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TECHNICAL SPECIFICATION

Renewable energy and hybrid systems for rural electrification –
Part 9-7: Recommendations for selection of inverters

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RENEWABLE ENERGY AND HYBRID SYSTEMS FOR RURAL ELECTRIFICATION –

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FOREWORD

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Technical specifications are subject to review within three years of publication to decide whether they can be transformed into International Standards.

IEC TS 62257-9-7, which is a Technical Specification, has been prepared by IEC technical committee 82: Solar photovoltaic energy systems.

The text of this Technical Specification is based on the following documents:

Enquiry draft	Report on voting
82/1473/DTS	82/1546A/RVDTS

Full information on the voting for the approval of this technical specification can be found in the report on voting indicated in the above table.

This document has been drafted in accordance with the ISO/IEC Directives, Part 2.

This part of IEC 62257 is to be used in conjunction with IEC 62257 (all parts).

A list of all parts in the IEC 62257 series, published under the general title *Renewable energy and hybrid systems for rural electrification*, can be found on the IEC website.

Future standards in this series will carry the new general title as cited above. Titles of existing standards in this series will be updated at the time of the next edition.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under "http://webstore.iec.ch" in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

A bilingual version of this publication may be issued at a later date.

RENEWABLE ENERGY AND HYBRID SYSTEMS FOR RURAL ELECTRIFICATION –

Part 9–7: Recommendations for selection of inverters

1 Scope

This part of IEC 62257, which is a technical specification, specifies the criteria for selecting and sizing inverters suitable for different off-grid applications integrating solar as an energy source.

As well as off-grid system, this document can also apply to inverters where a utility grid connection is available as a backup for charging batteries, but it is not intended to cover applications in which inverters synchronize and inject energy back into a utility grid, even though this capability may incidentally be a part of the functionality of the inverters.

Single and multi-phase applications are included.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60529, *Degrees of protection provided by enclosures (IP Code)*

IEC 61683, *Photovoltaic systems – Power conditioners – Procedure for measuring efficiency*

IEC 61800, *(all parts), Adjustable speed electrical power drive systems*

IEC 61800-3, *Adjustable speed electrical power drive systems – Part 3: EMC requirements and specific test methods*

IEC 61800-5-1, *Adjustable speed electrical power drive systems – Part 5-1: Safety requirements – Electrical, thermal and energy*

IEC TS 61836, *Solar photovoltaic energy systems – Terms, definitions and symbols*

IEC 62109, (*all parts), Safety of power converters for use in photovoltaic power systems*

IEC 62109-1, *Safety of power converters for use in photovoltaic power systems – Part 1: General requirements*

IEC TS 62257-2, *Recommendations for renewable energy and hybrid systems for rural electrification – Part 2: From requirements to a range of electrification systems*

IEC TS 62257-7-1:2010, *Recommendations for small renewable energy and hybrid systems for rural electrification – Part 7-1: Generators – Photovoltaic generators*

IEC TS 62257-7-4: *Recommendations for renewable energy and hybrid systems for rural electrification – Part 7-4: Generators – Integration of solar with other forms of power generation within hybrid power systems*

IEC 62548, *Photovoltaic (PV) arrays – Design requirements*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC TS 61836 and the following apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp

3.1
renewable energy
REN
energy from a source that is not depleted when used

3.2
hybrid power plants
multi-sources system with at least two kinds of energy generation technology

3.3
storage
storage of electrical energy produced by one of the generators of the system in a battery

3.4
DC bus
node of the electrical system to which the DC input of the battery inverter is connected to

3.5
AC bus
node of the electrical system to which the AC output of the battery inverter is connected to

3.6
black start
process of starting an electrical power supply without relying on any other external generating source

4 Overview

Inverters are used to convert DC power into AC power. For off-grid renewable applications, there are different types of inverters that may be used depending upon the architecture of the system.

Some systems work with batteries and use the firm energy they provide to form the conditions of the micro-grid (grid-forming inverters) and some inverters synchronize to an existing grid.

In addition, some inverters are bi-directional inverter/chargers, which not only convert DC battery current into AC, but also reverse the process and transform the AC current into a DC battery charging current to permit battery charging from the AC side of the inverter.

Off-grid inverters need to be correctly selected for the features which they possess, and sized accordingly depending upon the loads they shall feed or the energy sources they are fed by.

5 System architecture and inverter selection

Different sorts of system architectures of isolated electrification systems are given in IEC TS 62257-2. Not all of them require inverters, but several do. Depending on the situation encountered, the inverters will need to possess certain features.

Table 1 shows the system architectures from IEC TS 62257-2 that need inverters, and gives the general correspondence of which inverter is suitable for which application, with some exceptions noted.

Table 1 – Types of inverter and system architecture it is applicable to

Type of inverter	Principal system architecture	Description	Example applications	Variations on architecture
Variable Speed Drives	T1I-c	REN systems operating with no storage and no diesel generators or grid backup	Solar water pumping	Some drives may also use diesel or grid
Grid forming inverters that work with batteries	T2I	REN systems with storage and no diesel generators or grid backup REN and battery are coupled on the DC bus	Solar home systems	Some systems may allow generators or grid to connect via an additional battery charger
Grid-Tie Inverters that synchronize to another AC source	T3I	REN systems operating with diesel generators or grid backup but no storage	Reduction of diesel consumption in off-grid industrial applications	Some systems may use some battery storage to smooth transition between renewables and diesel
Bi-directional inverters that work with batteries	T4I	REN systems operating with diesel generators or grid backup and storage REN and battery are coupled at DC or AC bus	Mini-grid systems; telecommunications towers; larger solar home systems	Some mini-grid systems may not include diesel or grid back-up

NOTE There are also dual-mode inverters, which synchronize to a grid under normal circumstances, but under grid failure become grid-forming inverters. The typical application for this sort of inverter is for grid-connected systems, where the grid is weak and unreliable, and has been excluded from the scope of this document.

6 General considerations

6.1 Overview

The following are generally applicable to all types of inverters:

6.2 IP rating

All inverters should have an IP rating according to IEC 60529 suitable for the environmental conditions they will be installed in.

6.3 Ambient temperature

Inverters may not be installed in an ambient temperature outside of their specification.

Attention should be paid to how changing ambient temperature affects the power output of the inverters. Power/temperature curves of inverters are available from manufacturers which should be used for correct inverter sizing.

6.4 Altitude

Attention should be paid to the altitude in which the inverters will be installed.

Altitude has impact on insulation, clearances and creepage. When exceeding the altitude specification of the inverter a lower DC voltage may need to be applied.

Altitude also affects the ventilation of inverters. Outside of the altitude specification the manufacturer should be consulted regarding the power/temperature curves.

6.5 Direct sunlight

Special care should be taken when inverters will be exposed to direct sunlight. Direct sunlight can damage LCD screens on inverters, and under those conditions it may be necessary to select inverters without such screens, or to install them along with sun-shields.

6.6 Efficiency

The conversion efficiency of inverters should be considered at design stage to correctly quantify system performance.

6.7 No-load and stand-by power requirements

Consideration should be taken over whether the inverters have any stand-by or no-load power requirements, which may have an impact on overall system performance.

6.8 Ventilation requirements

Manufacturer's instructions regarding clearances around the inverters and sufficient ventilation in the spaces they are installed in shall be considered in order to avoid overheating of the units.

6.9 Earthing arrangements

Manufacturer's instructions should be consulted to ensure that the inverter is compatible with the system earthing arrangements. Applicable standards and regulations shall be followed regarding earthing of the system.

6.10 Waveform quality

Common types of inverter are pure sine wave inverters and modified sine wave inverters. Sine wave inverters will have a low harmonic distortion, while modified square wave inverters will have a higher harmonic distortion.

Although some loads will work with an inverter with higher wave-form distortion, others will not run at all or may get damaged, and other potential consequences are motor loads working less efficiently and timers not working properly. It is important to take into consideration the amount of harmonic distortion that can be tolerated by the loads in the system.

6.11 Compatibility with loads that produce significant harmonics

If any of the loads on the system cause significant harmonic currents, for example because of half-wave rectification in a welding machine, then the manufacturer should be consulted to ensure the inverter is capable of supplying energy to that load.

6.12 Electromagnetic interference

The inverter shall comply with any applicable international or local standards that regulate electromagnetic emissions.

6.13 Load growth

In some situations, the loads connected to the inverters may be predicted to increase over time, or there may be a degree of uncertainty over what will be connected. Inverters should be sized to take into account any predicted expansion of the loads originally considered.

6.14 Protection

All inverters being used with photovoltaic applications shall follow the safety requirements of IEC 62109.

Inverters may or may not have internal over-current and short-circuit protection. In the event they do not, then external protection needs to be considered in the overall system design.

7 Variable speed drives and T1I-c systems – REN systems operating with no storage, DC source to AC application

7.1 General

In this application the DC sources are converted directly into single- or poly-phase AC, making use of the solar resource as and when it is available. This is useful for where the application is not needed on demand. A typical use for this architecture is AC solar water pumping (AC Solar water pumping with an inverter is typically used for higher powered applications than the simpler and smaller DC to DC solar pumps which are not covered by this document).

Without a battery as support, the power to operate the load in the morning and evening is limited. Motors require magnetization and starting currents if supplied with fixed frequency, and there is a lot of reactive power required. In order to overcome this obstacle, AC solar pump systems will typically use variable frequency drives which will begin by magnetizing the motor with DC current (zero frequency) and then increase the frequency with a ramp while keeping the motor current low. The pump is operated at a lower frequency in the morning, pumping at a lower rate, and this rate increases as irradiance increases. See Figure 1.

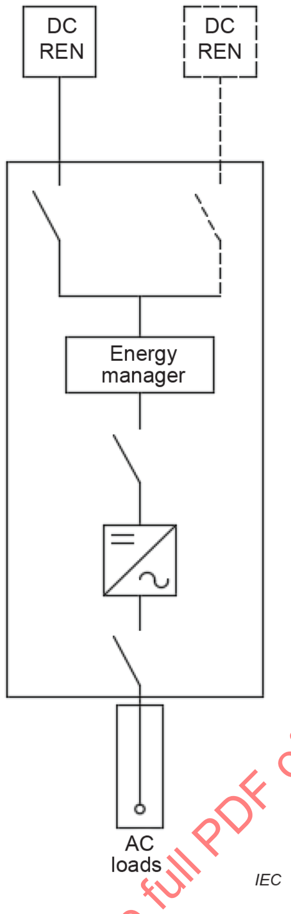

Figure 1 – Type T1I-c system – DC to AC with no batteries

7.2 Characteristics of the inverter

7.2.1 Frequency control

The inverter will be controlled by an energy manager, which should be capable to adjust its frequency depending upon the DC current provided, to be able to start the AC loads at low irradiance levels and ramp up the speed as the day progresses.

It may also be possible to have additional programming in the unit that controls the frequency according to other criteria (for example as a way of controlling water flow).

7.2.2 MPPT

To avoid redundancy and greatly oversizing the PV array at design stage, it is recommended that the inverter have a Maximum Power Point Tracker (MPPT) on the DC side, or be installed in series with an MPPT circuit. This means that the PV array can provide initial current requirements to obtain sufficient speed to start the water flow.

7.3 Sizing of the inverter

7.3.1 General

For solar pumping applications, the goal is to have the maximum amount of water drawn from a well during the sunny period of the day. In order to get even an initial flow of water, the head of the system due to well depth and friction losses needs to be overcome, for which a minimum pump speed needs to be obtained. When using an MPPT tracker, the power rating of the PV array connected to the drive will be similar to the power of the pump.

7.3.2 AC voltage

The output voltage of the drive needs to be selected so that it falls within the operating AC voltage of the load.

7.3.3 AC current

The drive should be selected so that its maximum current is equal to or more than the rated values of the load.

The inverter shall be protected from overload or short circuit.

7.3.4 DC voltage

The maximum voltage of the inverter shall be at least the open circuit voltage from the PV array circuit at the lowest expected temperature on site, as per IEC TS 62257-7-1. More detail on how to obtain this value is in IEC 62548.

7.3.5 DC current

The DC input current of the variable speed drive shall have an I_{sc} rating as defined in IEC 62109-1 of at least 1,25 × the short circuit current of the input circuit connected at STC, unless additional overcurrent protection is provided that is rated to protect the PCE.

For solar applications, the I_{sc} rating shall be determined following IEC TS 62257-7-1, or from IEC 62548.

7.4 VFD standards

Variable frequency drives should be fabricated according to: IEC 61800 series in general, IEC 61800-3 and IEC 61800-5-1.

7.5 Variations on the architecture

A common adaptation of the architecture presented in this subclause is one where variable frequency drives may also be kept running via a diesel generator or utility grid when the solar resource is no longer available. Although such a configuration is no longer a T1I-c architecture, the characteristics and sizing of the drives are very similar.

In this special case, attention needs to be made to prevent backfeed from grid to PV, either through galvanic isolation or by using diodes.

8 Uni-directional grid creating inverters that work with batteries – Type T2I systems – REN production with energy storage

8.1 General

In this application, renewable energy sources and batteries connect onto a DC bus. Batteries are kept charged solely via the DC renewable energy sources, and so there is no back-up from the grid or diesel generator.

The voltage of the DC bus is dictated by the voltage of the battery bank. The DC generators are connected to the DC bus via a charge controller, and the AC generators are connected to the DC bus via a rectifier/battery-charger.

From the DC bus, both DC loads and AC loads can be supplied, with AC loads being supplied via a suitable off-grid inverter. See Figure 2.

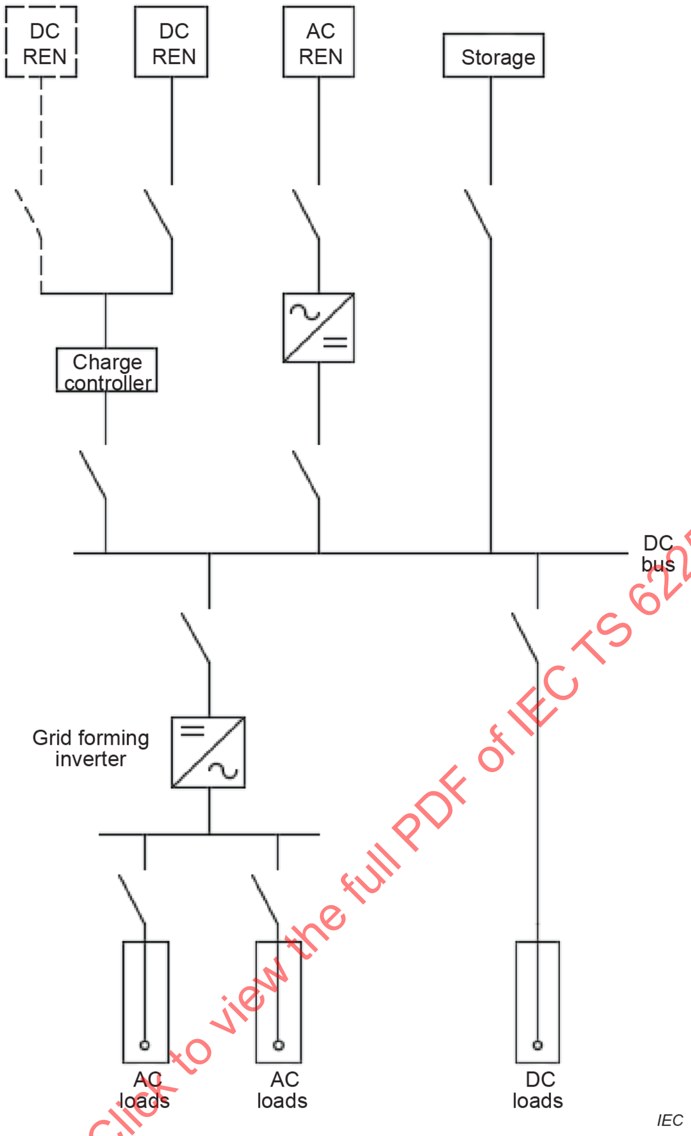

Figure 2 – Type T2I system – DC to AC with batteries

8.2 Characteristics of the inverter

8.2.1 Grid creation

8.2.1.1 General

The inverter required for this application needs to be capable of producing a nominal voltage and a fixed frequency, suitable for the loads that are attached to it.

The inverter shall have black-start capability, being able to produce the AC mini-grid without any external help.

Voltage/frequency tolerances and power quality shall meet the needs of the connected loads.

8.2.1.2 Three phase systems

3-phase off-grid systems will typically have a mixture of 3-phase and single-phase loads, resulting in in-balance.

In such a situation, a 3-phase inverter requires a neutral connection.

8.3 Sizing of the inverter

8.3.1 Input DC voltage

The nominal input DC voltage of the inverter should match the nominal voltage of the battery bank.

The maximum input DC voltage shall be greater than the maximum design voltage of the DC bus.

The inverter should be selected so that it can run from the minimum DC voltage from the battery bank.

8.3.2 Input DC current

The DC input of the variable speed drive shall have an I_{sc} rating as defined in IEC 62109-1 of at least 1,25 × the short circuit current of the input circuit connected at STC, unless additional overcurrent protection is provided that is rated to protect the PCE.

The solar contribution of I_{sc} shall be determined following IEC TS 62257-7-1, or from IEC 62548.

8.3.3 AC current and power

The inverter may be capable of delivering different currents for different periods of time and at different temperatures, for example there may be a continuous rating, a half hour rating and a 5 s rating at 25 °C.

The current ratings of the inverter should be greater than the expected currents demanded by the loads for the relevant time periods, and at the expected ambient temperature. For example, if start-up motor surges are expected from fridges for a few seconds, and the expected ambient temperature of the inverter is at 30 °C, the 5 s rating of the inverter should be capable of providing that current at that temperature.

The maximum active power may be affected by operating at a different power factor, and it should be ensured that the inverter can also provide the necessary power at the power factor it is expected to perform at.

8.3.4 AC voltage

The output voltage of the inverter should be within to the operating voltage of the loads being connected.

8.3.5 Power factor handling range

If the inverter is required to provide any sort of reactive power, then it shall be capable of operating at the required power factor.

8.4 Variations on the architecture

A generator set or grid may be used to vary this system architecture by incorporating an AC powered battery charger/rectifier that is connected to the batteries in parallel with the renewable energy sources. This may be used to keep the batteries charged. The battery management system is out of scope of this document, but it is noted here that care should be taken to properly coordinate multiple charge controllers and battery chargers.

9 Uni-directional inverters that synchronize to the grid – Type T3I systems – REN and diesel production without energy storage

9.1 General

In this type of situation there is typically no storage present, but there is a diesel generator to provide constant production. The inverters synchronize to the diesel generator in order to off-set diesel consumption.

Diesel generators are switched in and out according to the loads. For the health of the generators it is important that they operate at a minimum base-load or higher, otherwise they can suffer damage due to partial combustion and attention shall be paid to the fuel efficiency characteristics to minimise fuel consumption. They shall also be protected from reverse power flowing in from the renewable generation. In order to guarantee this, the renewable energy sources need to be controlled so that they do not generate more than a predetermined amount (considering sudden variations in load), and so they need a control system to limit their active power. See Figure 3.

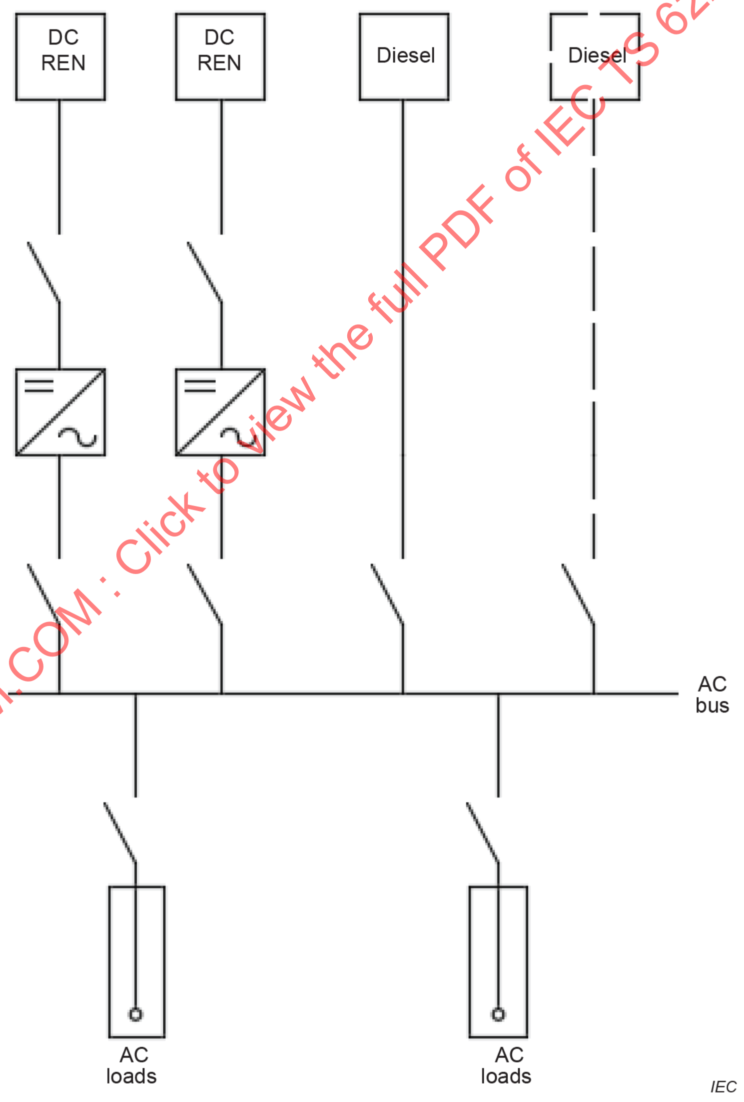

Figure 3 – Type T3I system – DC to AC with diesel but no batteries

9.2 Characteristics of the inverter

9.2.1 General

In this application, the inverters being used are typically very similar to grid-tie solar inverters, which instead of synchronizing to the grid are instead synchronized to the diesel generators via intelligent control systems that increase or reduce the amount of energy coming from PV depending on the needs of the system.

9.2.2 Grid synchronizing

The inverters shall be capable of synchronizing to the AC voltage and frequency on the AC bus.

Consideration should be taken that in an off-grid environment the variations of voltage and frequency are typically higher than in an on-grid environment. The control system of the inverter should be of sufficient quality to respond to changing load without causing power quality deviations beyond limits.

9.2.3 MPPT tracking

The conversion efficiency of the inverter is greater if it has an MPPT tracker, according to IEC 61683.

9.2.4 Active power control

To coordinate properly with the diesel generation, the inverters need to form part of an overall control system. The system shall be capable of controlling the active power of the inverters, and of switching in and out diesel generators, depending upon the AC loads being asked for.

Such a hybrid control system is described in more detail in IEC TS 62257-7-4.

9.2.5 Grid support

Inverters for this application may optionally provide support features that contribute to the stability of the grid.

Reactive power support is helpful since as diesel generators connect and disconnect, the reactive power of the grid will also change, and the inverters can help to stabilize it.

Ride through capabilities (for low voltage, high voltage, low frequency and high frequency) allow the solar system to continue running and maintaining the grid through issues associated with the diesel generators.

Frequency support allows the system to raise or reduce active power to help keep frequency within healthy limits.

9.3 Sizing of the inverter

9.3.1 Input DC voltage

The maximum voltage of the inverter input shall be at least the open circuit voltage from the PV array circuit at the lowest expected temperature on site, as per IEC TS 62257-7-1. More detail on how to obtain this value is in IEC 62548.

If the inverter has an MPPT tracker, the conversion efficiency is higher if the minimum and maximum PV array circuit voltage remains within the MPPT tracker range for the highest and lowest expected temperatures, taking into account any volt drop along DC cables.

9.3.2 Input DC current

The DC input of the variable speed drive shall have an I_{sc} rating as defined in IEC 62109-1 of at least 1,25 × the short circuit current of the input circuit connected at STC, unless additional overcurrent protection is provided that is rated to protect the PCE.

The solar I_{sc} shall be determined following IEC TS 62257-7-1, or from IEC 62548.

9.3.3 Output AC current and power

If the renewable energy generation is very small compared to the diesel, then it may run with very little control, but as the contribution rises, the control over the system needs to be tighter to protect the generators.

Details on the integration of hybrid systems can be found in IEC TS 62257-7-4.

9.4 Variations on the architecture

A variation on this architecture is the integration of some battery storage designed to smooth the balance between renewable and diesel generation and eliminate brusque changes due to transitions between generators or issues with the weather. Additionally, in some applications the use of a battery for power stability may even allow for the genset to turned off during periods of high PV output, with the battery providing spinning reserve to turn the genset back on in case of sudden loss of PV generation.

The inverters need to have a communication system capable of coordinating them with both the batteries and the diesel generators. If the batteries are coupled into the system on the DC side of the inverter, then the inverters will need to be bi-directional inverter/chargers, as described in Clause 10, and to use the battery without the genset the inverters should be 'dual-mode' inverters that can transition between grid-synchronizing to grid-forming.

10 Bi-directional grid creating inverters that work with batteries – Type T4I systems, RE and diesel with energy storage

10.1 General

These are hybrid systems that have battery storage and that usually integrate generator sets or grid to perform periodic recharging of the batteries or back-up supply to the users when the rest of the system is unavailable.

A bi-directional grid forming inverter produces an AC grid from power supplied by the DC bus, whose voltage is determined by the battery voltage. The inverter is capable of transmitting energy to the AC bus, and also charging the batteries from the AC bus. Renewable energy sources may be coupled to the DC bus via charge controllers, or to the AC bus.

When DC renewable energy sources such as solar are coupled to the AC bus, this needs to be via a synchronizing inverter such as described previously, which follows the voltage and frequency of the grid as produced by the grid forming inverter. See Figure 4.