

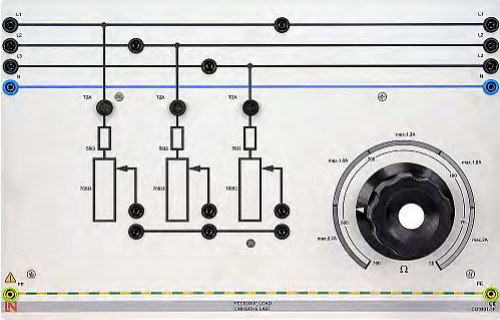
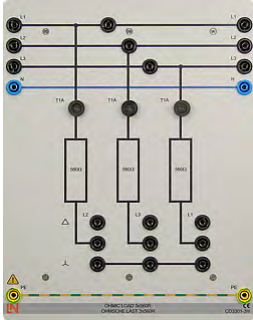
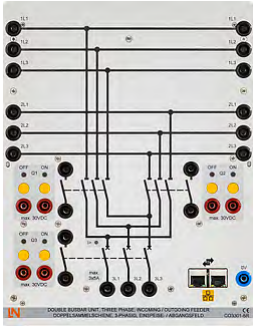
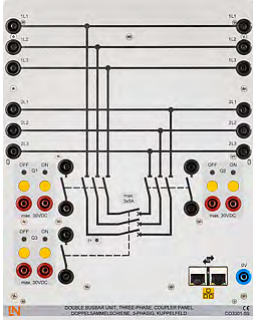
"Busbar Systems"




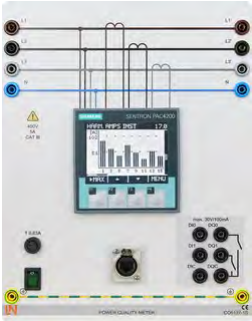
Experiment Objectives

- Understanding switchgear's basic design and power distribution.
 - Understanding the difference between an isolator and a circuit breaker.
 - Learning about the functions of double busbars.
 - Practice correct switching/changing sequences safely for humans and equipments.
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Equipment

Equipment	Part Number	Description	Quantity
	CO3301-3F	Resistive load, 3-phase, 1 kW	1
	CO3301-3H	Resistive load, 3x560 Ω	1
	CO3301-5R	Double busbar, 3-phase, incoming / outgoing feeder	4
	CO3301-5 S	Double busbar, 3-phase, coupler panel	1

	CO3301-3Z	Adjustable 3-phase power supply, 0-400 V/2 A	1

	CO5127-1S	Three-phase meter	1

Double Busbar

1. Description

Three-phase power with currents of up to 5 Amps per phase can be carried, measured and switched by means of the double busbar model. Also present on the board is a branch/connector which can be turned on and off through isolators. The subsequent circuit breaker also has a three-phase design and serves to switch the outgoing and incoming power feeders on and off, and to change busbars.

The isolators and circuit breakers are controlled manually by means of pushbuttons, or by means of a remote switching device (like PLC, protective relay, etc) through a control input. The isolators and circuit breakers are equipped additionally with an auxiliary contact through which indicator lights and other signaling devices can be switched. The switching status is indicated by LEDs. Overcurrent is also indicated by an LED and opens the switches. Certain switching combinations are interlocked - more on this later. Incorrect operations of this kind are indicated visually and acoustically by the models.

Switching can be performed in three different ways:

1. Manually on the device using on/off buttons.
2. By the way of digital control voltage inputs (max. 30 V DC).
3. Through Ethernet using Lucas-Nülle's SCADA Designer/Viewer.

2. Connection

Isolator Q1 connects busbar 1, Q2 connects busbar 2 of the corresponding field to circuit breaker Q3. For the outgoing field, the connection to the outgoing feeders is established by means of circuit breaker Q3. In the case of the coupling field, Q3 connects both isolators to coupling the busbars.

Several modules can be lay out successively to produce any required network configuration. The modules can be interconnected via the RJ45 port, and operated through Lucas-Nülle's SCADA Viewer/Designer. For this, the modules must be organized with different IP addresses in the LAN. The voltages of the busbars, the currents flowing through the circuit breaker, and status messages can be displayed with the software for the incoming and outgoing fields.

3. Control elements

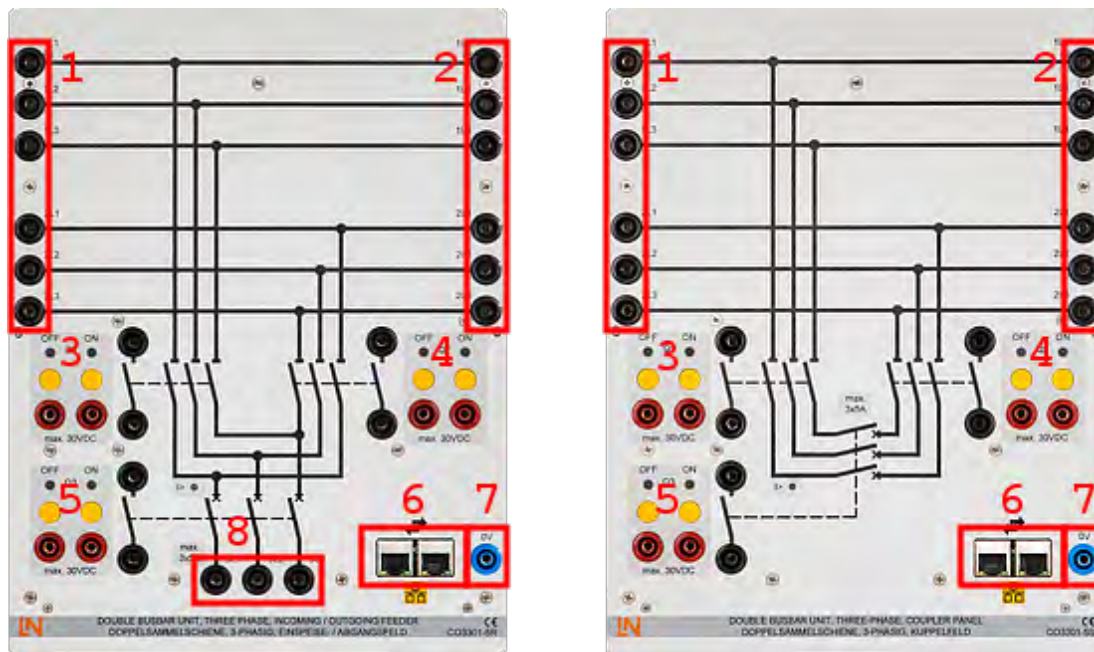


Figure 1:

Left: Incoming / outgoing feeders (CO3301-5R). Right: Coupler panel (CO3301-5S)

Component legend:

- 1: Busbar input 1 (top), busbar input 2 (bottom); L1, L2 and L3 in each case.
- 2: Busbar output 1 (top), busbar output 2 (bottom); L1, L2 and L3 in each case.
- 3: Control panel for isolator Q1.
- 4: Control panel for isolator Q2.
- 5: Control panel for circuit breaker Q3.
- 6: Ethernet connections for measurement and control.
- 7: 0 V connection (earth) for the control inputs (3-5). This is not a neutral conductor connection.
- 8: 400 V connection for feeder field L1, L2 and L3; the coupler panel does not have this line routing.

4. Isolator and Circuit Breaker Control

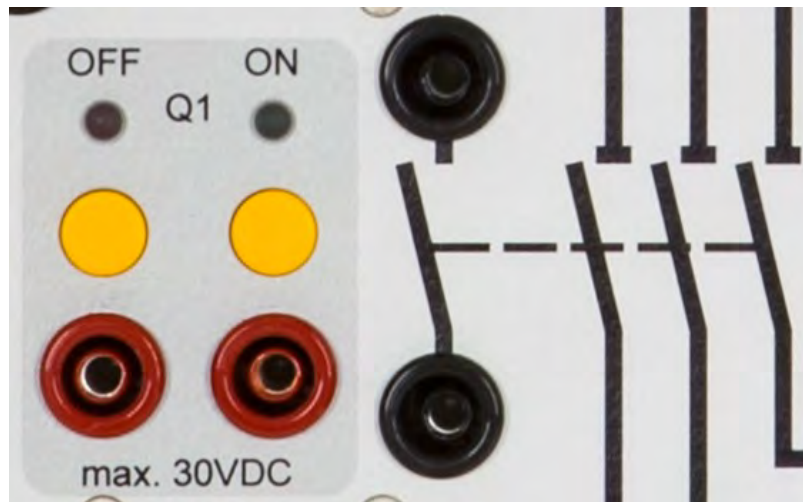


Figure 2:
Isolator in detail

1. Every switch has a red and a green status LED to indicate whether or not the switch is open.
 - a. OFF glows red when the switch is open; ON lights green when the switch is closed.
2. The yellow buttons can be used to change the switching status manually.
3. A control voltage (DC, 30V max) can also be used to change the switching status via the red jacks.
 - a. Connect your voltage source's earth terminal to 0 V of the busbar field to be addressed.
 - b. The pulses / continuous signals are opened / closed via the red input jacks.
 - c. OFF has dominant status across all three control platforms (buttons, control voltage and SCADA).
4. In addition to the three main contacts for L1, L2 and L3, there is an auxiliary NO-contact for further applications.

5. Interlocked switching operations

In general: ***An isolator is closed before the circuit breaker is closed. A circuit breaker is opened before the isolator is opened. As a result, the more robust circuit breaker is responsible for the critical part of switching, namely starting or stopping a flow of current.*** More information on the differences between isolators and circuit breakers is provided in the section on switching stations and substations.

This switching condition is also implemented in the operation of double busbars. Faulty switching instructions in this context are ignored, and indicated by means of a warning tone and a flashing light. An exception is the change of busbar without interruption, in which case it is permissible to close the second isolator after the first one and the circuit breaker have already closed. Further switching logic functions across devices and fields can be programmed individually via the SCADA Designer/Viewer PLC.

6. Operation with SCADA Designer/Viewer

When the control system is started via SCADA, the computer's current switching status is transmitted to the busbars.

- After a local network has been set up, it is possible to address/control the double busbars through a computer.

7. Technical details concerning the double busbar models CO3301-5R and CO3301-5S

1. Three-phase current measurement in the branch (with CO3301-5R): 0 to 5 Amps.
 2. Three-phase voltage measurement in the branch (with CO3301-5R) and the two busbars: 0 to 500 V.
 3. Control voltage: 24 V (for the digital inputs of the isolators and circuit breaker); the earth terminal of the control voltage source must be connected to the 0V jack of the busbars.
 4. Ethernet interfaces (100 Mbit).
 5. Integrated acoustic unit for issuing warnings and alarm signals. This feature can also be used specifically for localizing controlled modules.
 6. Integrated monitoring functions:
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- a. Overcurrent: 5 A, tripping time of 300 ms (maximum current through circuit-breaker Q3).
 - b. Overvoltage: 480 V, tripping time of 150 ms (maximum voltage at BB1, BB2 or feeder).
 - c. Maximum phase difference: 30° (maximum phase angle between 2 corresponding outer conductors).
 - d. Maximum voltage difference: 35 V (maximum voltage difference between 2 corresponding outer conductors).
 - e. Black start/dead busbar detection: 10 V (maximum busbar voltage at which a live outgoing / incoming feeder can be connected to the busbar) - the aforementioned conditions apply at higher voltages.
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8. General instructions on handling the double busbar modules CO3301-5R and CO3301-5S

- When necessary check whether your power supply has a clockwise rotary field using a phase sequence rotary field tester.
 - Both busbars within a module, as well as the individual modules are to be fed from the same voltage source.
 - If two or more different voltage sources (generator, transformer, constant voltage source, inverter etc.) are to be used, then you must ensure synchronization among them. (Refer to the experiment on generator control and synchronization).
 1. Sources which are galvanically isolated from each other, like several generators, must be connected so as to at least result in the same rotary field direction for all phases; further parameters such as voltage and frequency must also be observed.
 2. If several sources not galvanically isolated from each other are used, the rotary field direction and phase sequence for connection must be observed.
 - a. This is the case, for example, if you want to connect one or more power supplies for electric machines (CO3301-5U) to one or more controllable three-phase power supplies (CO3301-3Z) by means of busbars.
 - b. If you use different voltage sources for feeding, ensure that they are all operated via a matching, common fault-current circuit breaker, otherwise unwanted tripping may well occur.
 - An easy method of verifying these conditions is a phase-by-phase check of the voltages V_1 and V_2 requiring synchronization by means of a multimeter: $V_{1L1}-V_{2L1}$, $V_{1L2}-V_{2L2}$ and $V_{1L3}-V_{2L3}$ must all result in nearly 0 V.
 - In general: Changes to the experiment setup must be performed in the de-energized state.
 - Due to the heat generated by the electrical loads, ensure adequate ventilation and safety clearance to other devices.
 - Do not leave loads unattended during operation; turn off unnecessary loads.
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Background/Introduction

Electrical energy is transmitted and distributed via overhead lines and underground cables operating at different voltage levels, selections here are based on technical and economic criteria. To achieve high availability, it is necessary to interconnect networks to an appropriate degree to make sure dependable energy supply for consumers even in the event of failure of individual transmission paths.

Points inside a network where two or more lines meet are called **nodes**. Often present at these nodes are switching devices which isolate affected phases for the purpose of eliminating faults or performing maintenance and repairs. The switching facilities needed for this, including measurement, monitoring, protection and ancillary equipment, are arranged structurally to form what is known as **switchgear**. If the switchgear includes transformers for changing voltage levels, one speaks of a **substation**.

A distinction is made here between high, medium, and low voltage systems, depending on the voltage levels involved:

- Low voltage systems operate in the range up to 1 kV and are usually situated in compact, prefabricated switch cabinets.
- Medium voltage systems operating at up to 20 kV (or 30 kV in some countries) are designed as indoor installations, many of them found in residential and industrial areas.
- High voltage systems operating at up to 380 kV (or 750 kV and 1000 kV in some countries) are usually designed as outdoor installations for financial reasons.

Due to their longer isolation paths, however, high-voltage systems take up a lot of space, besides being a visual and acoustic nuisance for their environment. To confront these disadvantages, equipments which active components are encapsulated in an isolating, gaseous atmosphere at overpressure are used (usually SF₆, sulphur hexafluoride). This permits significant reductions in switching distances, isolation paths and the dimensions of the switchgear. The outcome is more compact high-voltage switchgear which can also operate as an indoor installation in residential and industrial areas.

Another difference between the individual voltage levels is reflected in the measures for protection against faults such as short circuits.

- Low and medium voltage networks make use of blow-out fuses (low voltage/high power or high voltage/high power).
- For physical reasons, however, this is not possible in high voltage networks. These use protective relays which detect faults and transmit appropriate commands to circuit breakers capable of switching high currents.

1. Switching Stations and Substations

- Despite their marked differences, switchgear installations always incorporate a set of identical assembly groups:
 - a. Busbars
 - b. Circuit breakers and isolators
 - c. Current and voltage transformers
 - d. Surge arresters
 - e. Earthing isolators
 - f. In some cases: Transformers

Depending on local structural conditions and technical requirements for switchgear, plans involve selection of either an open/large design or an encapsulated/compact design. If appropriate space is available, the open, air-insulated design proves to be the cost-effective alternative.

These assembly groups are selected and dimensioned in accordance with relevant requirements as well as expected mechanical and electrical loads. Additional facilities for control and monitoring are present to perform the often required remote control of such switchgear. Furthermore, the quantities of energy supplied to consumers are measured by the switchgear; beside equipments' measurements and protections to keep save them against overvoltage, overcurrent, short-circuit and other kinds of faults.

Switchgear integrated into combined networks fulfills as an important switching feature in the context of a smart grid. Switching stations of this kind allow selection of current paths, sources and sinks based on power levels, besides enabling inter-regional planning of power routes and load control.

A. Busbars

At the core of a switchgear installation is the busbar whose design depends on the operating voltage as well as currents expected during normal operation and in the event of faults. One possible design comprises solid copper bars (Figure 1). These are often used in the low-voltage range, but also for some medium-voltage applications.



Figure 1:

Solid copper busbars in the low-voltage range in an indoor switchgear cabinet. Due to the relatively low voltages, the three outer conductors (here: yellow, green, red) are only a few inches apart from each other.

At higher voltages, a use of solid conductors is avoided due to the skin effect; installed instead are hollow conductors usually shaped like tubes. In extreme cases, they can even be cooled internally to allow very large currents. Figure 2 shows three outer conductors incorporating wound and straight hollow tubes which are interconnected via a transducer.



Figure 2:

Three outer conductors (yellow, green, red) routed via transducers.

Wound and straight hollow tubes are used here.

Figure 3 shows a cost-effective, large-scale and commonly used outdoor installation with hollow tubular conductors. The conductors run at a height of several feet above the ground (visible continuously from left to right in the picture). The hollow conductors are supported by insulators on the ground, otherwise air serves as the insulation path over appropriate intervals. Incoming and outgoing feeders at this kind of facility are connected to the hollow tubular conductors via scissor-type isolators/pantograph isolators (and circuit breakers). Running crosswise above the hollow tubular conductors are overhead lines connected to the upcoming pylons and establishing the link to the switchgear.



Figure 3:
Outdoor switchgear with hollow tubular conductors and overhead lines

If the facility has to be more compact, and perhaps even be integrated into a residential/utility building, it requires gas-tight encapsulation. Encapsulation allows atmospheric air, which is quite conductive by comparison, to be replaced with a gas mixture comprising SF₆ (sulphur hexafluoride) which is a better insulator. This has a lower breakdown tendency, and allows the distances between the various potentials to be significantly reduced, thus enabling installation inside rooms and cabinets. Due to the gas apparatus, additionally required control mechanisms etc., such facilities entail higher equipment and maintenance costs.



Figure 4:

An indoor unit encapsulated in SF₆ (sulphur hexafluoride).

The picture shows all components such as busbar, circuit-breakers, isolators and control panel

B. Circuit breakers and isolators

Switching operations as part of high voltage technology require elaborate switches for disconnecting the electric circuits. These switches must be capable of disconnecting the full operating current, as well as the fault current in the event of a fault, they are known as **circuit breakers**. Modern circuit breakers with the high-voltage rating of 380 kV, for example, can switch 80 kAmps reliably and non-destructively.

Figure 5 shows the sectional model of a circuit breaker with a low oil content. One arm of the circuit-breaker is able to switch 110 kV; the series arrangement of two switches (Y-shaped here, the second arm being visible on the right) doubles the switching capacity to 220 kV. The total short-circuit switching capacity is 1.3 GW, or nearly 6 kA. The oil forming part of the design serves for cooling and suppressing electric arcs during switching. Despite the greater tendency to use vacuum switches and SF₆ switches today, the fundamental principle has not changed: *The resultant electric arc is cooled to induce a renewed breakdown of the already ionized air and/or confined to certain areas of the switch in order to lengthen the arc's path (serves to increase the reverse voltage). Usually, the electric arc is then extinguished at the first zero crossing of the source voltage.*

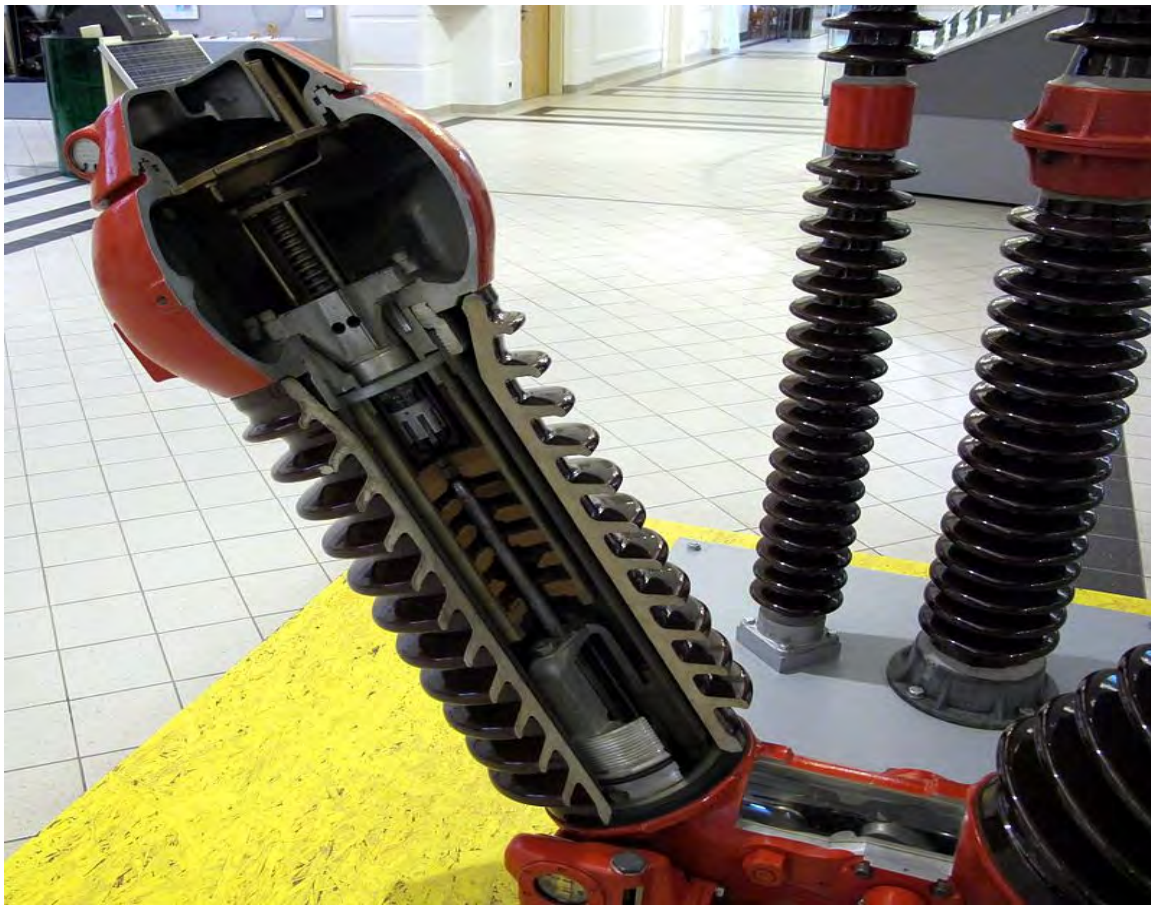


Figure 5:

Sectional model of a 220kV circuit breaker with a low oil content (no oil is visible, due to the sectional view)

Isolators are used as a supplement to the relatively small, open spark gap of a circuit breaker. In the simplest case, they comprise a conductive blade which possesses a rotary bearing and which can be swivelled into a contact fitting. Isolators ensure reliable disconnection, also in the event of overvoltages, short circuits and lightning strikes; furthermore, their switching status is indicated optically or through inherent design.

There are further designs, some of them hybrid, such as the load-break switch. It can switch operating currents and indicate safe, open connections, but cannot switch short-circuit currents.



Figure 6:
Pivoted, open isolators

Isolators allow maintenance to be performed safely at the facility. In contrast to a circuit breaker, an isolator may only be actuated in the de-energized state, i.e. the associated circuit breaker must be open. To avoid false switching, the isolator and associated circuit breaker of encapsulated facilities are mechanically Interlocked. The isolator also serves to produce a visible disconnection point, which is invisible in the case of circuit breakers because it is situated in an arc conduit. The visible disconnection point is a required measure when de-energizing line segments, and serves for safe work on switchgear.

C. Arrangement of the assembly groups

According to its various functions, every switchgear facility and substation is divided into individual fields. A distinction is made here between incoming-feeder, outgoing-feeder and coupling fields.

The layout of each field is largely standardized. These fields are generally represented in single-pole mode in circuit diagrams. In this kind of representation, only the resources needed for the facility to function are drawn using standardized symbols:

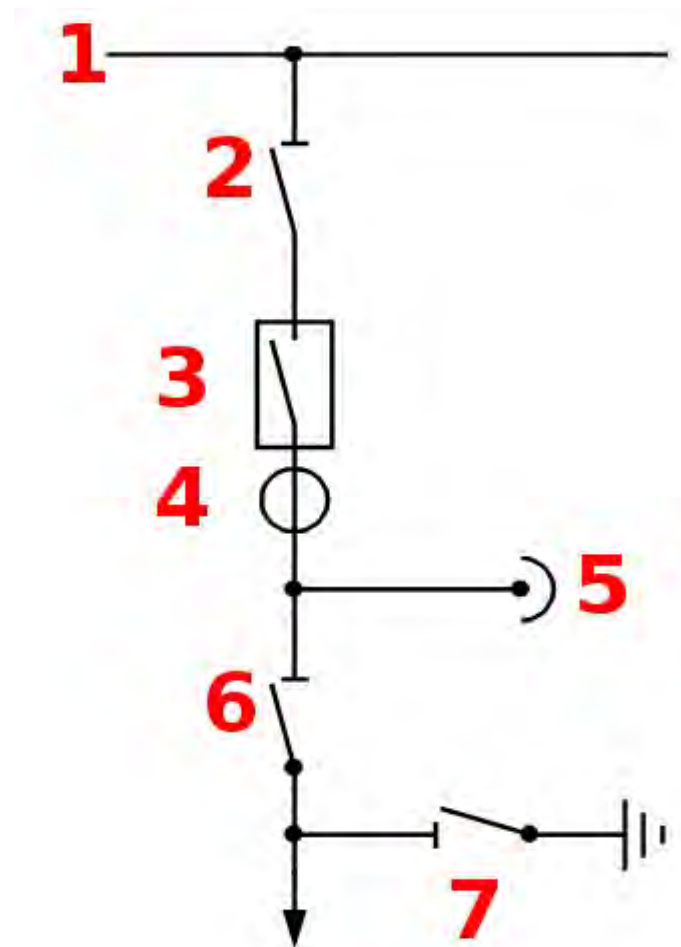


Figure 7:

Block diagram of a branch (1. busbar; 2. busbar disconnecter; 3. circuit breaker; 4. current transformer; 5. voltage transformer; 6. overhead line disconnecter; 7. earthing disconnector)

The circuit shown in Figure 7 applies equally to incoming and outgoing feeders. The two isolators are used to disconnect the circuit breaker, including the current and voltage transformers. If the facility has several busbars, multiple busbar disconnectors are accordingly needed too, as shown for two busbars in Figure 9. The transformers register the data required by systems for operation, metering and protection.

Disconnected lines must be earthed for maintenance work on high voltage installations. Neighboring, active lines apply capacitive and inductive influences, while lightning strikes and other voltage sources are also possible; without earthing, it is therefore unlikely that the disconnected line is at earth potential. Due to its function, the earthing disconnector is also sometimes known as "earthing for work". Disconnectors are also known as Off-Load switches since they can't switch off active current in networks. Figure 8 shows the circuitry of a simple facility consisting of one busbar, one incoming feeder, and two outgoing feeders.

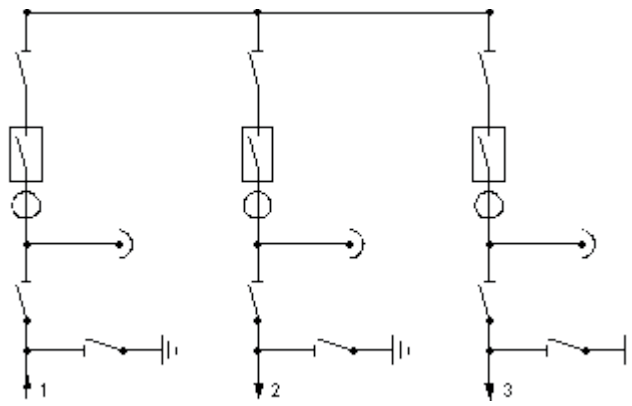


Figure 8:

Facility with busbar, incoming-feeder field and outgoing-feeder field

Normally, at least two busbars are operated in parallel to allow large sections to be disconnected in the event of a fault or when work is needed.

For the purpose of clarity, Figure 9 and subsequent illustrations no longer show the current / voltage transformers or overhead-line / earthing disconnectors.

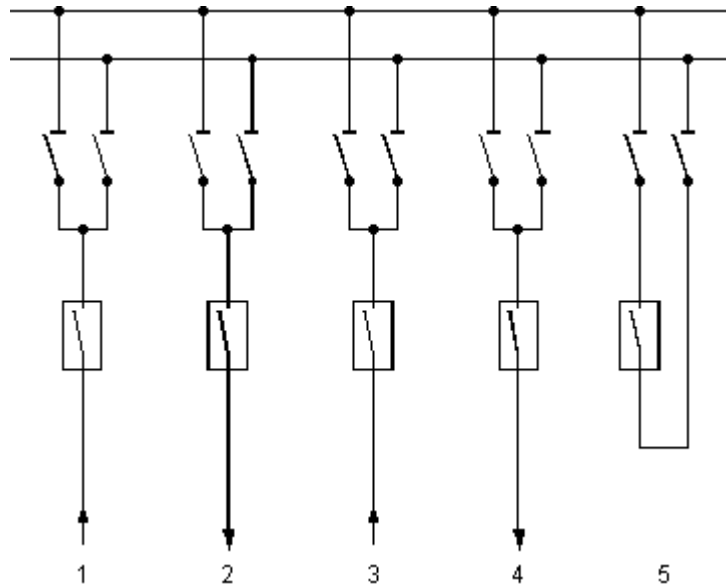


Figure 9:

Facility with two busbars and coupling field

With the help of the circuit breaker in the coupling field, the two busbars can be connected to form a single node. This coupling is known as **transverse coupling**, and allows busbars to be changed without interruption. According to requirements, incoming-feeder fields and outgoing-feeder fields can be connected to the individual busbars without any interruptions in supply.

Because isolators can only be switched in the de-energized state, a circuit breaker is needed for coupling two busbars. If the busbars in Figure 9 need to be coupled together, the two isolators should be closed first, followed by the circuit breaker

During coupling of busbars, appropriate measures (e.g. adjustment of transformer step switches) are needed to equalize potentials, otherwise excessively high compensation currents flow when the busbars are interconnected. Once the busbars have been coupled, the branches can be switched back and forth between the busbars as required, because there is no longer any potential difference. Before an isolator is opened, it is simply necessary to ensure that the other isolator of the same branch is first closed. Otherwise an isolator would be opened under load and thereby get damaged, besides possibly causing further damage to the facility. Appropriate interlocks (electric or pneumatic) are used to secure the isolators against accidental opening.

If the facility shown in Figure 9 is to be extended to three busbars, only three instead of two isolators need to be installed per branch. As the number of busbars increases, so does the flexibility in achieving the desired network configuration. Transfer busbar is the term used for an additional busbar which is connected via a separate circuit breaker or a coupling field to the remaining busbars (Figure 10).

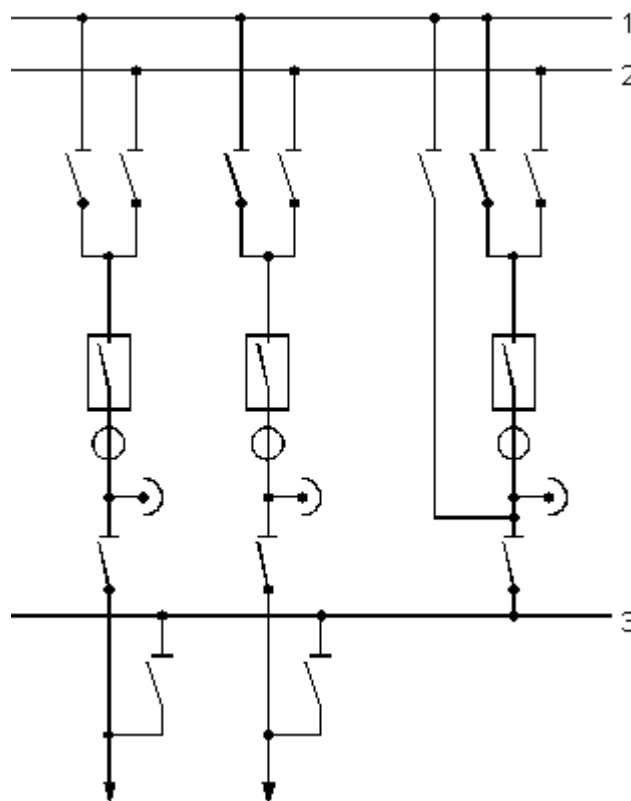


Figure 10:
Facility with two busbars and a transfer busbar

At this facility, the equipment situated between the busbars and the transfer busbar can be disconnected for the purpose of inspection, without a need to open the relevant branch. This also applies to the current and voltage transformers in the configuration shown in Figure 10. During operation with a transfer busbar, the transformers and protective relays in the branch containing this busbar must therefore perform the protection and measurement tasks for the associated line. However, this is only possible if transformers possessing identical transformation ratios are installed in all branches. If this condition cannot be met, the current and voltage transformers must be situated behind the transfer busbar (on the line side). But this in turn obstructs an inspection of these devices. Large facilities often incorporate a further switching option enabling longitudinal disconnection of long busbar systems. Called **longitudinal coupling**, this option can be combined with transverse coupling as shown in Figure 11.

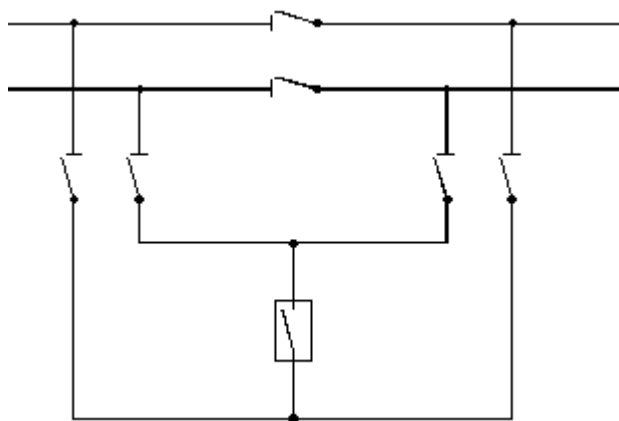


Figure 11:
Coupling field with longitudinal and transverse coupling

Though very elaborate, this coupling with six isolators offers a multitude of circuit variants. It permits both busbars to be linked longitudinally, besides allowing transverse couplings in the left-hand or right-hand busbar section. Other representations of busbar couplings are also available depending on operational requirements. The equipment and related switching connections described above constitute only one of the facility's parts needed directly for operation. They are supplemented by other components such as surge arresters, earth-fault quenching coils, choke coils and coupling capacitors for transmitting carrier frequencies in high-voltage lines, and often also facilities for reactive power compensation.

2. Basic circuitry of a double busbar system

Busbars are an important component of switchgears designed to receive and distribute incoming electrical energy.

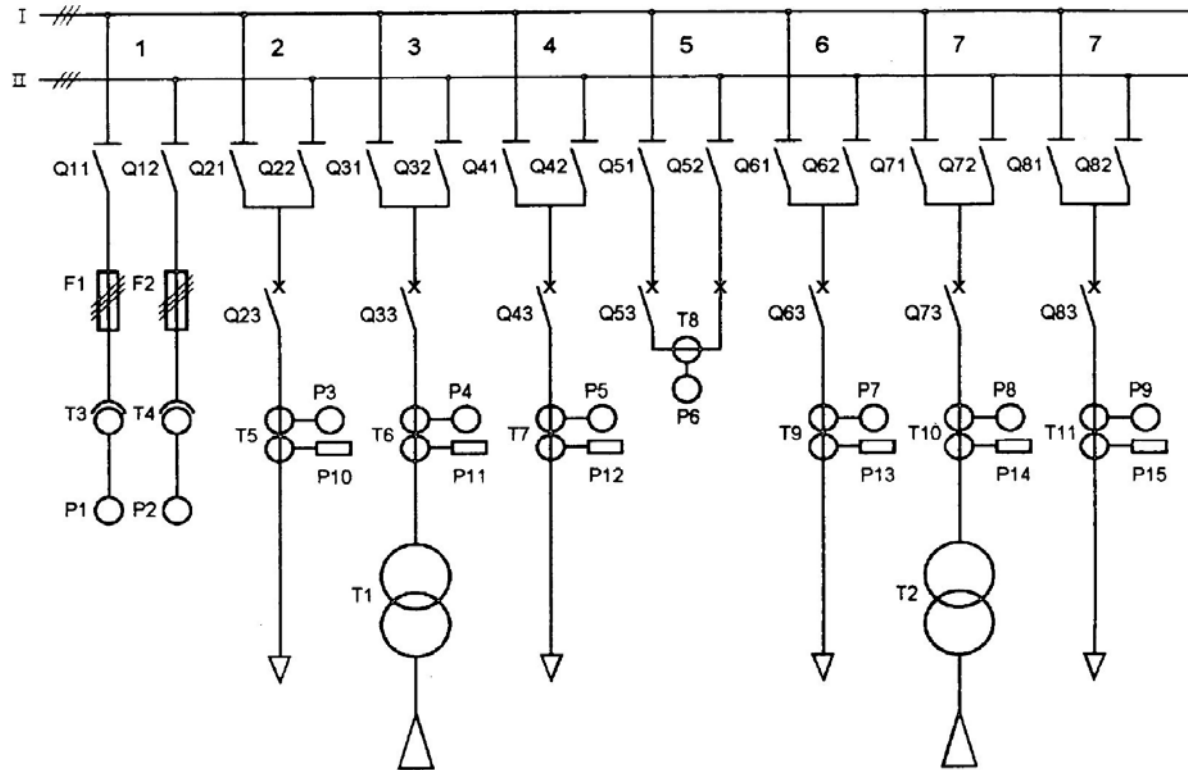


Figure 1:

Switchgear facility with double busbar (I and II) for three-phase current (single-phase representation)

- Field 1: Measurement field with high-power fuses (F1, F2), voltage transformers (T3, T4) and voltmeters (P1, P2).
- Fields 2, 4, 6 and 8: Outgoing feeders for consumers.
- Fields 3 and 7: Incoming feeders with transformers T1 and T2.
- Field 5: Coupler.
- T5 to T11: Current transformers with 2 cores for measurement and protection.
- P3 to P9: Ammeters.
- P10 to P15: Protective devices.
- Qn1 and Qn2: Isolators.
- Qn3: Circuit breakers.

Figure 1 comprises a single-pole block diagram of a facility with 2 incoming feeders, 1 measurement field for both busbars, and 1 coupling field. Other important components here include the isolators, circuit breakers, high-power fuses, voltage and current transformers, voltmeters and ammeters, as well as protective equipment and controllers. The switching devices can be actuated by hand, a motor, or compressed air. In the case of large switchgear facilities like the one illustrated, control should be possible locally or from a control room (again, either manually or via programmable controllers).

If in Figure 1, for example, the previously inactive consumer 2 is *switched on*, the sequence described next must be observed when busbar I is selected.

- **Isolator Q21 ON; isolator Q22 remains OFF.**
- **Circuit breaker Q23 ON.**

If this outgoing feeder is to be *switched off* again, the sequence described next must always be observed.

- **Circuit breaker Q23 OFF.**
- **Isolator Q21 OFF.**

The other fields are switched in a similar manner. Only the circuit breakers can be used to connect / disconnect the power or short-circuit currents. The isolators must always be actuated in the de-energized state. **Busbar change** is always a special switching process. If in Figure 1, for example, incoming feeders 3 and 7 as well as outgoing feeders 2, 4, 6 and 8 need to be switched without interruption from busbar I to busbar II so as to free busbar I, the coupling switch from field 5 must be included. The switching sequence in Figure 1 is then as follows:

1. Isolator Q51 ON, isolator Q52 ON, circuit breaker Q53 ON. Both busbars' voltages are then identical in terms of value, phase angle and frequency.
 2. Isolator Q22 ON, isolator Q21 OFF
 3. Isolator Q32 ON, isolator Q31 OFF
 4. Isolator Q42 ON, isolator Q41 OFF
 5. Isolator Q62 ON, isolator Q61 OFF
 6. Isolator Q72 ON, isolator Q71 OFF
 7. Isolator Q82 ON, isolator Q81 OFF
 8. Circuit breaker Q53 OFF, isolators Q51 and Q52 OFF.
-

This disconnects and de-energizes busbar I. This laboratory model is intended to perform the above-mentioned switching procedures employed in reality, besides learning how to avoid incorrect switching operations and compare previous power distributions with new ones as well as the intermediate states. The sequence of partial diagrams a) to c) in Figure 2 below provides a basic representation of an initial state a), intermediate state b) and final state c). The coupling field is energized only during switchover if the coupling switch is on.

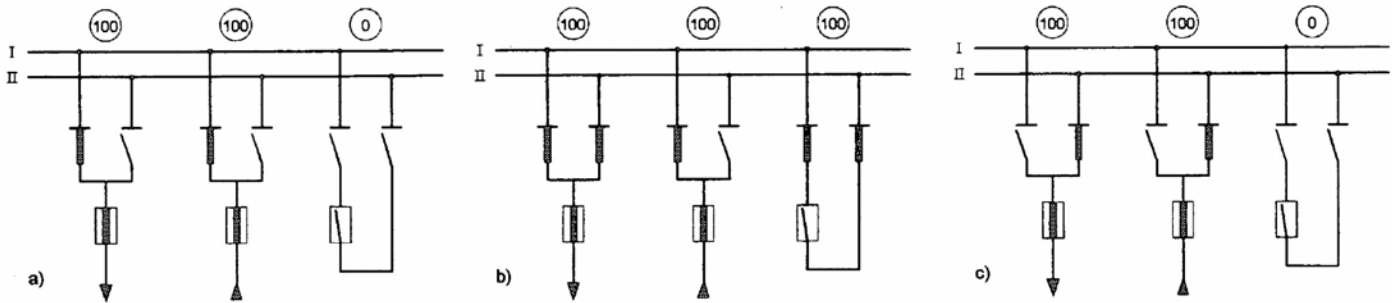


Figure 2:

Switching states before (a), during (b) and after (c) busbar change with power indication

In an absence of mechanical, electrical and program-controlled interlocks, a switchover action's success or failure depends on the operator (switching foreman, technician, engineer). Incorrect operation of isolators can result in electric arcs which cause significant damage and a failure of the power supply in the affected area. For this reason, basic skills in handling switching devices forming part of switchgear are crucial, and protection of switchgear against switching errors has a very high priority. Taking these requirements into account too, the training model presented here can be controlled by a PLC (programmable logic controller).

Assembly Instructions

To study the relationships applicable to switchgear, we will set up the training workplace shown in Figure 1 (Figure 9 of section switching stations and substations) and basically perform the switching operations described in the section related to the basic circuitry of a double busbar model.

To fully utilize a double busbar system's faculties, it would be practical to supply each busbar from a separate voltage source. However, this would require installation of a synchronization mechanism upstream. The circuit in this experiment is fed by a single power source.

To achieve different loads for the individual busbars and produce a compensation current via the coupler panel, one busbar can be tapped before the line model, the other busbar after the line model.

In practice, this situation arises when a substation is fed both by a remote and a nearby power plant.

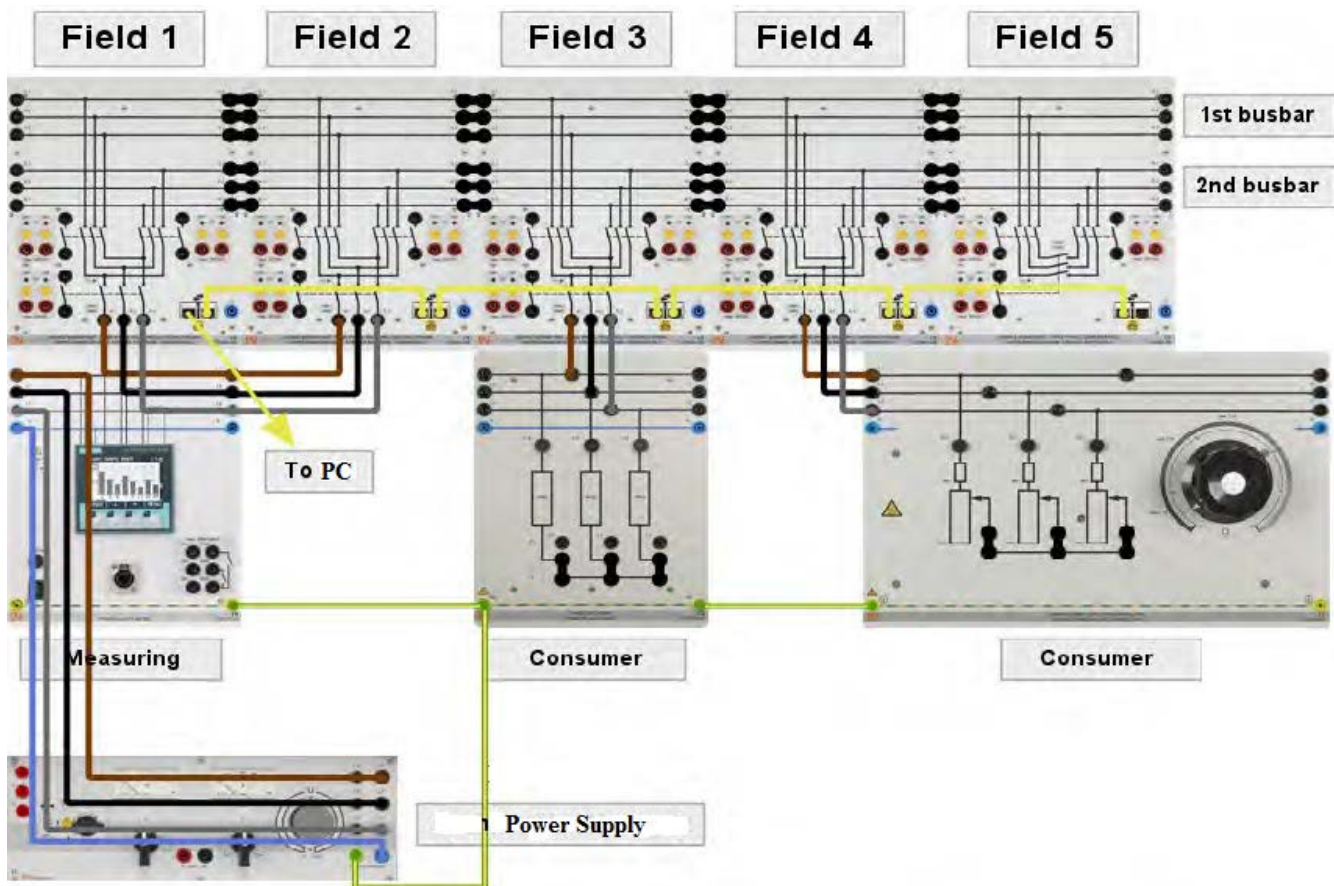


Figure 1:
Basic layout of the training workplace

Fields one to four comprise outgoing feeders (CO3301-5R), field 5 comprises a coupler panel (CO3301-5S) for coupling both busbars. A variable three-phase transformer is used for incoming feed through fields 1 and 2; a fix resistive load is employed in the case of field 3; a variable resistive load is used for field 4; and field 5 does for coupling both busbars.

The following setting only applies to experiments with the double busbar system:

1. Switching devices are generally positioned in the OFF state.
2. Connect the fixed resistive load (CO3301-3H) star configuration.
3. Set the variable resistive load (CO3301-3F) to 200 Ω and connect it in star configuration.
4. Set up the circuit of Figure 2 and determine the expected current at 220V and 200 Ω using equation 1. Record this value.
5. Turn on the three-phase AC voltage supply and adjust to a line-to-line voltage of 220 V_{LL}.
6. With the help of the multi-function meter (CO5127-1S or CO5127-1Y) adjust the three phase current near of the calculated current of step by means off the variable resistive load (CO3301-3F). Record this value.
7. Turn off the three-phase AC voltage supply and connect circuit of Figure 1.

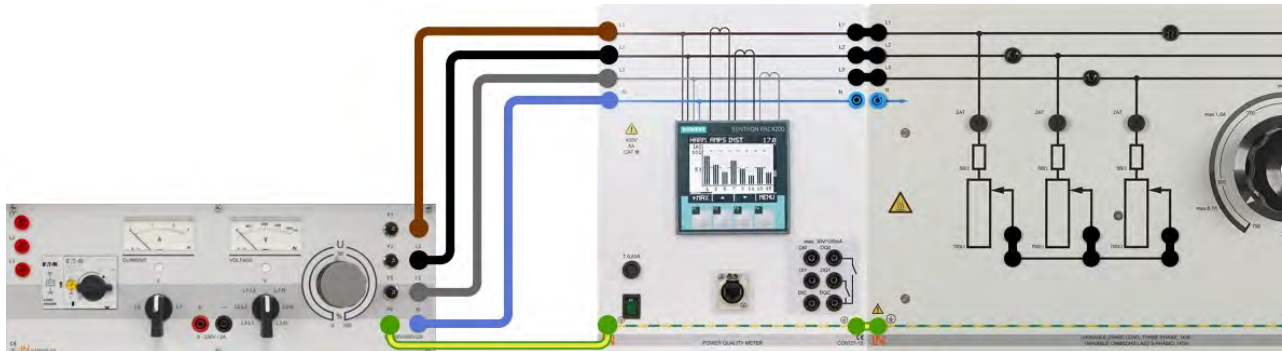


Figure 2:

Layout for current adjustment

$$I = \frac{220 V}{\sqrt{3} * 200 \Omega} \quad \text{Equation 1: Three Phase Current}$$

The currents and their distribution change depending on the load and transition resistances. In the case of our double busbar model, the relationships involving load currents and transition resistances are less favourable than those of a real double busbar facility; as a result, the currents may not be distributed as expected.

All isolators and circuit breakers of the double busbars should be open at the beginning of each experiment.

Controlling double busbars via SCADA

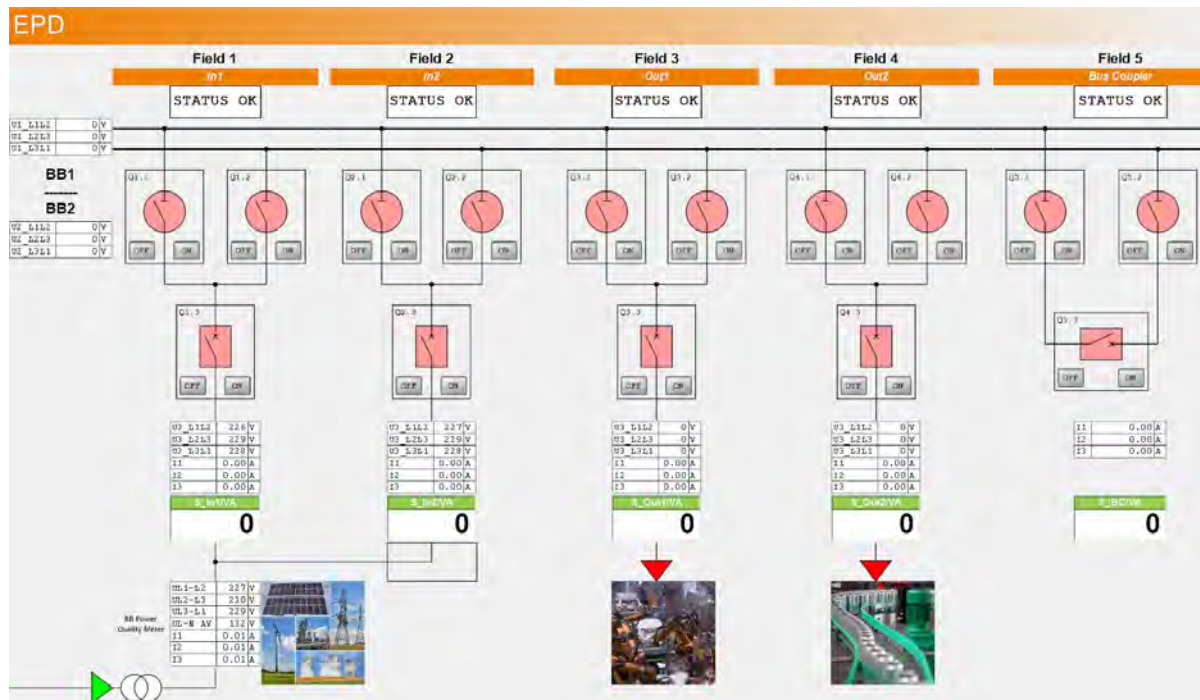



Figure 1:

Control of double busbars via SCADA

In addition to manual control, it is possible to control the double busbars with the help of Lucas-Nülle's SCADA software Viewer (SO4001-3 H).

Apart from pushbutton control via the front panel and manual software control, the busbars can be controlled automatically via the internal "soft" PLC of the SCADA software.

*After starting the SCADA software and opening the file named **EPD.pvc** you need to **initialize** an Ethernet configuration for the double busbars; a detailed description of this is provided in the chapter on connection via Ethernet. Also requiring initialization is the IP address of the employed measuring device.*

Proceed by connecting your SCADA software via  to the hardware. If something is wrong with the Ethernet connection to the busbars or the multi-function meter CO5127-1S, an error message is issued at this point. The causes of any error messages must be resolved before SCADA can be connected. Once all devices have been properly configured, the system is online and you can read operating values and perform switching operations.

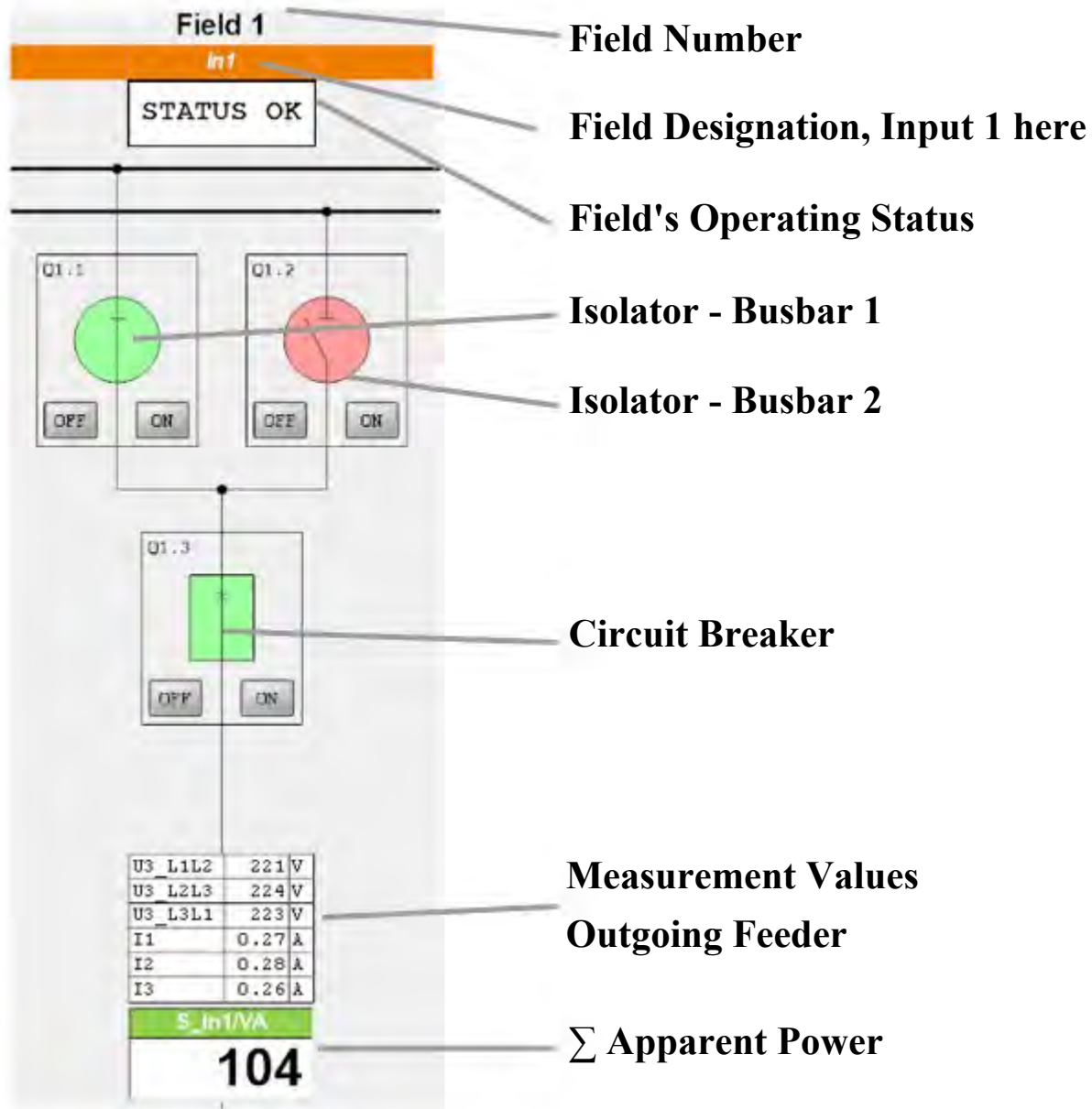


Figure 2:
Details of double busbar control via SCADA

Figure 2 shows the control panel of a busbar outgoing feeder CO3301-5R.

- The field's operating status is indicated under the field designation; if the SCADAViewer is connected, you can request further information on the operating status with a left-click:

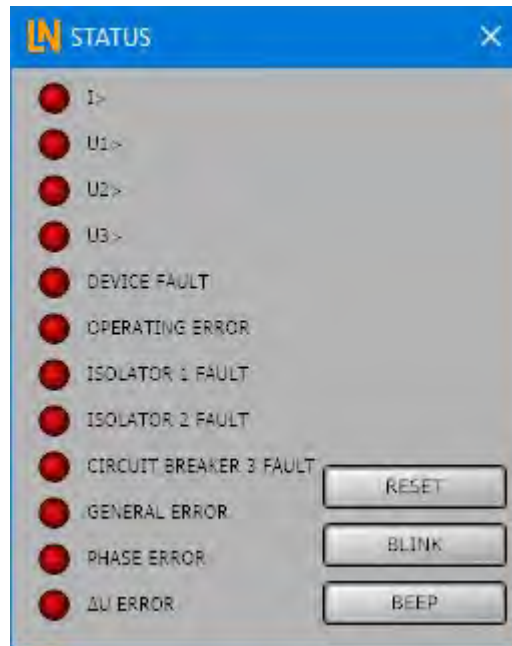


Figure 3:
Information on a busbar field's status

1. After resolved a busbar error, you can reset it here by means of the reset BUTTON.
 2. The BLINK and BEEP buttons function respectively for optical and acoustic signaling of the hardware currently being addressed.
- The OFF and ON buttons can be used to switch isolators Qx.1 and Qx.2 as well as circuit breaker Qx.3, where "x" represents the field number.
 - The button in the Viewer symbolizes the state of the corresponding switch via colours in the circuit diagram.
 - Indicated below that are the field's line-to-line voltages, line currents and apparent powers.
 1. The apparent powers are calculated approximately from the line currents and the line-to-line voltages via the PLC.

Coupler panel CO3301-5S behaves like the outgoing feeder field, except that there is no outgoing feed voltage V3 in this case.

Unless stated otherwise, line voltages and currents are involved here. Busbar systems often distribute only the outer conductors, while the neutral and protective conductors are formed locally, for example, via a transformer star point. In practice, busbar voltage specifications therefore usually refer to the outer conductors.

Experiments

In the next experiments, you will perform switching operations for each individual field following the switching commands provided in each case or step. After every switching operation, the switch position is verified and the corresponding measured values of field's line-to-line voltages (V_{LL}), line currents (I_{LL}) and apparent powers (ΣVA) are recorded in the indicated table.

All isolators and circuit breakers of the double busbars should be open at the beginning of each experiment. (Standby Position - All Off).

1. Single Busbar Operation with One Incoming Feeder

Procedure

Follow following steps and record the measured values in Table 1. All other fields must remain in the standby position otherwise indicated. Turn on the AC power supply to 220 V_{LL} .

➤ Switch ON (for example, switch on a load or consumer).

1. Field 1 (Incoming feeder 1): 1. Isolator Q1.1: **ON**
2. Circuit breaker Q1.3: **ON**
2. Field 3 (Outgoing feeder 1): 1. Isolator Q3.1: **ON**
2. Circuit breaker Q3.3: **ON**
3. Field 4 (Outgoing feeder 2): 1. Isolator Q4.1: **ON**
2. Circuit breaker Q4.3: **ON**

➤ Switch OFF (for example, switch off a load or consumer).

4. Field 3 (Outgoing feeder 1): 1. Circuit breaker Q3.3: **OFF**
2. Isolator Q3.1: **OFF**

	Busbar 1	Busbar2	Infeed 1			Infeed 2			Outfeed 1			Outfeed 2			Bus Coupler		
Steps	V	V	V	I	ΣVA	V	I	ΣVA	V	I	ΣVA	V	I	ΣVA		I	
1																	
2																	
3																	
4																	

Table 1:

Single Busbar Operation with One Incoming Feeder

All isolators and circuit breakers of the double busbars should be open at the beginning of each experiment. (Standby Position - All Off).

2. Single Busbar Operation with Two Incoming Feeder

Procedure

Follow following steps and record the measured values in Table 2. All other fields must remain in the standby position otherwise indicated.

➤ Switch ON (for example, connecting two different loads fed by two voltage sources).

1. Field 1 (Incoming feeder1): 1. Isolator Q1.1: ON
2. Circuit breaker Q1.3: ON
2. Field 3 (Outgoing feeder 1): 1. Isolator Q3.1: ON
2. Circuit breaker Q3.3: ON
3. Field 4 (Outgoing feeder 2): 1. Isolator Q4.1: ON
2. Circuit breaker Q4.3: ON
4. Field 2 (Incoming feeder2): 1. Isolator Q2.1: ON
2. Circuit breaker Q2.3: ON

➤ Switch OFF (for example, disconnecting two different loads fed by several voltage sources).

5. Field 3 (Outgoing feeder 1): 1. Circuit breaker Q3.3: OFF
2. Isolator Q3.1: OFF
6. Field 4 (Outgoing feeder 2): 1. Circuit breaker Q4.3: OFF
2. Isolator Q4.1: OFF

	Busbar 1	Busbar2	Infeed 1			Infeed 2			Outfeed 1			Outfeed 2			Bus Coupler		
Steps	V	V	V	I	ΣVA	V	I	ΣVA	V	I	ΣVA	V	I	ΣVA		I	
1																	
2																	
3																	
4																	
5																	
6																	

Table 2:

Single Busbar Operation with Two Incoming Feeders

All isolators and circuit breakers of the double busbars should be open at the beginning of each experiment. (Standby Position - All Off).

3. Double Busbar operation with two incoming feeders

Procedure

Follow following steps and record the measured values in Table 3. All other fields must remain in the standby position otherwise indicated.

- **Switch ON (for example, connecting several loads supplied by two voltage sources; in this process, the load current is distributed among several busbars).**

1. Field 1 (Incoming feeder1): 1. Isolator Q1.1: **ON**
2. Circuit breaker Q1.3: **ON**
2. Field 3 (Outgoing feeder 1): 1. Isolator Q3.1: **ON**
2. Circuit breaker Q3.3: **ON**
3. Field 2 (Incoming feeder2): 1. Isolator Q2.2: **ON**
2. Circuit breaker Q2.3: **ON**
4. Field 4 (Outgoing feeder 2): 1. Isolator Q4.2: **ON**
2. Circuit breaker Q4.3: **ON**
5. Field 5: Coupler panel: 1. Isolator Q5.1: **ON**
2. Isolator Q5.2: **ON**
3. Circuit breaker Q5.3: **ON**

- **Switch OFF (for example, disconnecting several loads whose currents were previously distributed among two busbars).**

6. Field 3 (Outgoing feeder 1): 1. Circuit breaker Q3.3: **OFF**
2. Isolator Q3.1: **OFF**
7. Field 4 (Outgoing feeder 2): 1. Circuit breaker Q4.3: **OFF**
2. Isolator Q4.2: **OFF**

	Busbar 1		Busbar2		Infeed 1			Infeed 2			Outfeed 1			Outfeed 2			Bus Coupler	
Steps	V		V		V	I	ΣVA	V	I	ΣVA	V	I	ΣVA	V	I	ΣVA	I	
1																		
2																		
3																		
4																		
5																		
6																		
7																		

Table 3:

All isolators and circuit breakers of the double busbars should be open at the beginning of each experiment. (Standby Position - All Off).

4. Busbar change without interruption

Procedure

Follow following steps and record the measured values in Table 2. All other fields must remain in the standby position otherwise indicated.

- **Busbar change without interruption: Switchover** (for example, switchover of several loads or consumers to a different busbar without interruption for the purpose of performing maintenance in the de-energized state without disrupting ongoing operations).

1. Field 1 (Incoming feeder1):
 1. Isolator Q1.1: ON
 2. Circuit breaker Q1.3: ON
- Field 2 (Incoming feeder 2):
 1. Isolator Q2.1: ON
 2. Circuit breaker Q2.3: ON
- Field 3 (Outgoing feeder 1):
 1. Isolator Q3.1: ON
 2. Circuit breaker Q3.3: ON
- Field 4 (Outgoing feeder2):
 1. Isolator Q4.1: ON
 2. Circuit breaker Q4.3: ON
- Field 5: Coupler panel:
 1. Isolator Q5.1: ON
 2. Isolator Q5.2: ON
 3. Circuit breaker Q5.3: ON
2. Field 1 (Incoming feeder 1):
 1. Isolator Q1.2: ON
 2. Isolator Q1.1: OFF
3. Field 2 (Incoming feeder 2):
 1. Isolator Q2.2: ON
 2. Isolator Q2.1: OFF
4. Field 3 (Outgoing feeder 1):
 1. Isolator Q3.2: ON
 2. Isolator Q3.1: OFF
5. Field 4 (Outgoing feeder 2):
 1. Isolator Q4.2: ON
 2. Isolator Q4.1: OFF

Turn off the three-phase AC voltage supply.

	Busbar 1	Busbar2	Infeed 1			Infeed 2			Outfeed 1			Outfeed 2			Bus Coupler		
Steps	V	V	V	I	ΣVA	V	I	ΣVA	V	I	ΣVA	V	I	ΣVA		I	
1																	
2																	
3																	
4																	
5																	

Table 4:
Busbar Change without Interruption

A change of busbar without interruption is generally slower because it involves more switching operations than a change of busbar with interruption. For many applications, however, this time factor is irrelevant due to the higher priority of continuous availability.

Report Questions

1. Name the four main properties of isolators.
2. Which line-to-line voltages are present on the busbars (I & II) in the switch on position of a single busbar operation with two incoming feeders?
3. Draw a diagram showing the present switching status of a double busbar operation with two incoming feeders in the switch on position.
4. How is the cumulative load distributed among the two incoming feed transformers of a double busbar operation with two incoming feeders in the switch on position?
5. What are the three main features of a *interruption-free* busbar switching operation?

References

Pierre Wasser, Jörg Ludwig, *Investigating Busbar Systems*, Lucas-Nülle GmbH, 2016.