Introduction

This trainer has been designed to provide students with a fully comprehensive knowledge in Electrical Power Engineering systems.
The trainer is composed of a set of modules for the simulation of the various subsystems forming a complete electrical power system, from power generation to energy utilization.
High voltage components have been scaled down for obvious reasons: a real 380 kV power transmission line is represented by a 380 V line in the laboratory. However, the same low voltage industrial equipment which is normally used in real systems has been used also in this laboratory, whenever this was feasible.

The trainer can be subdivided into four major study areas:

- Power Generation
- Power Transmission and Distribution
- Protection Techniques
- Energy Utilization

In the Power Generation section a two-pole alternator is investigated. A dc shunt wound machine performs the drive function. To determine some of the characteristics of the synchronous machine, the so called isolated operation situation is reproduced.
This is an operating mode in which the generator supplies only one single consumer.
Then, various synchronization circuits are assembled and the response of the machine is investigated in a constant-voltage constant-frequency system. In this situation, voltage and frequency are predetermined by the system and have constant values. Problems related to the protection of the generation are also dealt with.

In the Power Transmission and Distribution section a three-winding transformer is investigated. Then, a model of an overhead high voltage power line is used to investigate its performance characteristics under various load conditions.
Circuit configurations are connected for the demonstration of different neutral point connections in three-phase mains systems. Asymmetrical short-circuits are also simulated and reactive power compensation analyzed.

In the Protection Techniques section instrument transformers, to reduce the high current and voltage values so that they can be measured safely and economically, are studied. Then, the procedures which are most commonly used in protective technology are introduced and the most frequently used relays (under/over voltage relays, definite and inverse time over-current relays, earth-fault relays, etc.) are investigated.
Finally, over-voltage, under-voltage and earth fault monitoring and short-circuit protection of high voltage lines are analyzed.
Special attention is given to the issue of protection of the generation, of the transmission and of transformers.

In the Energy Utilization section the problems related to reactive power compensation are discussed as well as the methods and the equipment relevant to measuring the electrical energy in ac current and in three-phase networks: active and reactive energy induction meters and maximum demand meters.

Power Generation

The three-phase current has emerged as the simplest form of power, in terms of both transmission and universal application, in the area of public power supply.
In fact, three-phase currents can be transmitted to a voltage level which is suitable for the distances the power has to be transmitted and, furthermore, it is ideal for being used by the consumers.

The major problem is that electrical power cannot be stored in large quantities and, consequently, it has to be generated at the same time the consumer needs it. The generation of electrical energy is performed almost exclusively by means of high power synchronous machines, or alternators, whose construction design depends on the type of drive, which can normally be steam, gas or water.

Then, if the synchronous generator must be connected in parallel with a constant- voltage constant-frequency system, it has to reach its nominal speed, and the excitation voltage has to be increased from zero until the stator voltage is brought up to the same level as that of the network. To obtain this situation, the magnitude, the phase relation and the rotational direction of the two voltages must be in agreement.

This procedure is termed synchronisation. In this section a two-pole alternator is investigated.
A dc shunt wound machine performs the drive function (GTU 101.1).

To determine its characteristics the synchronous machine is operated in what is known as an isolated operation. In this configuration the generator supplies energy to one consumer only.
In this case, the alternator determines the voltage magnitude and the frequency.

Then, various synchronisation circuits are assembled and the response of the machine is investigated in a constant-voltage constant-frequency system. Here, voltage and frequency have constant values and are predetermined by the system.

Experiments GTU101.1

Alternator and parallel operation

- determination of the effective resistance of stator and exciter windings of the alternator
- determination of the mechanical and iron losses of the alternator
- recording the open-circuit curve at various speeds
- determination of the ohmic and stray losses of the alternator
- recording the short-circuit curve at various speeds
- calculating the synchronous reactance
- recording the response of the alternator operating with the excitation and speed kept constant under different types of load
- recording the regulation characteristics at different power factors
- determination of the conventional efficiency of the alternator using the open- and short-circuit test results
- becoming familiar with various lamp circuits used to connect an alternator
- in parallel to a constant-voltage constant-frequency system
- parallel operation using a synchronoscope
- response of the alternator on a constant-voltage constant-frequency system
- recording the V-curves (Mordey curves) of the synchronous motor

Configuration

		GTU101.1
Variable dc power supply	DL 1013T2	1
Resistive load	DL 1017R	1
Inductive load	DL 1017L	1
Capacitive load	DL 1017C	1
Shunt dc motor	DL 1023PS	1
Three-phase synchronous machine	DL 1026A	1
Three-phase synchronous machine	DL 2031M	1
Universal base	DL 1013A	1
Electronic tachometer	DL 2025DT	1
Experiment transformer	DL 1055TT	1
Three-phase power supply	DL 2108TAL-SW	1
Variable dc power supply	DL 2108T01	1
Power circuit breaker	DL 2108T02	1
Moving coil ammeter (100-500-1000ma)	DL 2109T1A	2
Moving coil ammeter (1.25-2.5a)	DL 2109T2A5	2
Moving iron voltmeter (600v)	DL 2109T1PV	1
Synchronization indicator	DL 2109T1T	1
Phase sequence indicator	DL 2109T2T	1
Double frequencymeter	DL 2109T16/2	1
Double voltmeter (250-500v)	DL 2109T17/2	1
Power meter	DL 2109T26	1
Power factor meter	DL 2109T27	1
Synchronoscope	DL 2109T32	1
Moving coil ammeter (100-1000ma)	DL 2109T1AB	1
Moving coil voltmeter (15-30v)	DL 2109T2VB	1
Connecting leads	DL 1155GTU	1
Table	DL 1001-1	1
Frame	DL 2100-3M	2
Accessory: storage cabinet	DL 2100TA	1
for countries with 3-phase mains different from 380v:		
Three-phase transformer	DL 2100TT	1

Power Transmission and Distribution

The major advantage of ac and three-phase technology over dc technology is that the electrical power is generated economically in large power stations relatively far from the end users, transported at high voltage over long distances with very little power loss and finally made available to the consumers the way they need it.
This is possible only by using transformers. In fact, they are suitable for stepping up the voltage of the generator to values which are suitable for high voltage systems, for power exchanging between networks, for stepping down the voltages to the medium voltage level and then for feeding the power into the low voltage network.
In this laboratory a three-winding transformer is investigated. It consists of three individual poles with different connection possibilities on the primary side and variable secondary voltage. The third winding (tertiary winding) is designed as the delta stabilizing winding needed for asymmetrical loads.
Overhead power lines are mainly used to transmit electrical energy from the power stations to the consumers. However, in densely populated areas the power can only be supplied via cables.
Both means of transmission, overhead lines and cables, are included in the general term “line”.
Today, the public supply of power takes place almost exclusively by means of three-phase current with frequency of 50 or 60 Hz, depending upon the Country.
Due to the phase shift of the three currents in a three-phase system, a rotating field is created which is ideal for use by consumers. Furthermore, another advantage of three-phase systems is that they provide the consumers with two different levels of voltage, so that he can use his equipment in the best economical way.
In this laboratory a three-phase model of an overhead power transmission line (with a simulated length of 360 km long, a simulated voltage of 380 kV and a simulated current of 1000 A) is used, with a scale factor of 1:1000.
The performance characteristics of the line are investigated under various load conditions. Circuit configurations are then connected for the demonstration of various neutral point connections in three-phase mains systems. Asymmetrical short-circuits are also simulated.
Questions regarding reactive power compensation are finally addressed. But, transmission networks require a great number of lines and transformers as well as switchgears and substations.
Of course, because of the importance of electrical power, special attention is paid to guaranteeing the smooth operation of all the transmission devices.

Various voltage levels are used for transmitting power; the levels are determined by the amount of power and the distance; the higher the transmission voltages, the lower the currents as well as the transmission losses. However, it must also be considered that network investment costs increase with the voltage.

To evaluate the optimum network configuration heavy calculations have to be carried out. In this laboratory the basic circuits of power engineering, series and parallel connections of operating equipment (lines, transformers) as well as circuits involving the conversion of delta connections to star connections and vice versa, are analyzed.

Also busbars, disconnectors, power circuit breakers, voltage and current transformers are studied; these, in fact, are among the most important components of a switching station.

Three-phase transformer - GTU102.1

- determination of the vector group of the three-phase transformer
- determination of the voltage transformation ratio of the transformer operating at no-load
- determination of the current transformation ratio of the transformer operating with short-circuit
- determination of the equivalent circuit quantities based on the consumed active and reactive power
- measurement of the effect of the load type and magnitude on the performance of the secondary voltage
- determination of the efficiency of the transformer
- investigation of the zero-impedance of the three-phase transformer with various connection modes
- examination of the load capacity of the secondary side using a single-phase load with different connection modes on the primary side
- determination of the influence of a delta stabilizing winding
- demonstration of the possibility of utilizing a three-phase transformer in economy connection (autotransformer)

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Overhead line model - GTU102.2

- measurement of the voltages in no-load operation
- concept of operating capacitance
- line model with increased operating capacitance
- measurement of current and voltage relationship of an over-head line in matched-load operation; interpretation of the terms: characteristic wave impedance, lagging and leading operation, efficiency and transmission losses
- measurement and interpretation of the current and voltage ratios of a transmission line during a three-phase short-circuit
- measurement and interpretation of the current and voltage ratios of a transmission line with mixed ohmic-inductive and pure inductive loads
- measurement and interpretation of the current and voltage ratios of a transmission line with mixed ohmic-capacitive and pure capacitive loads
- investigation on the performance of a transmission line with isolated neutral point connection in the case of a fault to earth
- measurement of the earth-fault current and the voltage rise of the faulty phases
- determination of the inductance of an earth-fault neutralizer for the overhead line model
- investigation on the performance of a transmission line with a fault and comparison of the current values with those determined during earth-fault with isolated neutral point system
- measurement of the fault currents of asymmetrical short-circuits and comparison of the results with those for a three-phase fault
- investigation on the effect of parallel compensation on the voltage stability at the load and the transmission losses of the line
- investigation on the effect of series compensation on the voltage stability at the load
- use of measurement techniques to determine the zero-phase sequence impedance of the overhead line model and comparison of this value with the theoretical one

Series and parallel connection of HV lines - GTU102.3

- measurement of the voltage distribution in the series connection of two lines without operating capacitances
- measurement of the voltage distribution in the series connection of two lines with operating capacitances
- measurement of the voltage distribution in the parallel connection of two lines without operating capacitances
- measurement of the voltage distribution in the parallel connection of two lines with operating capacitances

Busbar systems - GTU102.4

- operation of a switching station with two busbars and different voltages
- busbar transfer with interruption of the power supply to the consumer
- busbar coupling and bus transfer without interruption of the power supply to the consumer
- switching sequence for disconnectors and power circuit breakers

		GTU102.1	GTU102.2	GTU102.3	GTU102.4	TOTAL
Variable three-phase power supply	DL 1013T1	1	1	1		1
Line model	DL 7901TT		1	2	1	2
Three-phase transformer	DL 1080TT	1	1	1	1	1
Resistive load	DL 1017R	1	1	1	1	1
Inductive load	DL 1017L	1	1	1		1
Capacitive load	DL 1017C	1	1			1
Three-phase power supply	DL 2108TAL-SW		1		1	1
Power circuit breaker	DL 2108T02		1	1	4	4
Double busbar with two disconnectors	DL 2108T02/2				1	1
Double busbar with four disconnectors	DL 2108T02/4				1	1
Line capacitor	DL 2108T03		2			2
Petersen coil	DL 2108T04		1			1
Moving coil ammeter (100-500-1000mA)	DL 2109T1A	1	1			1
Moving coil ammeter (1.25-2.5A)	DL 2109T2A5	2	3	3	3	3
Moving iron voltmeter (600V)	DL 2109T1PV		2		2	2
Moving iron voltmeter (125-250-500V)	DL 2109T3PV	2		3		3
Power meter	DL 2109T26	2	1			2
Power factor meter	DL 2109T27		1			1
Connecting leads	DL 1155GTU	1	1	1	1	1
Table	DL 1001-1	1	1	1	1	1
Frame	DL 2100-3M	2	2	2	2	2
Accessory: Storage cabinet	DL 2100TA	1	1	1	1	1
For Countries with 3-phase mains different from 380V:						
Three-phase transformer	DL 2100TT	1	1	1	1	1

Protection Techniques

In electrical power supply systems, currents and voltages are constantly measured and monitored to ensure that they remain within certain limits.
These values are needed in order to provide constant information on the state of the system, to calculate the amount of power supplied to a customer and to switch off rapidly faulty sections of a network in case of a fault.
In general, the current and voltage values are so high that they cannot be measured directly and special transformers have to be used to reduce these values to a level which can be measured safely and economically.
In this laboratory single and three-phase current and voltage transformers are studied.
But, a very important subject must also be considered, the one related to the protection of electrical power systems, in order to avoid that any fault could spread through the network and result in a collapse of the entire power supply system. In cases of short-circuit, for instance, the very high fault currents produced can destroy parts of the system and could often even endanger the lives of humans.
For these reasons, special protection systems, which must react quickly and reliably in the event of faults, have been developed in the area of electrical power distribution.
A fundamental task of a protective system is to recognize the damaged system component and, where possible, to disconnect only this component so that the remaining power distribution can be maintained.
In this laboratory a number of protective relays are analyzed: under/over voltage time relays, definite time over-current relays, inverse time over-current relays, earth-fault relays, etc.).
Then, special attention is paid to the problem of high voltage line protection, with discussions on the criteria about the most suitable protective system to be used. Experiments on over-voltage and under-voltage monitoring, short-circuit protection and earth-fault monitoring complete the analysis of this very important problem.

Protection of HV line - GTU103.3

- demonstration of how an under/over voltage time relay monitors the protection of a load against under- and over-voltage
- demonstration of the protection of a transmission line connected in a solid earthed network, when there is a three-phase, two-phase or single-phase short-circuit
- demonstration of how an earth-fault warning relay monitors the transmission line for an earth fault in a network with isolated neutral connection

Instrument transformers - GTU103.1

- determination of the transformation ratio of a current transformer for various primary currents and investigation on the influence of the load on the transformation ratio
- explanation of the terms: ratio error (current error), accuracy class and rated accuracy limit factor
- test on the performance of the current transformer at over-current
- assembly of the common current transformer circuit for measurement on three-phase network
- measurement of the zero-phase sequence current of a three-phase system
- measurements on a summation current transformer
- demonstration of the principle of differential protection
- determination of the transformation ratio of a voltage transformer for various primary voltages and investigation on the influence of the load on the transformation ratio
- explanation of the terms: ratio error (voltage error) and accuracy class
- assembly of the common voltage transformer circuit for measurements in three-phase network
- measurement of the residual voltage in a three-phase system with a fault to ground
- assembly of a voltage transformer circuit in open delta connection
- measurement of the three conductor voltages on symmetrical and asymmetrical loads

Protective relays - GTU103.2

- determination of the transformation ratio of a current transformer for various primary currents and investigation on the influence of the load on the transformation ratio
- explanation of the terms: ratio error (current error), accuracy class and rated accuracy limit factor
- test on the performance of the current transformer at over-current
- assembly of the common current transformer circuit for measurement on three-phase network
- measurement of the zero-phase sequence current of a three-phase system
- measurements on a summation current transformer
- demonstration of the principle of differential protection
- determination of the transformation ratio of a voltage transformer for various primary voltages and investigation on the influence of the load on the transformation ratio
- explanation of the terms: ratio error (voltage error) and accuracy class
- assembly of the common voltage transformer circuit for measurements in three-phase network
- measurement of the residual voltage in a three-phase system with a fault to ground
- assembly of a voltage transformer circuit in open delta connection
- measurement of the three conductor voltages on symmetrical and asymmetrical loads
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		GTU103.1	GTU103.2	GTU103.3	TOT
Variable three-phase power supply	DL 1013T1	1	1		1
Line model	DL 7901TT			1	1
Three-phase transformer	DL 1080TT		1	1	1
Resistive load	DL 1017R	1	1	1	1
Experiment transformer	DL 1055TT	1			1
Three-phase power supply	DL 2108TAL-SW		1	1	1
Power circuit breaker	DL 2108T02		1	1	1
CT load	DL 2108T10	1			1
VT load	DL 2108T11	1			1
Under/over-voltage time relay	DL 2108T12		1	1	1
Inverse time over-current relay	DL 2108T13		1		1
Definite time over-current relay	DL 2108T14		1	1	1
Combined over-current & earth fault relay	DL 2108T15		1		1
Single-phase directional relay	DL 2108T16		1		1
L/C loads	DL 2108T17		1		1
Three-phase over/under voltage relay	DL 2108T18			1	1
Moving coil ammeter (100-500-1000mA)	DL 2109T1A	4			4
Moving coil ammeter (1.25-2.5A)	DL 2109T2A5		1	1	1
Moving iron ammeter (5A)	DL 2109T5A	2			2
Moving iron voltmeter (125-250-500V)	DL 2109T3PV	4	1	1	4
Single-phase current transformer	DL 2109T21	1			1
Three-phase current transformer	DL 2109T22	1			1
Three-phase current transformer	DL 2109T23	1			1
Three-phase voltage transformer	DL 2109T24	1	1	1	1
Summation current transformer	DL 2109T25	1			1
Acoustic continuity tester	DL BUZ		1	1	1
Electronic stopclock	DL CRON		1		1
Connecting leads	DL 1155GTU	1	1	1	1
Table	DL 1001-1	1	1	1	1
Frame	DL 2100-3M	2	2	2	2
Accessory: Storage cabinet	DL 2100TA	1	1	1	1
For Countries with 3-phase mains different from 380V:					
Three-phase transformer	DL 2100TT	1	1	1	1

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Energy Utilization

Energy consumers, in particular the large ones like the industrial plants, are now obliged, either by contract or for reasons of economy, to provide reactive power compensation for their equipment.
If the consumer refuses to set up a compensating facility, the power supply companies install reactive power meters and the reactive power which is consumed must be paid for.
However, even modern and efficient compensating facilities often create difficulties in generating harmonic currents and generate harmonic-related problems in conjunction with other components of the network.
In fact, the compensating capacitors and the feeding transformers or the supply network form a parallel oscillating circuit that can result in resonances which may cause damage to all the adjoining network installations.
The subjects related to reactive power compensation and reactive power controllers are addressed in this laboratory.
Finally, the laboratory deals also with the problem of the measurement of active and reactive power. Induction meters are usually employed for measuring electrical energy in ac current and in three-phase networks.

These meters firstly provide the basis for calculating the cost of the power to be debited to the consumer and secondly are an important mean for the power supply companies to identify the need for an extension or a modification of the supply network.
These topics are analyzed from the theoretical point of view and also by means of practical examples.

Power factor improvement - GTU104.1

- demonstration of the manual operation on the control of reactive power at various inductive loads
- demonstration of the automatic operation on the control of reactive power at various inductive loads and at different sensitivities

Energy meters and tariffs - GTU104.2

- demonstration of the measurement of active energy consumption
- demonstration of the measurement of reactive energy consumption
- determination of the meters constant
- demonstration of the measurement of the maximum demand
- demonstration of load cut-off operation

		GTU104.1	GTU104.2	TOTAL
Resistive load	DL 1017R		1	1
Inductive load	DL 1017L		1	1
Three-phase squirrel cage motor	DL 1021	1		1
Magnetic powder brake	DL 1019P	1		1
Brake control unit	DL 1054TT	1		1
Load cell	DL 2006E	1		1
Optical transducer	DL 2031M	1		1
Universal base	DL 1013A	1		1
Three-phase power supply	DL 2108TAL-SW	1	1	1
Power circuit breaker	DL 2108T02		1	1
Reactive power controller	DL 2108T19	1		1
Switchable capacitor battery	DL 2108T20	1		1
Moving coil ammeter (1.25-2.5A)	DL 2109T2A5	2	1	2
Moving iron voltmeter (125-250-500V)	DL 2109T3PV		1	1
Power meter	DL 2109T26	1	2	2
Power factor meter	DL 2109T27	1		1
Three-phase power meter	DL 2109T29		1	1
Three-phase Active and Reactive Energy Meter	DL 2109T34		1	1
Electronic stopclock	DL CRON		1	1
Connecting leads	DL 1155GTU	1	1	1
Table	DL 1001-1	1	1	1
Frame	DL 2100-3M	2	2	2
Accessory: Storage cabinet	DL 2100TA	1	1	1
For Countries with 3-phase mains different from 380V :				
Three-phase transformer	DL 2100TT	1	1	1

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Summary

		TOTAL GTU 101	TOTAL GTU 102	TOTAL GTU 103	TOTAL GTU104	TOTAL GTU
Variable three-phase power supply	DL 1013T1		1	1		1
Variable dc power supply	DL 1013T2	1				1
Line model	DL 7901TT		2	1		2
Three-phase transformer	DL 1080TT		1	1		1
Resistive load	DL 1017R	1	1	1	1	1
Inductive load	DL 1017L	1	1		1	1
Capacitive load	DL 1017C	1	1			1
Shunt dc motor	DL 1023PS	1				1
Three-phase synchronous machine	DL 1026A	1				1
Three-phase squirrel cage motor	DL 1021				1	1
Magnetic powder brake	DL 1019P				1	1
Brake control unit	DL 1054TT				1	1
Optical transducer	DL 2031M	1			1	1
Load cell	DL 2006E				1	1
Universal base	DL 1013A	1			1	1
Electronic tachometer	DL 2025DT	1				1
Experiment transformer	DL 1055TT	1		1		1
Three-phase power supply	DL 2108TAL-SW	1	1	1	1	1
Variable dc power supply	DL 2108T01	1				1
Power circuit breaker	DL 2108T02	1	4	1	1	4
Double busbar with two disconnectors	DL 2108T02/2		1			1
Double busbar with four disconnectors	DL 2108T02/4		1			1
Line capacitor	DL 2108T03		2			2
Petersen coil	DL 2108T04		1			1
CT load	DL 2108T10			1		1
VT load	DL 2108T11			1		1
Under/over-voltage time relay	DL 2108T12			1		1
Inverse time over-current relay	DL 2108T13			1		1
Definite time over-current relay	DL 2108T14			1		1
Combined over-current & earth fault relay	DL 2108T15			1		1
Single-phase directional relay	DL 2108T16			1		1
L/C loads	DL 2108T17			1		1
Three-phase over/under voltage relay	DL 2108T18			1		1
Reactive power controller	DL 2108T19				1	1
Switchable capacitor battery	DL 2108T20				1	1
Moving coil ammeter (100-500-1000mA)	DL 2109T1A	2	1	4		4
Moving coil ammeter (1.25-2.5A)	DL 2109T2A5	2	3	1	2	3
Moving iron ammeter (5A)	DL 2109T5A			2		2
Moving iron voltmeter (600V)	DL 2109T1PV	1	2			2
Moving iron voltmeter (125-250-500V)	DL 2109T3PV		3	4	1	4
Synchronization indicator	DL 2109T1T	1				1
Phase sequence indicator	DL 2109T2T	1				1
Double frequencymeter	DL 2109T16/2	1				1
Double voltmeter (250-500V)	DL 2109T17/2	1				1
Single-phase current transformer	DL 2109T21			1		1
Three-phase current transformer	DL 2109T22			1		1
Single-phase voltage transformer	DL 2109T23			1		1
Three-phase voltage transformer	DL 2109T24			1		1
Summation current transformer	DL 2109T25			1		1
Power meter	DL 2109T26	1	2		2	2
Power factor meter	DL 2109T27	1	1		1	1
Three-phase power meter	DL 2109T29				1	1
Synchronoscope	DL 2109T32	1				1
Three-phase Active and Reactive Energy Meter	DL 2109T34				1	1
Moving coil ammeter (100-1000mA)	DL 2109T1AB	1				1
Moving coil voltmeter (15-30V)	DL 2109T2VB	1				1
Electronic stopclock	DL CRON			1	1	1
Acoustic continuity tester	DL BUZ			1		1
Connecting leads	DL 1155GTU	1	1	1	1	1
Table	DL 1001-1	1	1	1	1	1
Frame	DL 2100-3M	2	2	2	2	4
Accessory: Storage cabinet	DL 2100TA	1	1	1	1	1
For Countries with 3-phase mains different from 380V:						
Three-phase transformer	DL 2100TT	1	1	1	1	1