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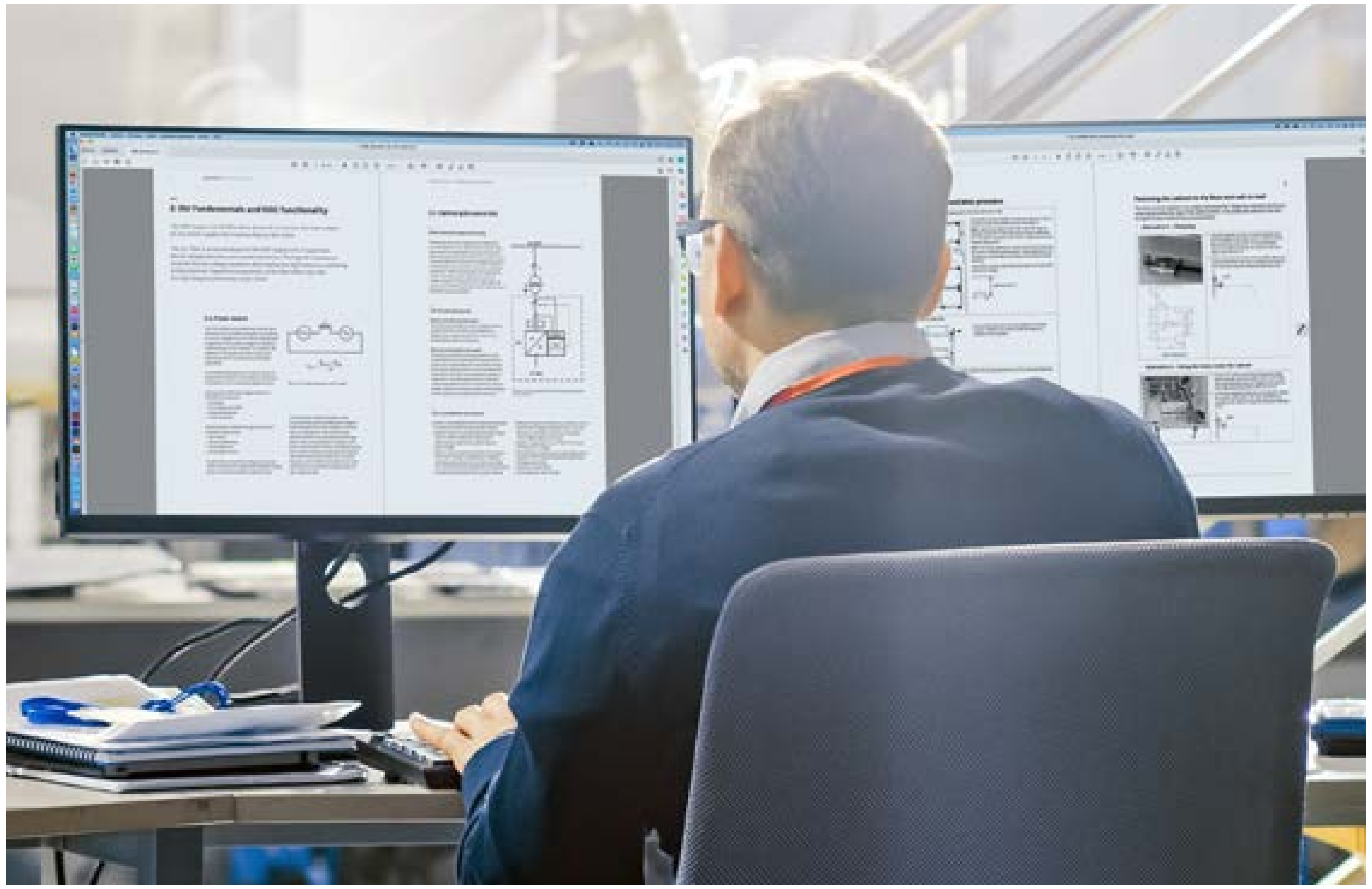
ABB DRIVES

Hybrid vessel – Optimal grid control
Application guide



- The purpose of this document is to give sufficient information about Optimal Grid Control functionality features, operation and dimensioning for the configuration and design of converter systems
- This guide is primarily intended for engineers in sales, sourcing and electrical system designing

This guide focuses on the Optimal Grid Control functionality, its offering and features.

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1. Introduction

1.1. Purpose of the document

The purpose of this document is to give sufficient information about Optimal Grid Control functionality features, operation and dimensioning for the configuration and design of converter systems. This guide is primarily intended for engineers in sales, sourcing and electrical system designing. Detailed information on parameters and connection is available in product manuals and order related drawings.

This guide focuses on the Optimal Grid Control functionality, its offering and features.
Since OGC is a control mode of ISU, a short introduction of ISU is included.

Definitions:

- IGBT Supply Unit (ISU) is a four-quadrant active front-end converter designed to supply energy from three-phase grid to converter DC-circuit.
- LCL filter is an AC-filter in input of ISU.
- ACS880 Optimal Grid Control is a control mode of the IGBT supply unit. It is also known as AC-control mode.
- Auxiliary Measurement Unit (BAMU) is an adapter for the connection of current transformers and grid voltage measurements to the IGBT supply unit.
- Main Circuit breaker is a circuit breaker dedicated to a converter connected to the grid.
- ISU voltage in this guide means the voltage between semiconductors and the LCL-filter.
- U1 synchronization is a method to synchronize the OGC controlled ISU converter to the grid. It always uses the U1 measurement channel of the BAMU.
- U2 synchronization is a method to synchronize the OGC controlled ISU-supplied grid with external loads to another grid. It always uses the U2 measurement channel of the BAMU.
- Voltage reserve is the difference between maximum ISU voltage and actual output of the converter.
- System Drives or ABB System Drives is a business unit for drive manufacturing in ABB.
- A multidrive is a module based engineered drive solution with a common DC-bus arrangement where one or several power electronic consumers are connected.
- A multidrive has single power supply and a DC-bus arrangement where one or several inverters are connected to control the motors.

1.2. Abbreviations

Table 1. List of abbreviation	
ACS880	ABB Low voltage frequency converter
BAMU	Auxiliary Measurement Unit
CT	Current transformer
ISU	IGBT Supply Unit
LCL	LCL filter
MCB	Main Circuit breaker of drive
SCB	Circuit breaker in switch gear
OGC	ACS880 Optimal Grid Control functionality of the ISU
U1	Voltage measurement channel 1 in BAMU
U2	Voltage measurement channel 2 in BAMU
VT	Voltage transformer
PMS	Power management system

1.3. Related documents

General manuals	Code (English)
ACS880 multidrive cabinets and modules safety instructions	3AUA0000102301
Electrical planning instructions for ACS880 multidrive cabinets and modules	3AUA0000102324
Mechanical installation instructions for ACS880 multidrive cabinets	3AUA0000101764
Cabinet design and construction instructions for ACS880 air-cooled and liquid-cooled multidrive modules	3AUA0000107668
Optimal grid control of ACS880 IGBT supply control program Supplement	3AXD50000164745 *)
ACS880 grid converter, Optimal grid control (option +N8053) supplement	3AXD50000220717
BAMU-12C auxiliary measurement unit hardware manual	3AXD50000117840
External LCL filter dimensioning instruction	3AXD10000642629 *)
ACS880 IGBT supply control program firmware manual	3AUA0000131562

*) You can find manuals on the Internet. See www.abb.com/drives/documents.
For manuals not available in the document library, contact your local ABB representative.

1.4. Limitation of liability

The designer of the system takes the responsibility of the functionality and the safety of the design. The design and installation must always be made according to applicable local laws and regulations as well as according to good engineering practices. ABB does not assume any liability whatsoever for any system design or installation which breaches the local laws and/or other regulations. Furthermore, if the recommendations given by ABB are not followed and/or ABB equipment are used against their intended purposes, the equipment may malfunction and/or experience problems that the warranty does not cover. Full consistency between an application document and associated equipment level documents cannot be guaranteed. In case of conflicting or missing information contact ABB.

2. ISU Fundamentals and OGC functionality

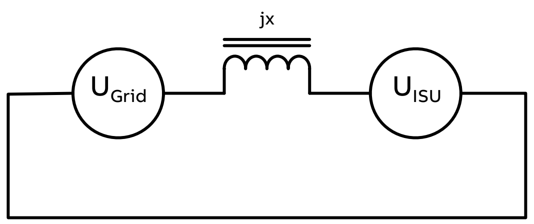
The IGBT supply unit rectifies three-phase AC current for the intermediate DC link which supplies the inverters that run the motor.

The LCL filter is an essential part of the IGBT supply unit. It suppresses the AC voltage distortion and current harmonics. The high AC inductance smooths the line voltage waveform distorted by the high frequency switching of the converter. Capacitive components of the filter effectively filter the high frequency harmonics (over 1 kHz).

2.1. Power control

The ISU transfers power between the AC-grid and the DC-circuit of the converter by creating a counter voltage and controlling its phase and magnitude. The counter voltage is created by making pulses of DC-voltage. To maintain the stability of the grid both active power and reactive power must always be controlled separately.

A simplified illustration of current creation is presented in Figure 1. The power for control is calculated from current and voltage vectors.



$$\bar{I}_{Grid} = \frac{\bar{U}_{Grid} - \bar{U}_{ISU}}{jx}$$

Figure 1. ISU voltage, impedance jx and Grid voltage.

Active power reference is given by one of the following sources:
- P/f droop
- DC-voltage controller
- External reference
- Fixed reference

Reactive power reference is given by one of the following sources:
- Q/U droop
- External reference
- Fixed reference
- AC voltage control

To define the correct ISU voltage and current vectors (phase and magnitude), the grid voltage vector as well as impedance between grid and ISU power module must be known. In most of the control modes grid voltage is back calculated from ISU voltages, currents and LCL impedance. The control is also synchronized to the estimated grid voltage phase. The synchronization imposes some basic requirements in terms of voltage quality. ISU control methods are designed to satisfy the needs of a power supply for a variable frequency drive (VFD) controlled motor and thus requires a sufficient voltage quality in the supplying grid.

2.2. Optimal grid control OGC

Power electronic supply unit shortly

The power electronic supply unit is defined in grid standards. It is a static device, whose main purpose is to supply electric power to the grid. The standards have defined several requirements for these devices to ensure the reliable operation of the grid in every possible operation and fault situations. These requirements are called grid codes. Typically, large installations such as windmill parks for example, are inspected and approved as fulfilling the grid code requirements by local power companies.

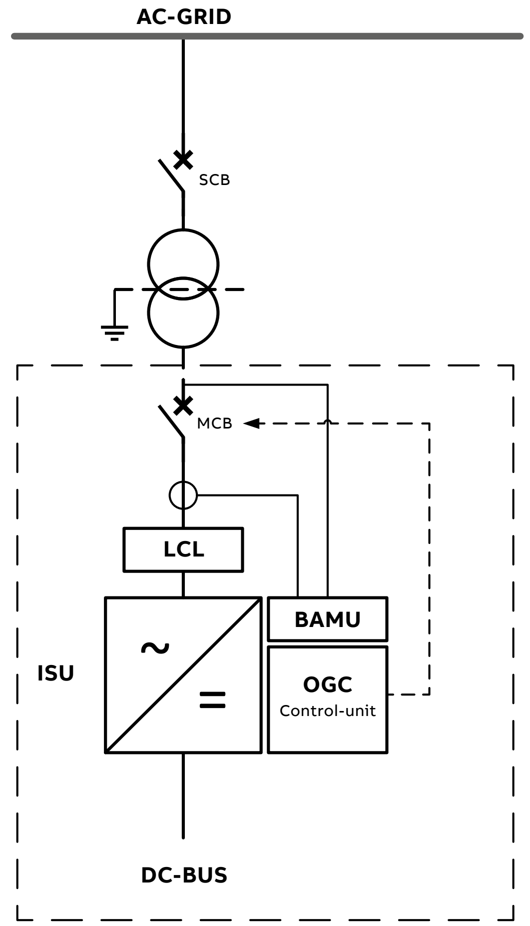


Figure 2. OGC controlled ISU. The scope of supply is represented by the dashed line.

OGC functionality shortly

What is the OGC functionality?
The OGC functionality is an AC-voltage control mode of the ISU. An OGC controlled ISU is designed to supply power from a DC-circuit to the grid as shown in Figure 2.

Where is it intended to be used?
The OGC controlled ISU is intended for small, isolated grids (ex: ships) and strong industrial grids. Even though the OGC controlled ISU has some grid code functions, it is not designed to fulfill them. The OGC functionality is a feature collection in standardized product software. Unless acquired as part of a multidrive cabinet design it does not include project related design or simulation work at the time of purchase.

OGC controlled ISU main features

An OGC controlled ISU has the following features:
- Droop control (P/f droop and Q/U droop)
- Ability to start to voltage-free grid (aka"black start"), unlike traditional supply units, which always need to be synchronized to grid voltage.
- Short-circuit current contribution for a preset time even if the grid-voltage has collapsed. Unlike a conventional ISU, an OGC controlled ISU can both synchronize the ISU to the grid and operate in shorted grid without grid voltage.
- Ability to supply controlled asymmetric current (positive and negative sequence but not zero sequence), and distorted (non-sinusoidal) current depending on the load.
- Inbuilt compensators for 3rd 5th 7th 11th and 13th harmonic voltage.
- Two different inbuilt synchronizing algorithms.
- Supports both island and parallel operations.
- Voltage supervision
- Frequency supervision
- DC-voltage dip ride through

Drive transformer

Arguments supporting the use of a drive transformer:

1. The first and most common argument to purchase a transformer is to adapt different voltage levels together.

2. The creation of neutral point to ISU supplied grid requires a drive transformer, where on the grid side a winding connection with neutral point is used. These connections are Y-connection, Z-connection, and extended Z-connection. On the drive side a D-connection is typically used.

3. A transformer boosts the drive's ability to compensate reactive power. Reactive power causes a significant voltage drop in the LCL-filter. If a voltage drop is too high, the ability to supply reactive power is lost as well as the capacity to compensate for asymmetric loads or harmonics. When the capacity to supply reactive power is required it typically leads to the need for a transformer with reduced rated voltage on the drive side. A power factor of 0.8 typically leads to about 7.5% voltage drop.

More information available in chapter 5.

4. A drive transformer cuts the current path of common mode currents. The common mode voltages cannot create flux and thus pass the transformer, because they are of the same magnitude, frequency, and phase in every phase winding. The use of a drive transformer is the most powerful way to eliminate common mode currents.

Also, some consequences need to be considered when drive transformers are added to the system:

1. Pulse width modulation (PWM) frequency converters create high frequency harmonic voltage disturbances. Drive transformers must be equipped with earthed screens between their primary and secondary windings in order to mitigate pollution caused by these harmonics.

2. Transformers draw high starting current at connection to grid. This current transient is called inrush current. Inrush current peaks can be up to twenty times the rated current of the transformer and last around one hundred milliseconds. In weak grids this transient can cause a voltage drop, which leads to blackout.

   To avoid the problem in weak networks, the transformer must be pre-magnetized before connection. This can be done by using dedicated a pre-magnetization circuit or by pre-magnetizing it using the OGC functionality.

3. Reactive power causes a significant voltage loss also in transformer winding. This should be taken into consideration when selecting transformers' rated voltages.

4. According to IEC transformer standards, a transformer's primary side is defined as the higher voltage side of the transformer. Thus, depending on the case, the primary of the transformer can be on the drive or the grid side.

3. Properties of the OGC functionality

3.1. Stand-alone and parallel operation

An OGC controlled ISU creates a 3-phase network. The OGC controlled ISU can operate as a stand-alone or connected in parallel with other independent power supplies using droop-control.

3.2. Current and voltage measurements

Measuring transformers

The use of the OGC functionality in ISU requires the grid voltage measurements and current measurement signals. Those are necessary for:
- Droop control
- Operation during short-circuit or in grid, whose short-circuit current is low.
- Synchronization
- Harmonic compensation

Current transformers (CT), with an accuracy class 1% or better must be used for current measurements. Note, that as presented in Figure 2, the CTs must be placed next to LCL on the grid side to eliminate errors caused by the parallel current path through the LCL capacitors.

Voltage transformers (VT) are not usually needed, but the measured voltage can be connected straight to BAMU terminals. However, the VTs must be used if the peak value of the voltage exceeds 1000 V. Voltage can be measured from several different places in the supplying grid, depending on the design. This is handled later in this document with synchronization.

When voltage measurement is on the grid side of the drive transformer, the measured voltage may have the wrong direction, if the transformer vector group is not taken in consideration.
An OGC controlled ISU supports all the common transformer vector groups.

Auxiliary measurement unit BAMU-12

The use of an OGC controlled ISU requires voltage and current measurements. The BAMU unit converts electrical signals to optical ones that can be used by the ISU. BAMU-12 includes two 690V RMS three-phase channels for voltage measurements, and one three-phase current measurement channel for CTs with a 1 A secondary circuit.

For more information see BAMU-12 hardware manual document nr. 3AXD50000117840.

3.3. Start-up

In-built charging or external charging

External charging is necessary when charging energy cannot be supplied through the ISU (ex: starting to a voltage-free grid). Charging is described in more detail in paragraph 4.3.

Start-up and synchronization

The voltages of ISU and grid must be synchronized before connecting a running ISU to a live grid. Synchronization methods and prerequisites are described in paragraph 4.3.

3.4. AC-control mode aka OGC

—
License key

Activation of AC-control mode requires a multidrive license key nr N8053.

—
Control of active and reactive power

OGC aka AC-control mode is a control mode with droop controllers for active and reactive power. This method allows several independent power supplies to run in parallel. In parallel operation the load-share between power supplies can be adjusted by controlling droop offset.

—
External DC-control needed

When active power is controlled by AC-droop-control, it follows grids power demands, neglecting the needs of DC-bus. To enable proper functioning of the converter DC-voltage must be controlled. Thus, the DC-bus voltage must be controlled by an external device. This external device may be for example another ISU, DC-DC chopper, or a battery source.

—
Grid supporting functions

An OGC controlled ISU has the following grid supporting functions:

- Short-circuit current contribution. OGC can support short-circuit a preset time to help to ensure the correct functioning of the grid protection.
- Unbalanced current compensation can be used to improve voltage quality in asymmetrically loaded grids.
- Harmonic compensation for 3rd, 5th, 7th, 11th and 13th harmonic components

These functions are discussed in more detailed in chapter 4.3.

3.5. Other ISU control modes

Other ISU control modes are DC-control mode and Power control mode. In these modes the OGC features are disabled. The user interface enables the user to transition between online modes.

Transition is discussed later in chapter 4.4.

Technically the ISU works for both power directions in the same way and the technical limitations are similar for both directions. However, it is designed to satisfy the needs of a four-quadrant motor converter, not to be used as a “power electronic supply unit” as defined in grid standards. Due to this approach, there are no inbuilt grid supporting features in these modes. The only exception is the ability to supply the requested amount of reactive power to existing grid.

In DC-control and Power control modes the ISU requires an existing grid voltage where the controller synchronizes the counter voltage pulses. The quality requirements of supply voltage are defined in the ISU FW manual 3AUA0000131562.

—
Power control mode

In power control mode ISU power follows active and reactive power references, which can be assigned freely via user interface. In this case an external device is needed to generate DC as in AC control mode.

—
DC-control mode

In DC-control mode the DC-voltage controller sets the ISU power to the value which keeps DC-voltage level constant. Active power direction can vary depending on the case from AC to DC and vice versa.

DC-voltage control only affects active power (there is no reactive power in DC-circuits), the control of reactive power is taken care of by a reactive power controller. The default reference for this controller is set to zero. However, the reference can be routed to an external reference or set to a non-zero constant value. Instructions can be found in ISU FW manual 3AUA0000131562.

3.6. Offering and scope of supply

—
Offering

The OGC functionality can be used both in liquid-cooled and air-cooled converters. Its availability is however limited to multidrive and module offerings. To activate the OGC functionality a multidrive license key is required. In addition, the hardware arrangement for the OGC controlled ISU requires fiberoptic communication, thus it is only available in module sizes which use BCU control boards.

—
Scope of supply in multidrive

A complete OGC controlled ISU consists of the following components:

- LCL, network filter
- ISU, IGBT Supply unit options:
  - +N8053: Optimal grid control MU license
  - +C186: Optimal grid control hardware, current and voltage measurement with BAMU (including current transformers) MCB
- Current measurement
- Voltage measurement

Note:
In multidrives all these are included at delivery. CTs are inbuilt in the supply cabinets. Voltage transformers are not always needed and not included in the System Drives scope of delivery. The activation of the OGC functionality requires a license key, which is an option for multidrives and is available in module offerings.

4. Operation and start-up of OGC controlled ISU

4.1. Droop control

—

P/f droop

Droop control is a control mode, which sets the output frequency of the converter to a value defined by output power and droop curve.

Figure 3 illustrates an example of P/f-droop control. The load curve describes the need for converter power as a function of frequency. Respectively droop curve defines output frequency of the converter as a function of measured output power. Power control of the converter increases or decreases (depending on the approaching direction) the output power of the converter until the output frequency f_1 corresponds with the measured output power P_1. In a steady state the output frequency is defined by the intersection of droop curve and load curve.

The load curve is related to the connection state of the grid. It changes when other loads or suppliers are connected or disconnected to the grid.

A necessary condition for P/f droop control is a positive frequency dependence of output power. This is generally fulfilled because of the behavior of typical loads, which have increasing or constant torque curves and thus an increasing power curve. The exception is a pure resistor load, which has no frequency dependence and thus cannot be controlled with droop controller.

This method allows several independent power supplies to run parallel, which is the major reason for its widespread use in power generation.

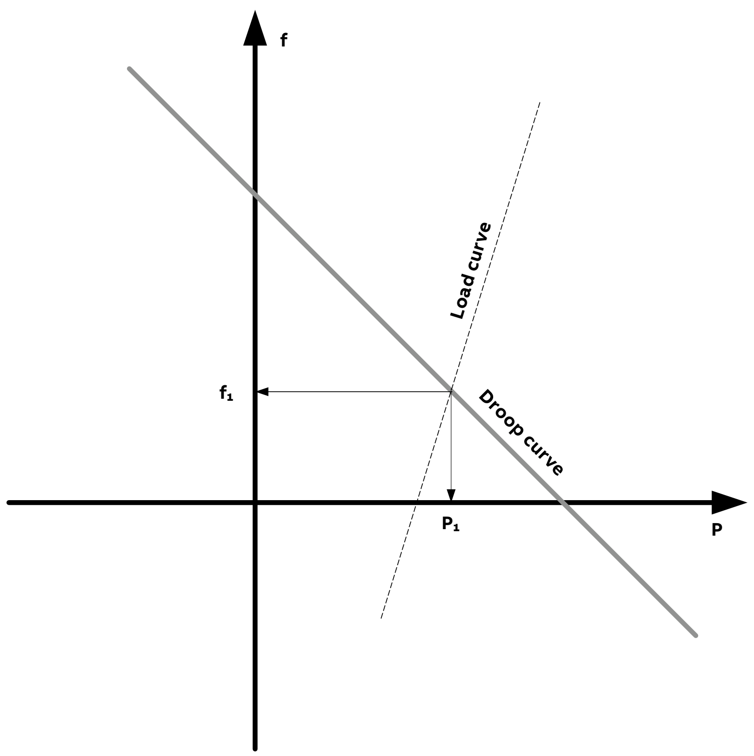


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Figure 3. An example of P/f droop. Working point (P_1, f_1) is in the intersection of curves.

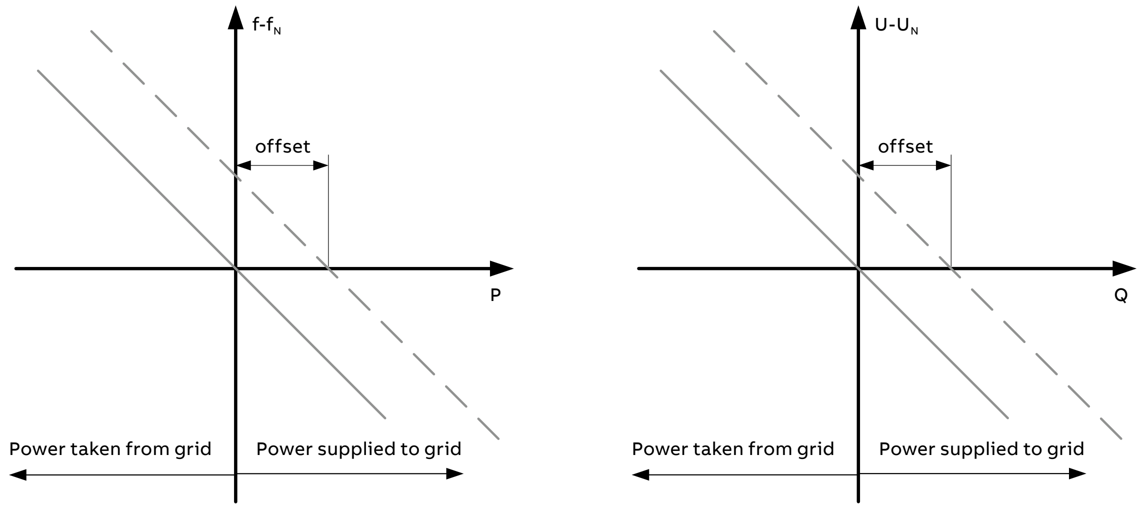

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Figure 4. P/f droop on left and Q/U droop on right side. The positive power direction in the figure is from OGC controlled ISU to grid.

Q/U droop
Reactive power generation is needed in distribution grids to supply the reactive power required by motors and inductors. Inductances have a rising Q/U load curve and can thus be controlled by Q/U droop similarly to active power with P/f droop.

In Figure 4 the right side represents reactive power vs. voltage droop. In Q/U droop the Q-axis passes voltage axis at rated voltages.

Droop setting
Steepness and offset of the droop curve can be set via parameters found in the operation manual. Figure 4 is an illustration of P/f and Q/U droops. Note that in the figure the P-axis is drawn at rated frequency and respectively the Q-axis at rated voltage. The typical settings for droops are 2% and 4%. This means that with rated active power the impact to frequency is 2% or 4%.

$$\frac{\Delta f}{f_n} = 4\% \times \frac{P}{P_N}$$

Usually both reactive and active droop have the same slope.

$$\frac{\Delta U}{U_N} = 4\% \times \frac{Q}{Q_N}$$

The steeper the slope is, the higher the control gains but the risk for unstable control is also increased.

Droop offsets
The droop-curve can be shifted via the power offset parameters. This is a high-resolution method to change on-line the power balance between power sources in the grid.

Virtual impedance
Virtual impedance is not a real impedance, but a set of parameters, which replicates in closed loop control the behavior of a real added serial impedance in main circuit. This can be used to tune and damp possible oscillations with droop control. The rule of thumb is that added virtual resistance increases damping and added inductance changes the critical frequency.
It is case dependent which one of these works better or if they should be combined.

4.2. Other control modes

In other control modes the OGC functionality is disabled, and it operates as a normal ISU.

4.3. Operation

—

Charging and control of DC-voltage

Before closing the MCB the DC-circuit must always be charged up to avoid tripping to a current peak at connection. This is done in typical ISU through an internal charging circuit and inbuilt charging sequence. The charging circuit takes energy from the grid side of the MCB. When this is not possible, the external charging logic must be used. This kind of cases occur for example, when the MCB is open to be synchronized to the grid or if the grid is voltage-free at start.

An OGC controlled ISU cannot control DC-voltage because its active power is controlled to satisfy the needs of an AC-grid. Thus, in a DC-circuit some other equipment which takes care of the stability and level of the DC-voltage must always be connected.

—

Start to voltage-free network

When the ISU is started from a voltage-free network, it charges the inductances and capacitances with preset voltage ramping, however limiting the maximum current to preset limits.

The no-load losses of LCL and power electronics as well as the charging energy of DC-capacitors and transformer flux must be provided by an external supply. The starting sequence of the drive system or charging circuit must be designed to cover this need of energy to avoid the collapse of DC-voltage and trip.

—

Start to live network

There are two ways to start the ISU from a live grid. It can be started in DC-control or Power-control mode. The mode can be changed after start online to AC-control if needed. The ISU can also be started in AC-mode with the MCB disconnected and then the MCB can be synchronized to the grid.

—

Network Synchronization

Network synchronization is used to eliminate the transient currents during the connection of the circuit breaker. Synchronization requires information about phase, direction, and magnitude of the voltages on both sides of the circuit breaker to be synchronized. The ISU control unit is always aware of the voltage created by itself and it can be calculated to the circuit breaker. Voltage on the grid side of the open circuit breaker must be measured.

The OGC functionality has two inbuilt algorithms for synchronization, U1 and U2. They are designed to be used for different initial operation states.

U1-Synchronization of the OGC functionality
The U1-synchronization algorithm of the OGC is designed to synchronize the ISU to a live grid. The function forces the state of controllers and voltage vectors to the same value as the measured grid voltage and thus it can make very accurate and fast corrections. The function is not recommended for synchronization of circuit breakers when any external load (apart from a drive transformer) is connected to the ISU. In these cases, the current transients in loads can be high, due to fast voltage amplitude and phase corrections by the synchronization function.

U1-Synchronization of circuit breaker in switchgear
To eliminate the inrush current of the drive transformer, it can be pre-magnetized using the OGC functionality before being switched on by synchronizing it to the supplying grid. Voltage transformers are needed for voltage measurement if grid voltage exceeds 690 V. The OGC functionality supports all common transformer voltage groups. The arrangement principle is presented in Figure 5.

U1-Synchronization of MCB
Synchronizing the drive's MCB can be necessary in some special cases, for example when the ISU is started with an under dimensioned temporary supply whose short-circuit impedance is very high. In these cases, a resonance between the generator inductances and LCL may occur before the ISU pulses are enabled. The control performance of a generator is typically far too poor to prevent the oscillation. This can be avoided by starting the converter up in OGC mode and synchronizing the MCB. This way LCL voltage is all the time controlled.

MCB synchronization can also be necessary to prevent charging current peaks of LCL capacitors at start. This is also necessary only when operated in very weak networks. The schematic drawing is presented in Figure 6.

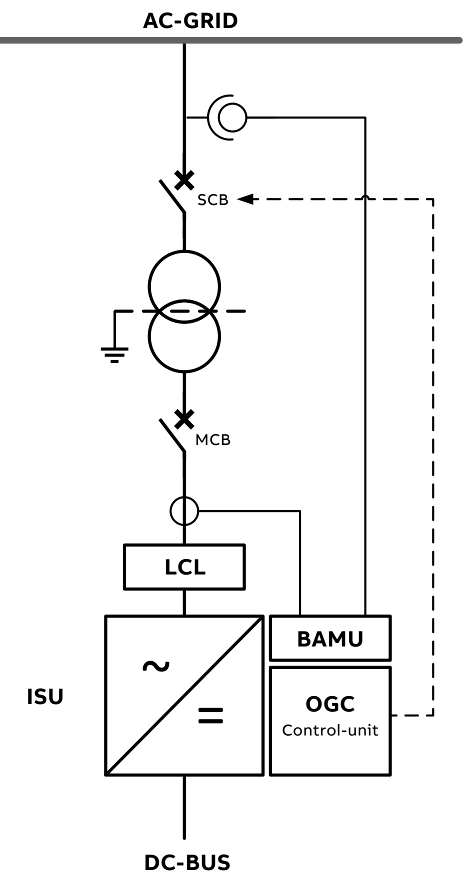

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Figure 5. U1-synchronization of SCB.

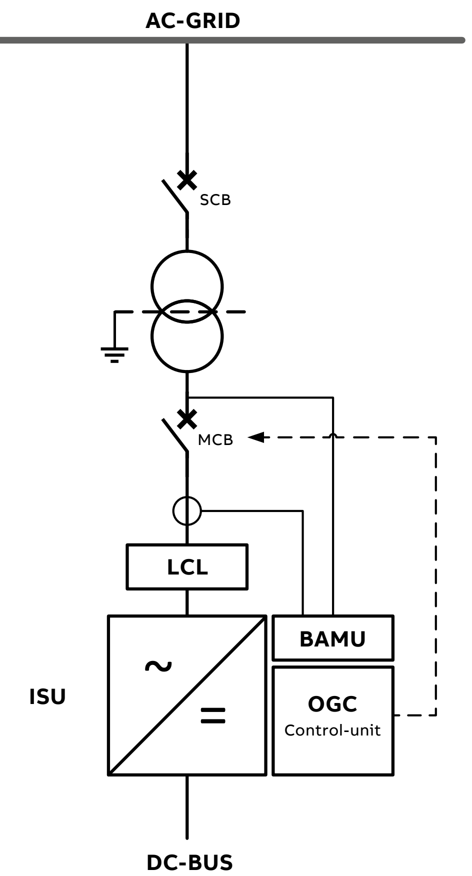

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Figure 6. U1-synchronization of MCB.

U2-Synchronization, synchronization to external grid
The purpose of U2-synchronization is to connect smoothly the OGC controlled ISU powered AC grid to another one. U2-synchronization slowly drives the frequency and voltage difference over the circuit breaker to zero by controlling references.

The U2-synchronization algorithm of the OGC functionality can be used when the converter has a load connected before synchronization. Because U2-synchronization is an inbuilt converter function, it cannot be used to control power supplies other than the ISU itself.

If there are several power supplies connected to the grid to be synchronized, an external synchronization device must be considered.

An example of grid with U1 and U2-synchronizations is illustrated in Figure 7. When the synchronization command is given to the OGC controlled ISU, it ramps the output voltage (magnitude, frequency and angle) to match it with the ones of the grid. Once the synchronization conditions are within the tolerance window, the close command is sent to the breaker. When the OGC controlled ISU receives a "breaker closed" status signal, control is given back to the droop controllers.

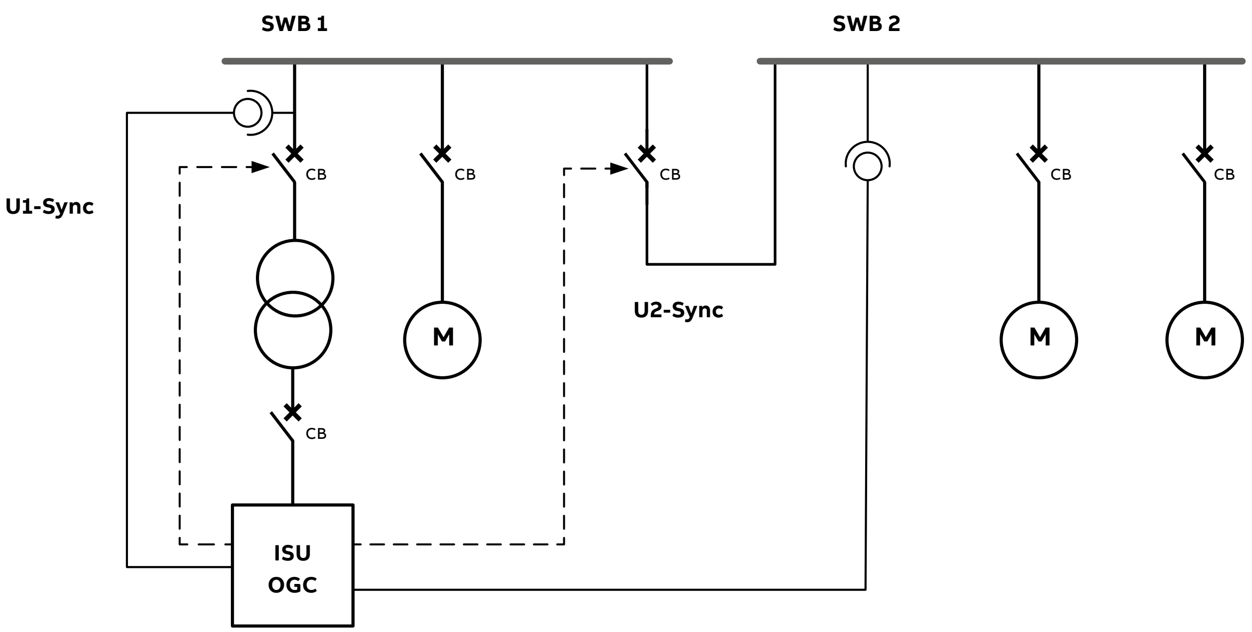

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Figure 7. An example of U1 and U2-synchronizations. U1 synchronizes OGC controlled ISU to SWB1 and U2 synchronizes SWB1 to SWB2.

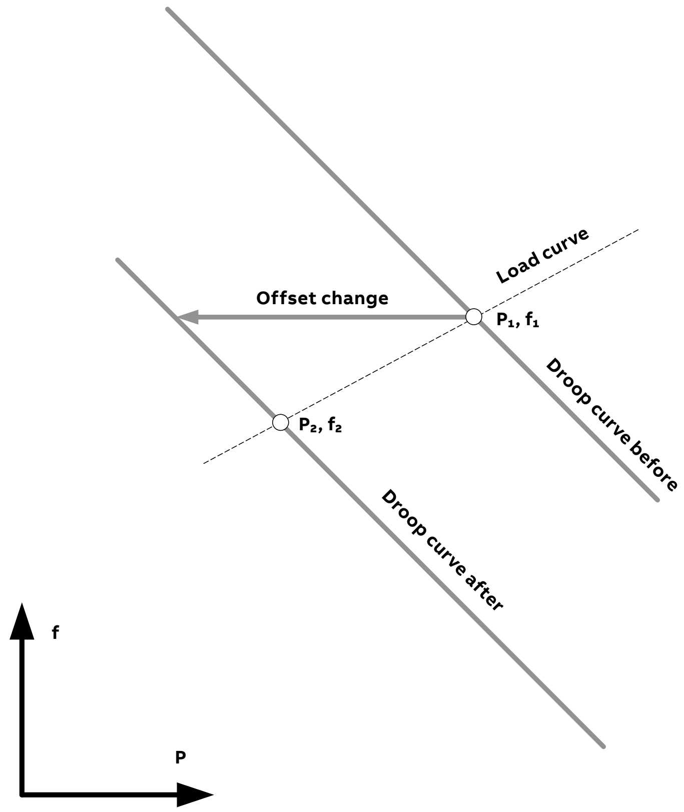

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Figure 8. Load share by reducing droop offset.

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Normal operation

Load share

In parallel operation the load-share between power supplies can be adjusted on-line by drifting the droop curves. Droop offset shifts the droop curve, keeping its slope unchanged. The OGC controlled ISU can receive offset reference via the ACS880 control interface, which is described in detail in the IGBT supply unit firmware manual and supplement.

Figure 8 represents the principle of load share. The operation point before the offset value is changed is point (P_1, f_1) at the intersection of grid's actual load curve and droop curve. After shifting the droop curve to the left by reducing the offset value, the new operation point (P_2, f_2) is found at the intersection of the load curve and shifted droop curve.

The control of offset is typically done by an external power management system (PMS), which is a grid level overriding system. There are several commercial PMS manufacturers, but their solutions are similar in the sense that they always control grid state by keeping the power consumption and power production of different parallel supplies in balance as presented in Figure 9.

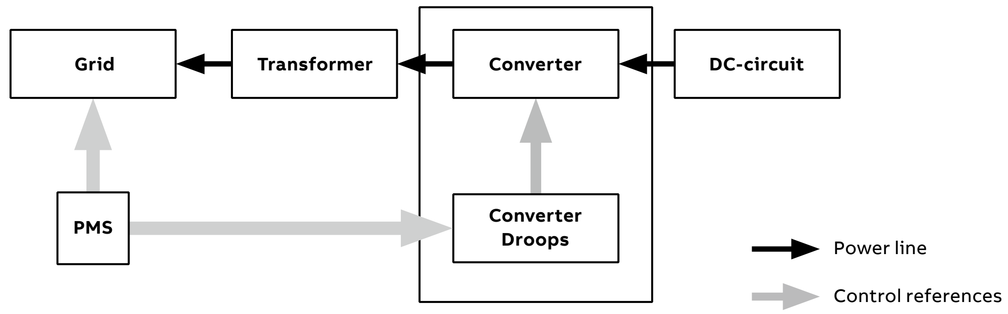

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Figure 9. A simplified example of control hardware interface.

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Reactive power

In order to compensate for a voltage drop it is required to always use a drive transformer when the capacity to supply reactive current is required.

Reactive current causes a significant voltage drop in inductances. The voltage drop in inductances is a vector variable and its direction has a great importance. The active current component causes a voltage drop in inductances, which is perpendicular to the supplying voltage which can often be ignored. Unlike the active component, the reactive current component causes a voltage drop in inductances which goes in the opposite direction to that of the grid voltage. Thus, the inductive voltage drop cannot be neglected, but the supply voltage level must be low enough compared with DC-voltage to cause the desired reactive current.

The reactive voltage drop can be estimated by multiplying reactive current component with inductances of the LCL-filter and transformer. The voltage drop vector is perpendicular with current. With $\cos \varphi = 1$ and using notation Xk for transformer short-circuit inductance it yields the following equation for grid voltage:

$$U_{grid} = \sqrt{U_{isu}^2 - 3 \times (I \times X_k)^2}$$

When the system is loaded with a base current and using notation x_k for the transformer short-circuit inductance in per unit values the equation can be given as:

$$U_{grid} = U_{isu} \sqrt{1 - x_k^2}$$

The inductance of a drive transformer for low voltage drives is typically 6% and its base current is the rated current of the drive. The base current for the LCL is the rated current of the drive and the inductance is approximately 10%. For the evaluation of voltage drops the inductances of the drive and the transformer must be converted to the same base. For example, when the rated current of the drive and the transformer is same, the total inductance is 0.06 + 0.10 = 0.16. With the rated current this leads to a voltage drop of $100\% \times (1 - \sqrt{1 - 0.16^2}) = 1.3\%$. The voltage drop of the active current component is minor and can be neglected. Often with the OGC the full performance is required down to $\cos \varphi = 0.8$. The current has a reactive component.

$$I_{react} = I \times \sin \varphi = I \times \sqrt{1 - \cos \varphi^2}$$

This means that with a reactive current with the same magnitude as that of the rated current, the voltage drop in our example (neglecting the part of the voltage drop caused by active current) is $100\% \times 0.16 \times \sqrt{1 - 0.8^2} = 16\% \times 0.6 = 9.6\%$. Then the rated transformer current causes a voltage drop in the 690V transformer and LCL around 66 volts. However, the OGC controlled ISU is selected to be able to supply short-circuit current and is thus over dimensioned, which leads to a higher rated (base) current and therefore to a lower voltage drop. Typically, the voltage drop with $\cos \varphi = 0.8$ is around 50 V for a 690 V drive. This must however be checked on a case-by-case basis.

—

Shorted grid

An OGC controlled ISU can support in grid short-circuit fault to enable grid protection to work properly. This means that it can supply sinusoidal short-circuit current the preset time. The short-circuit current can be limited by current limits, but the maximum current of the converter cannot be exceeded.

The short-circuit current is inductive current and does not pass the dc-circuit. The losses in short-circuit are supplied by the DC-bus.

—

Unbalanced grid

Network voltage may be distorted by an unbalanced load between phases. The OGC controlled ISU has the ability to correct this unbalance at the point where u1 voltage measurement is connected. This is done by supplying the needed amount of unbalanced current. The correction is limited by the current limits and voltage reserve. If either one of the phase currents reaches the current limit or if the needed voltage is higher than can be formed from actual DC-voltage, the correction cannot be fully done.

—

Harmonic compensation

In AC control mode it is possible to enable the harmonic compensation for 3rd, 5th, 7th, 11th and 13th voltage harmonics. The OGC controls the ISU into supplying a calculated amount of harmonic current to the network for harmonic elimination until the measured voltage component is cancelled out. The harmonic component to be compensated can be selected in OGC. Each individual harmonic current component can be separately limited by a dedicated current limit.

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DC-voltage dip ride through

“DC-voltage dip ride through” is a function which makes the optimal grid converter (OGC) stop consuming power from the DC link at voltage dip while it stays connected to a 400 VAC switchboard in order to quickly continue operation without resynchronization after a DC-voltage dip.

The function is described in more detail in the manual “Optimal grid control of ACS880 IGBT supply control program” 3AXD50000164745. *)

*) You can find manuals on the Internet.
See www.abb.com/drives/documents.
For manuals not available in the document library, contact your local ABB representative.

4.4. Transition between modes

All control mode changes are possible regardless of whether the grid converter is running or in stopped state with some limitations. Mode changes between rectifying control modes (ie. DC-voltage control and power control) are possible with all active and reactive currents. While converter operation is changed in running state between AC voltage control mode and rectifying control modes. The procedure must be executed through a transition state. In transition state the current has to be controlled close to zero by an external controller, before the mode change is commanded. The mode change causes a stepwise current change towards zero. A stepwise change in current may disturb other devices connected to AC grid or DC link, and at worst cause unstable control behavior. In change from rectifying control modes to AC voltage control, power control can be used to ramp power to zero. In change from AC voltage control to rectifying control modes, the upper level control system has to ensure that converter current is close to zero.

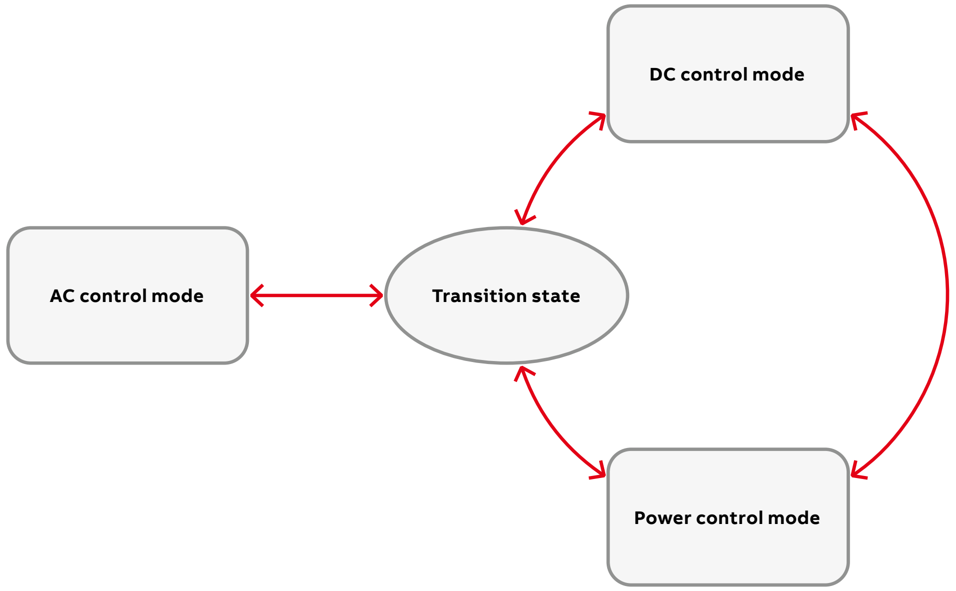

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Figure 10. Transition between modes.

5. Dimensioning

The purpose of this sectin is to open the principles of the dimensioning of the OGC controlled ISU. For the final dimensioning it is recommended to use the Optimal Grid Dimensioning Tool (Excel tool available through local sales managers). The dimensioning rules are found in detail in the ACS880 multidrives Optimal grid control (option +N8053) supplement 3AXD50000220717.

The basic rules for selection are presented below:

1. **Required short-circuit current capacity**
   OGC controlled ISU is selected according to short-circuit current requirements if there are any. The Optimal Grid Dimensioning Tool allows remarkably higher short-circuit current support when additional inductance is used than without it. The additional inductance limits the current slope and thus enables safe use of smaller margin between the current limit and the over current trip level. The short-circuit support capacity is verified with the additional 5 % inductance connected in series with the converter and without it.

   Note! When dedicated drive transformer is used, the inductance of the transformer is typically required to be 5% or more.

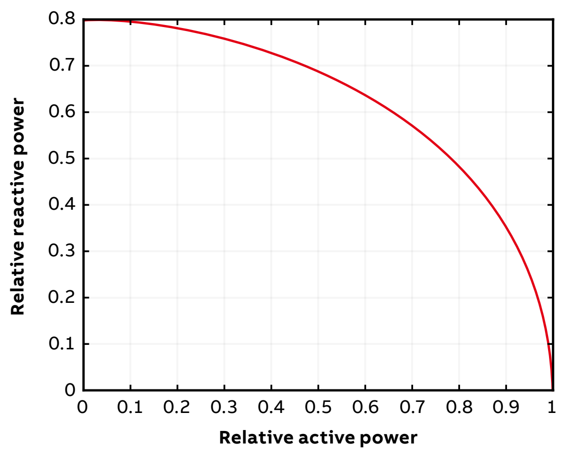

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Figure 11. Maximum allowed reactive power as a function of active power of ISU.

2. **Apparent power or current**
   If there are no short-circuit requirements, then the selection is made according to maximum apparent power. In this case attention should be paid also to derating factors, as described in the ISU manual. Semiconductors are heated up more by reactive than active current. The apparent power to be used in dimensioning must thus be calculated with the following equation:

$$S = \sqrt{P^2 + \left(\frac{Q}{0{,}8}\right)^2}$$

3. **Selection of DC-voltage**
   The over voltage withstandability of the capacitors is limited. This limit can be reached in two different ways:

- In cases where both the ISU and the INU trip simultaneously for an external disturbance (this is a very rare occasion but cannot be excluded) the energy stored in stator leakage inductances of the motor is discharged in the DC-capacitors.
- If the peak value of the voltage transients in the grid exceeds DC-voltage level it will be increased accordingly.

To have some margin for these phenomena and thus prevent unnecessary trips or capacitor failures it is recommended to select a conservative value for the DC-voltage as a basis for drive dimensioning. This kind of value is for example $U_{DC} = 1.45 \times U_{NISU}$ where U_{NISU} is the rated voltage of the ISU.

4. Voltage drop caused by reactive power
Reactive current causes a voltage drop in the transformer and LCL-filter. To be able to supply reactive power to the grid, the transformer drive size voltage added to the reactive voltage drop in transformer and LCL must be lower than the maximum terminal voltage of the power stage.
X_k is a reactance of transformer, typically 0.06 [p.u.], and X_{LCL} is a reactance of LCL filter, which is roughly 0.1 [p.u.]. Note, that the p.u. values for transformer and drive have different base impedances.

Using SI-units this yields to the inequality which defines transformer drive side voltage U_{tr}:

$$U_{tr} \leq \frac{U_{DC}}{1{,}03 \times \sqrt{2}} - \sqrt{3} \times I_{react} \times (X_k + X_{LCL})$$

See supplement for more information 3AXD50000220717.

Note that the voltage derating of the converter in the supplement does not take into account the voltage drop in the drive transformer. In the supplement the AC voltage used for derating is the voltage at the converter input terminals.

5. Voltage reserve for compensation of asymmetric load and harmonics
An additional voltage reserve must be reserved for harmonic compensation if compensation is needed. See the supplement.

6. Over voltage
Often the full performance of the converter is required in specified grid voltage area, which can be defined up to 10% over voltage. To be able to produce the required reactive power (and possibly demanded compensations of unbalanced current and harmonics), the voltage reserve must be high enough even with the highest grid voltage. The DC-voltage is fixed to the selected value, leaving the transfer ratio of the drive transformer as the only tool for controlling the voltage reserve. In these cases, the maximum specified over voltage must be used as the transformer voltage in the equation found in bullet 3.