the students learns how this factors contributes to the Tripping Characteristic of the relay.

The configurable transformer area of the Test Set is used to test Line to Line Faults and Line to Ground faults, both inside outside the protection zone.
Further tests can be carried out with this equipment. Disconnecting the trip circuit allows “steady state” measurements of the distribution of fault currents to be made, and investigations can be carried out into tripping conditions.

**PSA20 - DIRECTIONAL/NON-DIRECTIONAL OVERCURRENT RELAY**

The use of an overcurrent relay to only activate by fault currents in one direction is achieved by using the quadrature line voltage to act as a “polarising” voltage. The interaction between this and the line current enables the relay to sense the direction of the fault current. With the PSA20, students investigate the directional characteristics, and examine the Relay Characteristic Angle (RCA), also known as the Torque Angle, as well as the Lagging Angle of the line current.

![Diagram of PSA20](image)

Further experiments are performed on Parallel Feeder Distribution Systems, where the use of Directional relays ensures that only one of the two transformers will be tripped in the event of a fault.
PSA25 – FEEDER MANAGEMENT RELAY

This is the most comprehensive of the TecQuipment relays, and it is widely used to protect Transmission lines and underground Distribution networks. With it, students can explore the fundamentals of Differential Protection and Restricted Earth Protection. In particular, students analyse Biased Differential Protection Schemes, a central topic for Unit Protection.

Topics addressed by this relay include Interposing Delta-Star Transformers, High Impedance Relays and Winding Faults. Defined experiments include CT Polarity in Differential Protection Circuits and Restricted Earth Fault Protection.

CT POLARITY IN DIFFERENTIAL PROTECTION CIRCUITS
PSA30 – DISTANCE PROTECTION RELAY

Distance relays are used to limit the “reach” of a protection zone along a transmission line. They provide another method to assist in discrimination between protection devices.

The PSA30 is a full scheme relay with 18 measuring elements, or comparators, which allow a variety of characteristics to be established which determine the nature of the fault and the fault distance.

The principal experiment with this relay is the examination of a Three Zone Distance Protection Scheme, utilising the Transmission Line section of the console. Resistive Reach Calculations are also discussed as part of this experiment.

![Earth Fault Quadrilateral Characteristics](image)

EARTH FAULT QUADRILATERAL CHARACTERISTICS
THREE ZONE DISTANCE SYSTEM
FURTHER PROTECTION STUDIES WITH THE PSL RANGE

The PSL50, and its associated relays, constitutes a comprehensive test bed with which the student can investigate the fundamental characteristics of a range of protection relays. It is designed to be a standalone system which comprises elements of the modular PSL units that were discussed in the first four articles of this series.

The relays themselves can also be used as optional ancillaries to the modular PSL units to provide additional experimental scope. These were discussed in the previous articles and are summarised below;

**PSL50 SALIENT POLE GENERATOR**

Protection Relays built in:

- Interconnection Relay (MiCOM P341)

Experimental scope:

- Overcurrent Protection
- High Set Instantaneous Protection
- Reverse Power Protection
- Over-voltage Indication
- Under-frequency Indication
- Over-frequency Indication
- Tripping Sequence
- Rate of Change of Frequency Protection (ROCOF)
- Differential Protection around a generator (with the PSA15)

Optional Relays:

- Overcurrent and Earth Fault Relay (MiCOM P122) (PSA10)
- Differential Protection Relay (MiCOM P642) (PSA15)
- Directional/Non-Directional Overcurrent Relay (MiCOM P127) (PSA20)
- Feeder Management Relay (MiCOM P142) (PSA25)
PSL20 Transformer Trainer

Protection Relays built in:
- Directional/Non-Directional Overcurrent Relay (MiCOM P127) (PSA20)

Experimental scope:
- Directional/Non Directional Earth Fault
- Directional/Non Directional Phase Overcurrent
- Wattmetric Protection (Pe or Pe cos)
- Broken Conductor Detector
- Under Current
- Negative Phase Sequence Overcurrent
- Thermal Overload
- Under voltage
- Over voltage
- Residual Over voltage
- Blocking logic
- Cold Load Pick Up

Optional relays:
- Differential Protection Relay (MiCOM P642) (PSA15)
**PSL30 Transmission Line Simulator**

Protection Relays built in:

- Directional/Non-Directional Overcurrent Relay (MiCOM P127) (PSA20)

Experimental Scope:

- Directional/Non Directional Earth Fault
- Directional/Non Directional Phase Overcurrent
- Wattmetric Protection (Pe or le cos)
- Broken Conductor Detector
- Under Current
- Negative Phase Sequence Overcurrent
- Thermal Overload
- Under voltage
- Over voltage
- Residual Over voltage
- Blocking logic
- Cold Load Pick Up
- Protection Relay Discrimination
- Directional Overcurrent Protection
- Distance Protection
- Grading

Optional Relays:

- Overcurrent and Earth Fault Relay (MiCOM P122) (PSA10)
- Feeder Management Relay (MiCOM P142) (PSA25)
- Distance Protection Relay (MiCOM P441) (PSA30)
PSL40 DISTRIBUTION TRAINER

Protection Relays built in:

- Directional/Non-Directional Overcurrent Relay (MiCOM P127) (PSA20)
- Single Phase Overcurrent Relay (MiCOM P120)
- Three Phase Overcurrent Relay (MiCOM P121)

Experimental Scope:

- Distribution System Protection
- Distribution System Under Faults
- Protection Relay Discrimination
- Faults on an Unloaded System
- Faults on a Loaded System

Optional Relays;

- Overcurrent and Earth Fault Relay (MiCOM P122) (PSA10)
- Differential Protection Relay (MiCOM P642) (PSA15)
- Directional/Non-Directional Overcurrent Relay (MiCOM P127) (PSA20)
- Feeder Management Relay (MiCOM P142) (PSA25)
THE PSLHB HUB

One of the great advantages of the PSL Modules is that they can be interconnected to perform additional advanced experiments that would not be possible using the individual modules alone. This is achieved using the PSLHB Hub, which provides all the common connections between the individual modules.
The PSLSB Switched Busbar Module provides a convenient central test and control unit that provides common voltage and power ratings to the PSL modules. With the PSLSB, more advanced experiments can be performed in Differential Protection and Unit Protection.

The upper panel comprises a simple radial circuit that allows a single incoming feeder to provide a common input to three outgoing feeders. Each feeder includes a circuit breaker, multifunctional digital meters and current transformers.

The lower panel simulates a double busbar system - a main and reserve, just as we would see in a real world system. Bus coupler switches allow the two busbars to be split into four sections. Six feeders connect to the two busbars, allowing a very flexible way of interconnecting the other PSL modules in series or in parallel.

High Impedance differential protection is built up from first principles, culminating in a two, overlapping zone differential protection scheme for the busbar.

Protection Relays built in:

- 2x Feeder Management Relays (MiCOM P141)
Experimental Scope:

- CT Connections for Differential Protection
- Internal Faults - Phase to Phase (L-L)
- Internal Faults - Phase to Earth (L-E)
- External Faults (through faults)
- Differential Protection on Radial Circuits
- Introduction to Switched Busbar Protection
- Switched Busbar Zone Protection – Single Zone
- Switched Busbar Zone Protection – Two Zones
- Switched Busbar Zone Protection – Overlapping Zones

Optional Relays:

- Overcurrent and Earth Fault Relay (MiCOM P122) (PSA10)
- Directional/Non-Directional Overcurrent Relay (MiCOM P127) (PSA20)
- Feeder Management Relay (MiCOM P142) (PSA25)

Using the PSLSB with other PSL modules

A wide range of experiments can be designed and carried out by the student using the PSLSB and two or more of the other PSL modules.

As an example, using the PSL30 Transmission Line Simulator and the PSL40 Distribution Trainer, experiments can be performed on Three Phase Balanced Faults, and how to correctly implement effective Grading of Protection Relays.
FURTHER STUDIES IN PROTECTION

For further, more detailed study of Protection within the context of an integrated Electrical Power System, the PSS1 Power Systems Trainer takes the student to the next level. Whilst there is some overlap, obviously, between the PSL modules and the PSS1 in terms of the experiments that can be performed, the PSS1 is focused much more on the role and interaction of Protection within the wider context of a real world system. Some of the experiments that the student performs with the PSL modules, such as the more fundamental characteristics of a protection relay for example, are not covered by the PSS1. Instead, it is assumed that the student has already covered these topics and developed a mastery of the fundamental principles of Protection with the PSL range.

The next section, therefore, looks at the capabilities of the PSS1 and the scope of experimentation that it offers in the context of Protection, including the additional experiments that can be performed with the inclusion of the PSS3 Second Generator.
THE PSS1 POWER SYSTEMS TRAINER

The PSS1 is a self-contained unit that replicates all parts of an electrical power system and its protection, from generation through to utilisation.

THE PSS1, ABOVE, AND THE PSS3 ON THE NEXT PAGE, SHOWING THE PROTECTION RELAYS MARKED BY ASTERISKS
THE PSS3 SECOND GENERATOR

The PSS3 is a self-contained motor and generator set that connects to the Power System Trainer (PSS1) for extra experiments in central and embedded generation.

DESCRIPTION OF THE PSS1 AND PSS3, AND KEY EXPERIMENTS IN PROTECTION

The PSL range is very much geared towards understanding the fundamental principles underlying each of the main elements of an electrical power system individually. In the real world, of course, we rarely consider any of these elements in isolation. The PSS1 therefore looks at the entire system as a whole, and is focussed on how these elements interact with each other in a holistic system.

The PSS1 is essentially a scaled down version of a real-world power system, and uses many of the features of the PSL range, such as the per-unit-value system, identical Motor and Generator as the Prime Mover and industrial Protection relays and meters. The student therefore naturally progresses from the individual isolated module approach of the Power Systems Laboratory range, to a systems approach in a smooth and seamless transition.

The PSS3 is an optional add-on to the PSS1, comprising a duplicate Motor and Generator, for even further exploration of Protection experiments.

The construction and layout of the PSS1 makes it an extremely versatile trainer, allowing the student virtually unlimited flexibility and experimental scope. As a result, the PSS1 is ideally suited
for advanced project work and is a perfect system to perform scenario-based learning within either an academic environment, or in a more industrially-focussed technical training environment. The manual does define and cover a wide range of experiments that the student can perform initially, and many of these pick up where the PSL50 left off:

- Grading of Overcurrent Protection for Three-Phase Faults
- Multi-Shot Auto-Reclose
- High Set Instantaneous Settings
- Back Tripping
- Directional Control of Relay Tripping
- Three Zone Distance Protection Scheme
- Grid Transformer Differential Protection
- Busbar Protection
- Generator Protection

With the addition of the PSS3 Second Generator, further experiments are possible, focusing on the protection of embedded generation and interconnected systems:

- Protection of the Generator from internal earth and phase faults
- Protection from damage to the Generator that could result from disconnection from the Grid Network, known as “Loss of Mains” protection
- Protection of the intertie for phase and earth faults
- Neutral Voltage Displacement (NVD) protection
SINGLE SHOT AUTO RECLOSER SCHEMES FOR A TRANSIENT FAULT AND A PERMANENT FAULT
THREE-PHASE TRANSFORMER DIFFERENTIAL SYSTEM

SUMMARY

The above experiments are only a sample of the capability of the Power Systems Trainer in the context of Protection. The flexible design of the PSS1 and PSS3 allows for a much wider range of experiments to be designed and performed, and thus it is ideally suited for further project work and research activities. As it covers all the key elements of a power system, from Generation to Utilisation, it has become a very powerful tool to be used in Scenario Based Learning, in both an academic environment as well as in an industrial/technical training context. Many customers around the world have benefitted greatly from the TecQuipment Power Systems range, whether it is to teach students the fundamental principles of electrical power, or to train the next generation of electrical power system engineers serving the needs of industry.

For further details of the TecQuipment Power Systems range, and to see how it could be of value to your institution, please feel free to contact our Sales Team who will be more than happy to discuss your specific requirements.