DER Active Power/Reactive Power/Power Factor Value Encoding

The objective of this effort is to document the encoding of values that represent active power, reactive power, and power factor in information models used for DER. This is necessary to have consistent monitoring and control usage for these elements. The primary issue is the reference chosen and the meaning of the accompanying sign conventions. It seems particularly confusing for DER that support activity in all four quadrants.

What reference should be used for determining the sign of power, reactive power factor, and power factor?

What are the methods of representing a power factor value?

What is the behavior associated with reactive power when moving between active power injection and absorption?

Reference Orientation

The reference orientation consists of an active power producer (generator) and consumer (load). Typically, the utility system is identified as the producer and attached equipment as the consumer. In the case of DER, this convention is not appropriate because the DER is the power producer.

The current IEEE P1547 draft and IEC 61850-7-420 both assert that the generator reference/ sign convention is preferred for DER.

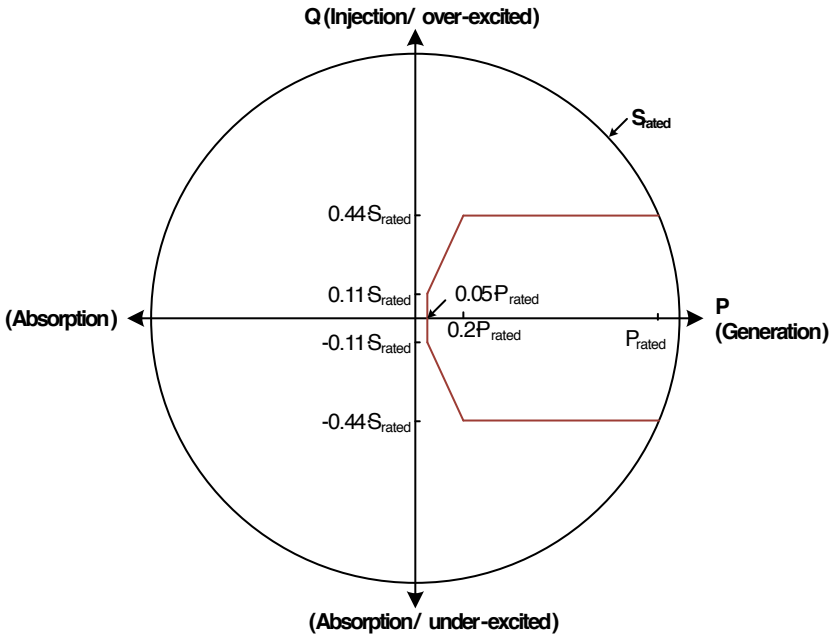
The sign convention for active power and reactive power can be determined by looking at the respective summary figures in the sections below based a generator reference. Injection of active power or reactive power is indicated with a positive sign. Absorption of active power or reactive power is indicated with a negative sign.

IEEE P1547

The current P1547 draft specifies the generator sign convetion should be used. Language and diagram from P1547:

*Where applicable, the stated technical specifications and requirements are given in **generator sign convention** which is opposite to load sign convention. In generator sign convention,*

- *a DER current **lagging** voltage provides / **injects** reactive power to the system (**over-excited** operation of DER, **positive** reactive power), and the **effect is an increase** of the applicable voltage;*
- *a DER current **leading** voltage consumes / **absorbs** reactive power from the system (**under-excited** operation of DER, **negative** reactive power), and the **effect is a decrease** of the applicable voltage.*

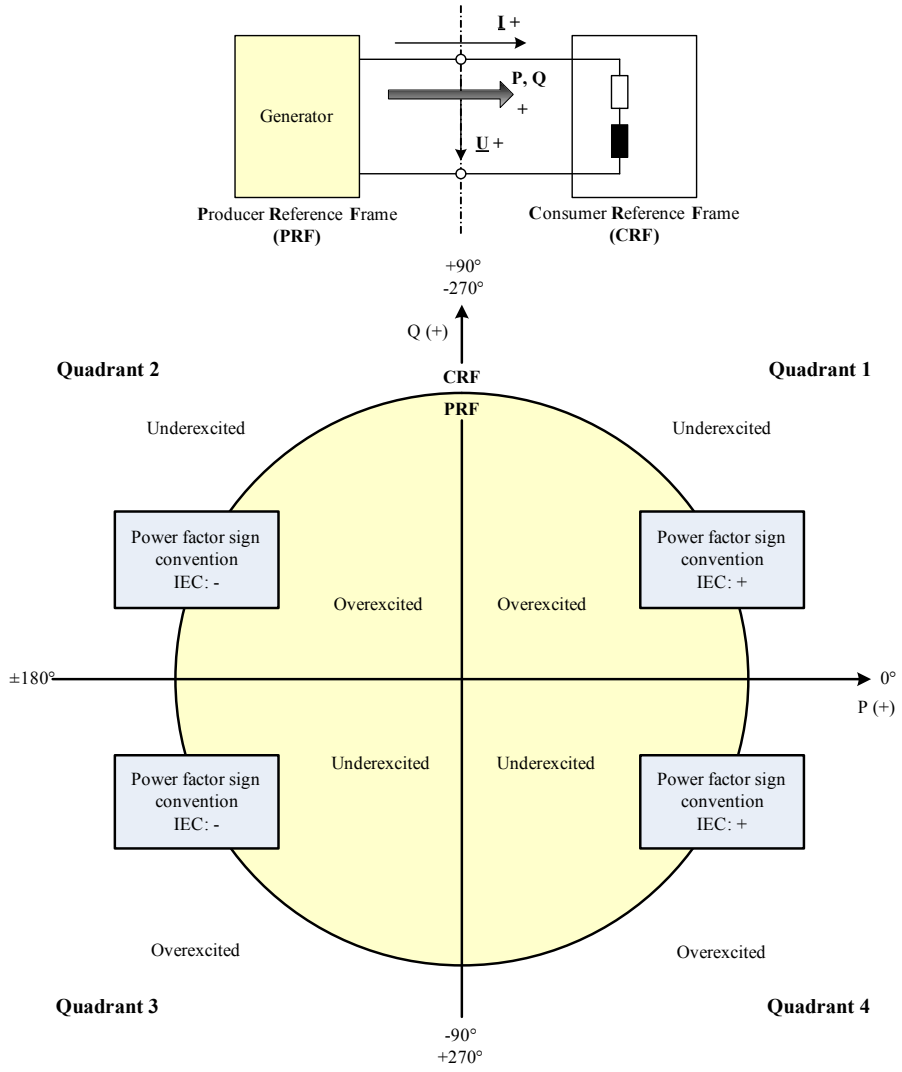


Category B

IEC 61850-7-520

The current IEC 61850-7-520 draft specifies the Producer Reference Frame (generator sign convetion) should be used. Language and diagram from IEC 61850-7-520:

Figure 5 shows the possible working areas of a DER system from both a Producer Reference Frame (PRF) and from a Consumer Reference Frame (CRF). In general for DER systems, the PRF is used, in which the 1st and 4th quadrants are for delivering power to the grid (vars either overexcited or underexcited, respectively), while the 2nd and 3rd quadrants are for receiving power from the grid (vars either overexcited or underexcited, respectively).



Power Factor Representation

A power factor value consists two elements: a value representing the ratio of active power to the apparent power, and the injection mode. The mode indicates whether reactive power is being injected or absorbed. Injection of reactive power is also referenced as one or more of the following: lagging, over-excited, inductive. Absorption of reactive power is also referenced as one or more of the following: leading, under-excited, capacitive.

There are at least three methods of representing a power factor value: IEC, EEI (also sometimes referenced as IEEE), and Q sign.

IEC Power Factor

The IEC power factor is represented using two separate elements: an element for value and an element for injection mode (termed excitation). The sign of the IEC power factor value is the mathematical sign derived from the ratio calculation.

Below is a table from IEC 61850-7-520 with the two representations:

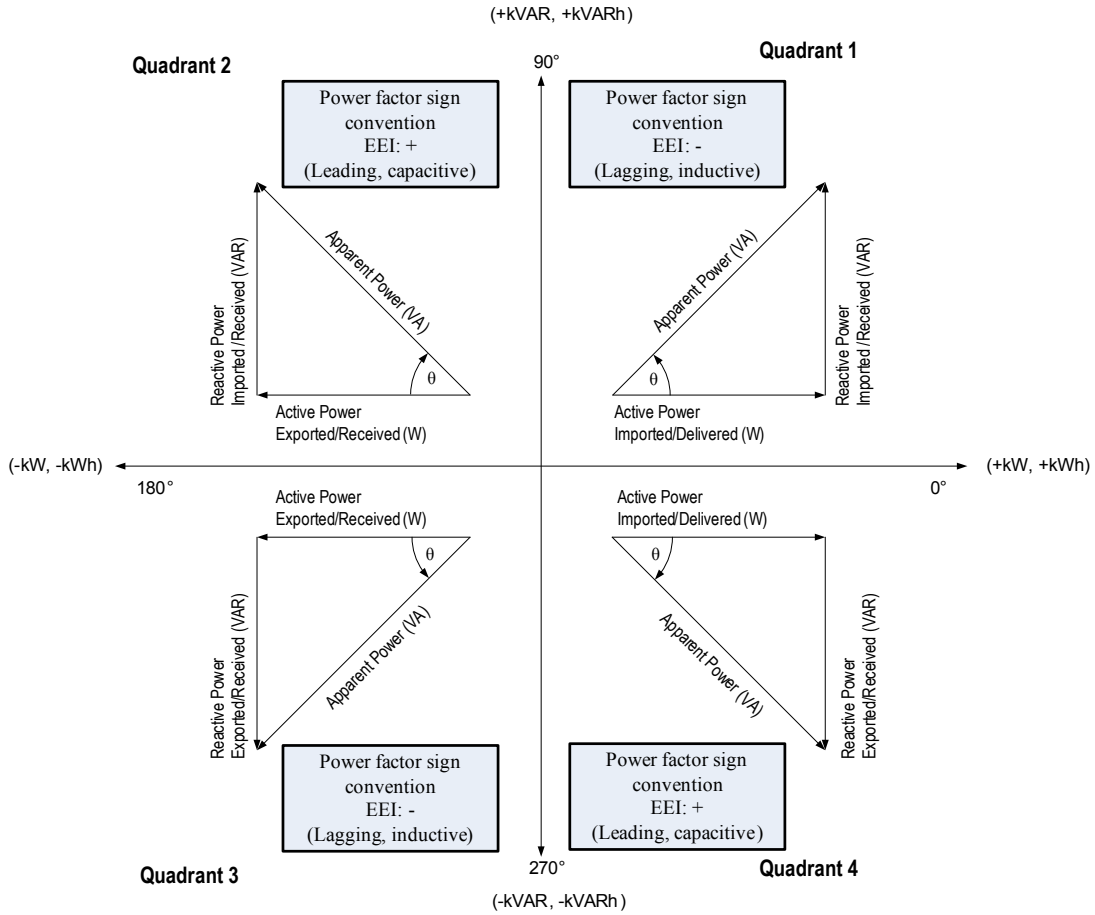
Quadrant	Excitation	PFSign Active Power (usually IEC)	PFSign (usually EEI)
I	Overexcited	+	–
II	Overexcited	–	+
III	Underexcited	–	–
IV	Underexcited	+	+

Note: The EEI column should be verified and may need to be adjusted based on the description of four quadrant operation. It appears to track the quadrants as outlined in the EEI diagram but does not consider that the EEI diagram seems to use a generator reference for quadrants 1 and 4 and a consumer reference for quadrants 2 and 3.

EEI Power Factor

The EEI power factor is represented using a single value where the mathematical sign is dropped and sign is instead used to indicate the injection mode. A positive sign indicates absorbing reactive power (leading, under-excited, capacitive) and a negative sign indicates injecting (lagging, over-excited, inductive). Below is a commonly referenced EEI power factor figure. Note that the diagram seems to use a generator reference for quadrants 1 and 4 and a consumer reference for quadrants 2 and 3.

The EEI Power Factor sign convention is based on the Power Triangle acc. Handbook for Electricity metering (EEI) and IEC 61557-12 (2007).



Note: Need a definitive reference for EEI power factor and any IEEE references.

Q Sign

Q sign is an alternate power factor representation that is in use but does not appear to have a standardized reference. The Q sign power factor is represented using a single value where the mathematical sign is dropped and sign is instead used to indicate the mode. The sign reflects the sign of power factor. A positive sign indicates injecting reactive power (lagging, over-excited, inductive) and a negative sign indicates absorbing reactive power (leading, under-excited, capacitive).

Power Factor Representation Usage

Both IEEE 2030.5 and SunSpec currently use the EEI sign convention for power factor.

Four Quadrant Operation

The primary challenge when working with the producer reference frame (PRF) and the consumer reference frame (CRF) is that when crossing from the right-hand plane (RHP) to the left-hand plane (LHP)—and vice versa—traditionally, the sign convention changes. Historically, there were few 4-quadrant devices that could operate in all quadrants, so this was not an issue, but now it must be defined and standardized.

Borrowing terminology from synchronous generators, generators in the RHP would use 'over-excited' to indicate the generator was in Q1 and producing reactive power (increase voltage), and 'under-excited' to indicate the generator was in Q4 and absorbing reactive power (decrease voltage).

In the LHP, loads could be characterized as either capacitive which would source reactive power (increase voltage) or inductive which would sink reactive power (decrease voltage).

The problem is that these nomenclatures do not apply to the other side of the P-Q plane, but the synonymous behavior is given the same name. While loads are never over-excited or under-excited and generators are not inductive or capacitive, for convenience these terms are recycled. This has caused significant confusion in the past.

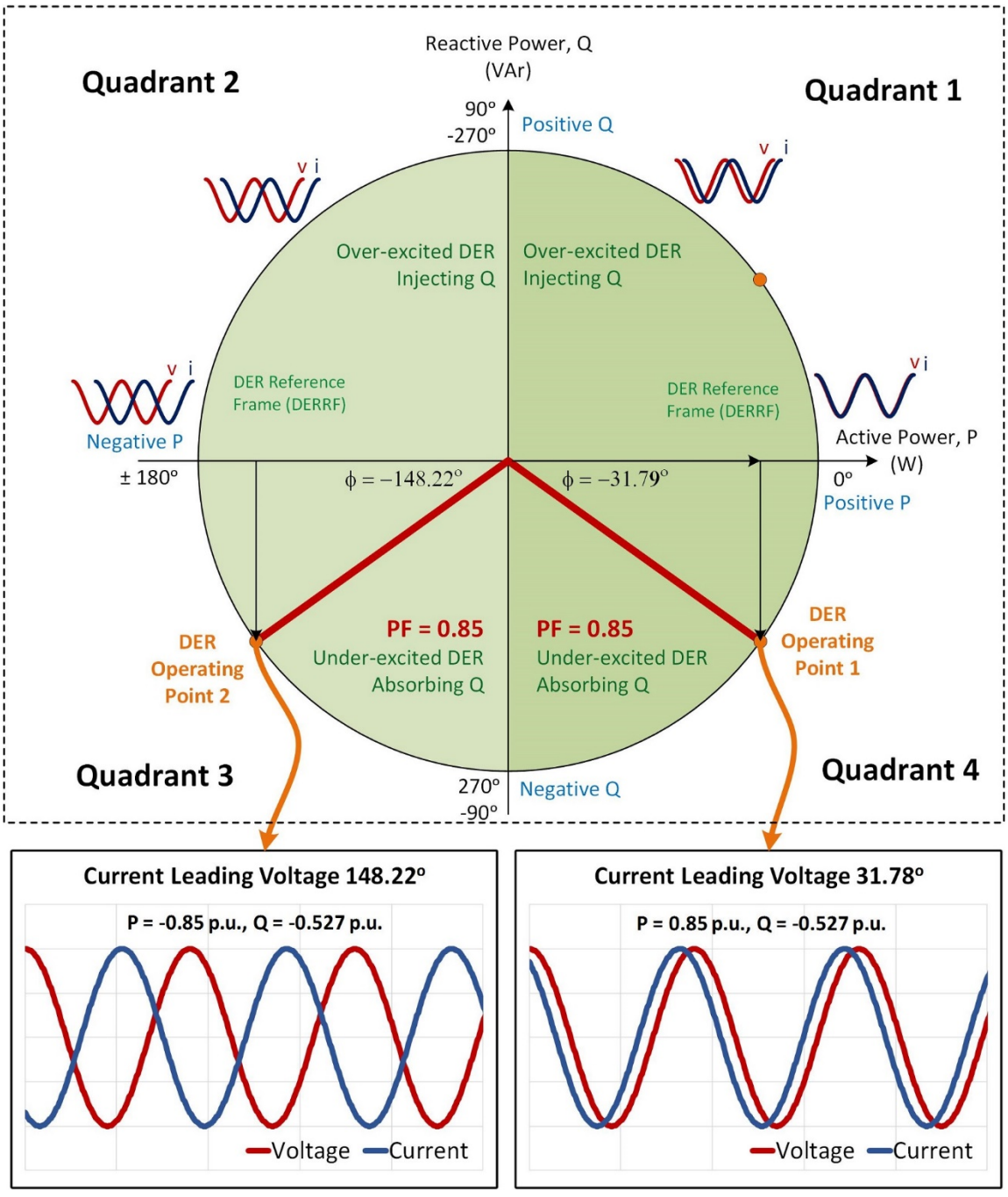
When operating (and testing/certifying) a 4-quadrant device, a single reference frame must be used because the laboratory will be configured a single time for the experiments. The current IEEE P1547 draft and IEC 61850-7-420 both assert that the generator reference/sign convention is preferred for DER. This reference requires that when the generator is injecting active power at unity power factors, the phase angle of current and voltage is zero. From that reference, point the current and voltage probes will not be changed and all further measurements will be made using that reference. This is difficult to represent in the EEI and IEEE formats, because the current sign is reversed in the LHP.

Another issue is the unclear definition of leading and lagging power factor (PF). Some standards only define the PF for one half of the P-Q plane, i.e., PF is not defined from 90^0-270^0. Therefore, a new reference at 180^0 is used (the current sign/measurement flipped) to produce PF values in the LHP. This is the case with EEI. IEC defines the power factor mathematically, as $\cos(\phi)$, but many in industry do not favor this approach because it does not differentiate between leading and lagging (Q1&Q4 and Q2&Q3).

Four Quadrant Power Factor/Reactive Power Behavior

The expectation for 4-quadrant capable DER is active power injection/absorption and reactive power injection/absorption operate somewhat independently. A DER should be able to maintain a power factor with a specified excitation while alternating between injecting and absorbing active power.

The following diagram illustrates an example of the change in phase angle to maintain a .85 power factor that is under-excited when switching from injecting to absorbing active power.



Value Encoding Summary

Using a generator reference, the following describes values associated with a four quadrant-capable DER:

1. When a DER injects active power (generation/storage discharge) the sign of active power is positive.
2. When a DER is injecting active power, it is operating in quadrants 1 or 4.

3. When a DER absorbs active power (usage/storage charge) the sign of active power is negative.
4. When a DER is absorbing active power, it is operating in quadrants 2 or 3.
5. When a DER injects reactive power, the sign of reactive power is positive.
6. When a DER injects reactive power, it is over-excited (effect is usually to raise voltage).
7. When a DER absorbs reactive power, the sign of reactive power is negative.
8. When a DER absorbs reactive power, it is under-excited (effect is usually to lower voltage).
9. When an active power control is set to a positive value, it is directing the DER to inject active power.
10. When an active power control is set to a negative value, it is directing the DER to absorb active power.
11. When a reactive power control is set to a positive value, it is directing the DER to inject reactive power (over-excited operation).
12. When a reactive power control is set to a negative value, it is directing the DER to absorb reactive power (under-excited operation).
13. When an EEI power factor control is set to a negative value, it is directing the DER to inject reactive power (over-excited operation).
14. When an EEI power factor control is set to a positive value, it is directing the DER to absorb reactive power (under-excited operation).

Additional References

The following sections contains additional descriptions of the properties of the four quadrants from different sources.

EPRI Common Inverter Functions Report

Figure from the EPRI Common Inverter Functions Report. Example of IEEE reference for power factor sign that is the same as EEI reference.

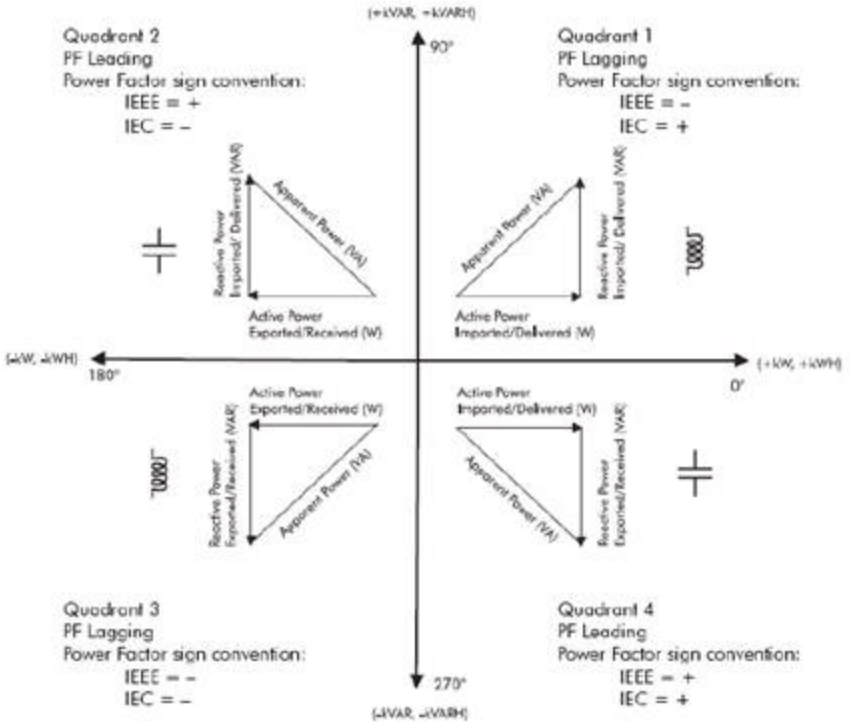


Figure 10-1
IEC and IEEE power factor sign conventions

IEEE Std 1459

Figure for load sign convention.

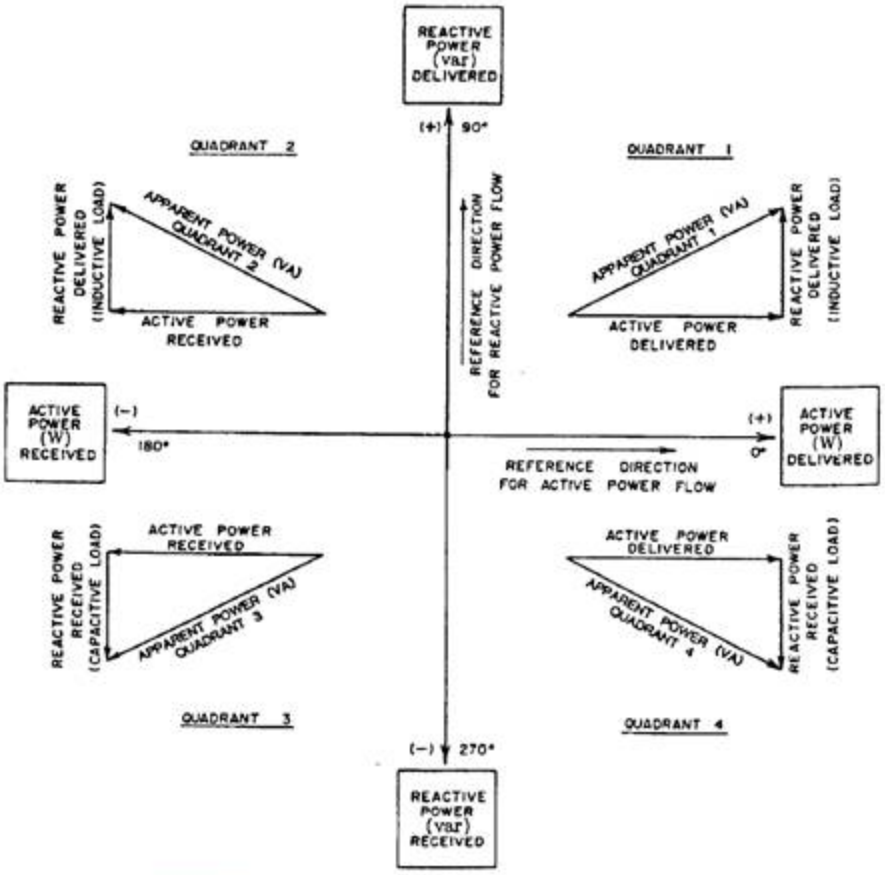


Figure 1—Four-quadrant power flow directions

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VDE AR

VDE AR load sign convention.

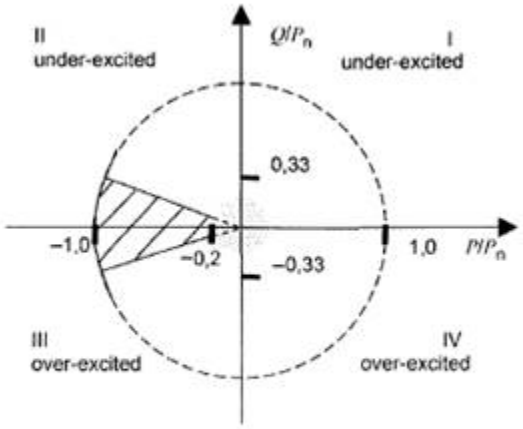


Figure 4 — Limit power range for the reactive power of a power generation system within the range of 3,68 kVA < $\sum S_{Emax}$ ≤ 13,8 kVA (load-reference arrow system)