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Grid-connected photovoltaic power systems: Survey of inverter and related protection equipments

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IEA PVPS

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Implementing Agreement on Photovoltaic Power Systems

TASK V

Grid Interconnection of Building Integrated

and Other Dispersed Photovoltaic Power Systems

Report IEA PVPS T5-05: 2002

GRID-CONNECTED PHOTOVOLTAIC POWER SYSTEMS: SURVEY OF INVERTER AND RELATED PROTECTION EQUIPMENTS

December 2002

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Foreword

The International Energy Agency (IEA), founded in November 1974, is an autonomous body within the framework of the Organisation for Economic Co-operation and Development (OECD) which carries out a comprehensive programme of energy co-operation among its 23 member countries. The European Commission also participates in the work of the Agency.

The IEA Photovoltaic Power Systems Programme (PVPS) is one of the collaborative R&D agreements established within the IEA, and since 1993 its participants have conducted various joint projects on the photovoltaic conversion of solar energy into electricity.
The members are: Australia, Austria, Canada, Denmark, European Commission, Finland, France, Germany, Israel, Italy, Japan, Korea, Mexico, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, the United Kingdom and the United States.

This report has been prepared under the supervision of PVPS Task V by

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in co-operation with experts of the following countries:

Australia, Austria, Denmark, Germany, Italy, Japan, Mexico, the Netherlands, Portugal, Switzerland, the United Kingdom and the United States

and approved by the Executive Committee of the PVPS programme.

The report expresses as accurately as possible the international consensus of opinion on the subjects addressed.

ABSTRACT AND KEYWORD

This report summarises the data obtained from survey of recent inverter technology and inverter protection equipments for grid interconnected PV systems. The results are based on the surveys using questionnaire to identify the current status of grid-interconnection inverter. This report was written as a reference for people interested to install grid-connected PV systems, electric utility company personnel, manufactures and researchers.

Keywords: Photovoltaic power generation, Grid interconnection, Utility distribution system, PV inverters, Inverter protection, Harmonics, Power factor, Islanding protection

EXECUTIVE SUMMARY

Background and objectives

Grid interconnection of photovoltaic (PV) power generation system has the advantage of more effective utilisation of generated power. However, the technical requirements from both the utility power system grid side and the PV system side need to be satisfied to ensure the safety of the PV installer and the reliability of the utility grid. Clarifying the technical requirements for grid interconnection and solving the problems are therefore very important issues for widespread application of PV systems.

The International Energy Agency (IEA), Implementing Agreement on Photovoltaic Power Systems (PVPS) Task V: *Grid Interconnection of Building Integrated and Other Dispersed Photovoltaic Power Systems* has conducted research into the grid interconnection issues through a process of international collaboration. The main objective of Task V was to develop and verify technical requirements, which may serve as technical guidelines for grid interconnection of building integrated and other dispersed PV systems.

Grid interconnection of PV systems is accomplished through the inverter, which convert DC power generated from PV modules to AC power used for ordinary power supply for electric equipments. Inverter system is therefore very important for grid connected PV systems. In order to achieve the objectives of Task V, survey for current inverter technology has done by distributing questionnaires to inverter manufactures. This report shows the result of survey.

Findings

Survey for status of inverter performance has been conducted by summarising the responses from manufactures. Surveyed subjects were as follows.

- Inverter Circuit and Control
  Type of conversion, Switching devices
  Grid condition (Electrical system, Voltage, Frequency)
  Inverter power ratings
  AC/DC voltage and frequency ratings
  Harmonic current
  Power factor
  Conversion efficiency
  Isolation between AC and DC
  Inverter control
  Operating environment (Temperature, Installation requirements, Audible noise, EMC standards)
- Protective Functions
  AC/DC protective functions
  Transient overvoltage protection
  Islanding protection
  Disconnecting/ restart procedure
  Location of protective functions
- System
  Cost of inverter systems
  Size and weight of inverter systems
  Other comments

Inverter technology is very important to have reliable and safety grid interconnection operation of PV system. It is also required to generate high quality power to AC utility system with reasonable cost. To meet with these requirements, up to date technologies of power electronics are applied for PV inverters. By means of high frequency switching of semiconductor devices with PWM (Pulse Width Modulation) technologies, high efficiency conversion with high power factor and low harmonic distortion power can be generated. The microprocessor based control circuit accomplishes PV system output power control. The control circuit also has protective functions, which provide safety grid interconnection of PV systems. Reduction of inverter system cost has been accomplished.

Conclusions

According to the survey, PV grid connection inverters have fairly good performance. They have high conversion efficiency and power factor exceeding 90% for wide operating range, while maintaining current harmonics THD less than 5%.

Cost, size and weight of PV inverter reduced recently, because of technical improvement and progress of circuit design of inverter and integration of required control and protection functions into inverter control circuit. The control circuit also provides sufficient control and protection functions like maximum power tracking, inverter current control and power factor control.

Still, there are some subjects that are not proven yet. Reliability, life span and maintenance needs should be certified through the long-term operation of PV system. Further reduction of cost, size and weight is required for more utilisation of PV systems. In future, if PV systems are widely spread, EMC could be the one subject for consideration.

1. Introduction

Task V is a working group of the International Energy Agency (IEA), Implementing Agreement on Photovoltaic Power Systems (PVPS). The title of the working group is "Grid Interconnection of Building Integrated and Other Dispersed Photovoltaic Power Systems."

The main objective of Task V is to develop and verify technical requirements that may serve as pre-normative technical guidelines for the network interconnection of building-integrated and other dispersed photovoltaic (PV) systems. These technical guidelines are intended to ensure the safe, reliable and low-cost interconnection of PV systems to the electric power network. Task V considers PV systems connected to the low-voltage network with a typical peak power rating of 1 to 50 kilowatts.

After the completion of first stage, Task V was extended to complete work on a new Subtask 50 entitled "Study on Highly Concentrated Penetration of Grid-connected PV Systems". Subtask 50 contains four subjects. They are:

Subject 51: "Reporting of PV system grid-interconnection technology"
Subject 52: "Research on Islanding"
Subject 53: "Experiences (performances) of high penetration PV systems"
Subject 54: "Capacity of the PV systems"

This report deals with one topic of Subject 51, "Reporting of PV system grid-interconnection technology". One of the important technologies for grid-connected PV system is the inverter technology, which convert PV module DC output power to AC power.

Grid interconnection of PV systems is accomplished through the inverter, which convert DC power generated from PV modules to AC power used for ordinary power supply for electric equipments. Inverter system is therefore very important for grid connected PV systems. In order to achieve the objectives of Task V, survey for current inverter technology has done by distributing questionnaires to inverter manufactures. The survey of PV inverter technologies has also done in completed subtask 10 work and summarized in task V report "GRID-CONNECTED PHOTOVOLTAIC POWER SYSTEMS: SUMMARY OF TASK V ACTIVITIES FROM 1993 TO 1998" Report IEA PVPS T5-03: 1999. Detailed report was not published as PVPS public report. This report shows the result of survey.

Surveyed subjects were as follows.

- Inverter Circuit and Control
  Type of conversion, Switching devices
  Applicable grid conditions (Electrical system, Voltage, Frequency)
  Inverter power ratings
  AC/DC voltage and frequency ratings
  Harmonic current
  Power factor
  Conversion efficiency
  Isolation between AC and DC
  Inverter control
  Operating environment (Temperature, Installation requirements, Audible noise, EMC standards)
- Protective Functions
  AC/DC protective functions
  Transient overvoltage protection
  Islanding protection

Disconnecting/ restart procedure
Location of protective functions

- System
  Cost of inverter systems
  Size and weight of inverter systems
  Other comments

Inverter technology is the key technology to have reliable and safety grid interconnection operation of PV system. It is also required to generate high quality power to AC utility system with reasonable cost. To meet with these requirements, up to date technologies of power electronics are applied for PV inverters. By means of high frequency switching of semiconductor devices with PWM (Pulse Width Modulation) technologies, high efficiency conversion with high power factor and low harmonic distortion power can be generated. The microprocessor based control circuit accomplishes PV system output power control. The control circuit also has protective functions, which provide safety grid interconnection of PV systems. Reduction of inverter system cost has been accomplished.

2. Outline of Inverter Technology

In the grid-interconnected photovoltaic power system, the DC output power of the photovoltaic array should be converted into the AC power of the utility power system. Under this condition, an inverter to convert DC power into AC power is required. There are various types of inverters as shown in Fig. 2.1. The line commutated inverter uses a switching device like a commutating thyristor that can control the timing of turn-on while it cannot control the timing of turn-off by itself. Turn-off should be performed by reducing circuit current to zero with the help of supplemental circuit or source. Conversely, the self-commutated inverter is characterized in that it uses an switching device that can freely control the ON-state and the OFF-state, such as IGBT and MOSFET. The self-commutated inverter can freely control the voltage and current waveform at the AC side, and adjust the power factor and suppress the harmonic current, and is highly resistant to utility system disturbance. Due to advances in switching devices, most inverters for distributed power sources such as photovoltaic power generation now employ a self-commutated inverter.

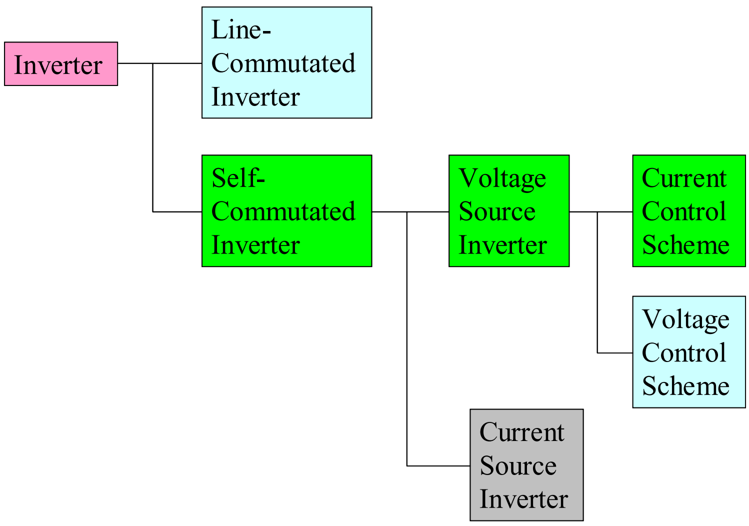

Fig. 2.1 Classification of inverter type

The Self-commutated inverters include voltage and current types. The voltage type is a system in which the DC side is a voltage source and the voltage waveform of the constant amplitude and variable width can be obtained at the AC side. The current type is a system in which the DC side is the current source and the current waveform of the constant amplitude and variable width can be obtained at the AC side. In the case of photovoltaic power generation, the DC output of the photovoltaic array is the voltage source, thus, a voltage type inverter is employed. The voltage type inverter can be operated as both the voltage source and the current source when viewed from the AC side, only by changing the control scheme of the inverter. When control is performed as the voltage source (the voltage control scheme), the voltage value to be output is applied as a reference value, and control is performed to obtain the voltage waveform corresponding to the reference value. PWM control is used for waveform control. This system determines switching timing by comparing the waveform of the sinusoidal wave to be output with the triangular waveform of the high-frequency wave, leading to a pulse row of a constant amplitude and a different width. In this system, a waveform having less lower-order harmonic components can be obtained.

On the other hand, when control is performed as the current source (the current control scheme), the instantaneous waveform of the current to be output is applied as the reference value. The switching device is turned on/turned off to change the output voltage so that the actual output current agrees with the current reference value within certain tolerance. Although the output voltage waveforms of the voltage control scheme and the current control scheme look substantially same, their characteristics are different because the object to be controlled is different.

Table 2.1 shows the difference between the voltage control scheme and the current control scheme. In a case of the isolated power source without any grid interconnection, voltage control scheme should be provided. However, both voltage-control and current-control schemes can be used for the grid interconnection inverter. The current-controlled scheme inverter is extensively used for the inverter of a grid interconnection photovoltaic power system because a high power factor can be obtained by a simple control circuit, and transient current suppression is possible when any disturbances such as voltage changes occur in the utility power system. Fig. 2.2 shows the configuration example of the control circuit of the voltage-type current-control scheme inverter.

Table 2.1 Difference between the voltage control scheme and the current control scheme inverter

	Voltage control scheme	Current control scheme
Inverter main circuit	Self-commutated voltage source inverter (DC voltage source)	
Control objective	AC voltage	AC current
Fault short circuit current	High	Low (Limited to rated current)
Stand alone operation	Possible	Not possible

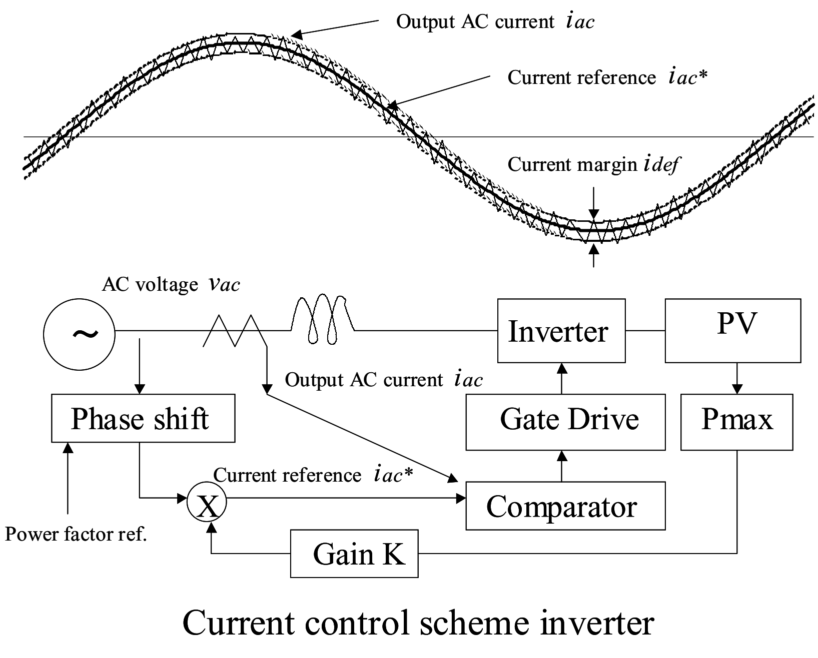

Fig. 2.2 Configuration example of the control circuit of the voltage-type current-control scheme inverter

3. Survey Results for Inverter Circuit Technologies

In this chapter, the results of the survey are summarized regarding main circuit system of the inverter, semiconductor switching devices used therein, operational conditions of inverter, characteristics of inverters and control systems.

3.1 Types of inverter

As described in Chapter 2, there are various types of inverter system configuration. However, a self-commutated inverter is usually used in a system with a relatively small capacity of several kW, such as a photovoltaic power system. This situation is reflected well by the results of this survey. The results of the survey show that the self-commutated voltage type inverter is employed in all inverters with a capacity of 1 kW or under, and up to 100 kW. The output waveform is adjusted by PWM control, which is capable of obtaining the output with fewer harmonic. The current control scheme is mainly used as described in Fig.3.1. However, some inverters employ the voltage control scheme. As described in Chapter 2, the current control scheme is employed more popularly because a high power factor can be obtained with simple control circuits, and transient current suppression is possible when disturbances such as voltage changes occurs in the utility power system. In the current control scheme, operation as an isolated power source is difficult but there are no problems with grid interconnection operation.

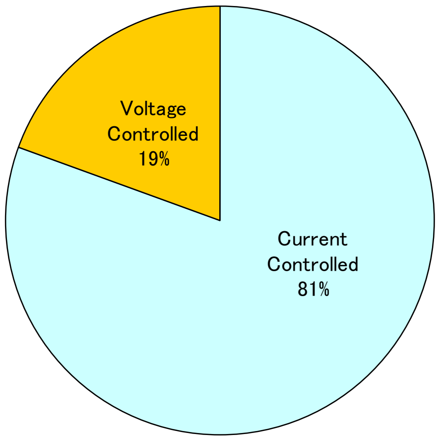

Fig. 3.1 Ratio of current controlled scheme and voltage controlled scheme inverters

3.2 Switching Devices

To effectively perform PWM control for the inverter, high frequency switching by the semiconductor-switching device is essential. Due to advances in the manufacturing technology of semiconductor elements, these high-speed switching devices can now be used. Insulated Gate Bipolar Transistor (IGBT) and Metal Oxide Semiconductor Field Effect Transistor (MOSFET) are mainly used for switching devices. IGBT is used in 62% of the surveyed products, and MOSFET is used in the remaining 38%. Regarding differences in characteristics between IGBT and MOSFET, the switching frequency of IGBT is around 20 kHz; IGBT can be used even for large power capacity inverters of exceeding 100 kW, while the switching frequency of MOSFET is possible up to 800 kHz, but the power capacity is reduced at higher frequencies. In the output power range between 1 kW to 10 kW, the switching frequency is 20 kHz, thus, both IGBT and MOSFET can be used.
High frequency switching can reduce harmonics in output current, size, and weight of an inverter.

3.3 Operational Conditions

3.3.1 Operational AC voltage and frequency range

Inverter should be operated without problem for normal fluctuations of voltage and frequency at the utility grid side. Accordingly, the operable range of the inverter is determined according to the conditions at the AC utility grid side. Because the conditions of the distribution system for interconnection differ by country, the operable range of the inverter also differs by country. The standard voltage and frequency for a single phase circuit is 230V and 50 Hz in Europe, 101/202 V and 50/60 Hz in Japan, and 120/240V and 60 Hz in USA. The standard voltage and frequency for a three-phase circuit is 380/400V and 50 Hz in Europe, 202 V and 50/60 Hz in Japan, and 480V and 60 Hz in the USA. For these standard values, the inverter can be operated substantially without any problems within the tolerance of +10% and –15% for the voltage, and ± 0.4 to 1% for the frequency.

3.3.2 Operational DC voltage range

On the other hand, the operable range of the DC voltage differs according to rated power of the inverter, rated voltage of the AC utility grid system, and design policy, and various values are employed. In this survey, the operable range of the DC voltage for a capacity of 1 kW or below includes 14-25V, 27-50V, 45-100V, 48-120V, and 55-110V. In addition, the operable DC voltage range for a capacity of 1 kW to 10 kW includes 40-95V, 72-145V, 75-225V, 100-350V, 125-375V, 139-400V, 150-500V, 250-600V, and 350-750V. The operable DC voltage range for a capacity of 10 kW or over includes 200-500V, and 450-800V.

3.3.3 Applicable PV array power

Fig. 3.2 shows the results of the survey for applicable rated power of the PV array to the rated output power of inverter. Although it cannot be defined unconditionally because the array output power differs according to conditions (latitude, angle of inclination of module, etc.) in an area in which the photovoltaic power system is installed, the PV array of the rated output power of about 1.3 times the rated output power of the inverter can be applied on average.

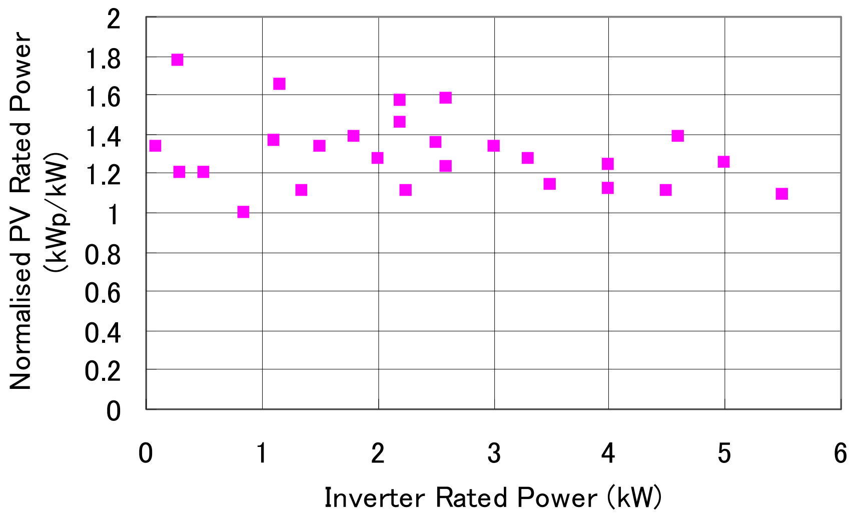

Fig. 3.2 PV rated power distribution

3.4 AC harmonic current from inverter

For the characteristic of the inverter, minimization of harmonic current production is required. As described in the Report of Task 5 "Utility Aspects of Grid Interconnected PV systems," Report IEA-PVPS T5-01: 1998, December 1998, harmonic current adversely affects load appliances connected to the distribution system, and can impair load appliances when the harmonic current is increased.
As described in Chapter 2, because the PWM control scheme is employed as the output waveform control of the inverter, the harmonic current from the inverter is very small, raising fewer problems. The results of this survey show that Total Harmonic Distortion (THD), the total distortion factor of the current normalized by the rated fundamental current of the inverter, is 3 to 5%.

3.5 Power factor

If the power factor reduces in the AC output of the inverter, influences such as voltage fluctuations in the power distribution system occur. Therefore, it is thus important not to let the power factor of the AC output of the inverter drop. The results of this survey show that a power factor of substantially 100% is obtained with the rated output, and a power factor of 90% or over is obtained even when the output power drops to 10%. Because the current control scheme is widely used in inverters, the power factor is usually controlled to be 100%. Some inverters have the capability to adjust the power factor. In an inverter using the current control scheme, adjustment is performed by shifting the phase of the reference value of the AC current with respect to the AC voltage. The purpose of adjusting the power factor is to suppress the voltage rise in the distribution system due to the output power from the photovoltaic power system. Power flow from PV system to distribution system causes voltage rise at the interconnecting point, which may cause excessive voltage of the distribution line.

3.6 Inverter conversion efficiency

If the power conversion efficiency of the inverter is small, the power generated by the PV array cannot be output to the AC utility system effectively. It is thus necessary to increase the conversion efficiency as high as possible. In addition, in the photovoltaic power system, the output power is changed by the quantity of solar radiation, the time period when output power is less than the rated PV array power is longer. Thus, inverter conversion efficiency is preferably higher over an extensive output range. To improve efficiency, it is important to use sophisticated circuit technology, for example, to reduce conduction losses of semiconductor switching devices and losses caused by switching, and reduce losses caused by cables. Some inverters had been less efficient, but efficiency has been improved in recent years.

Fig. 3.3 shows a summary of the results of a survey of the conversion efficiency. High efficiency is obtained over an extensive output power range, and the efficiency of 90% is obtained even when the output power is 10% of the rated value, and the maximum efficiency of 94-96% is obtained. It can be concluded from this finding that sufficient characteristics can be obtained for the efficiency of an inverter for the photovoltaic power system.

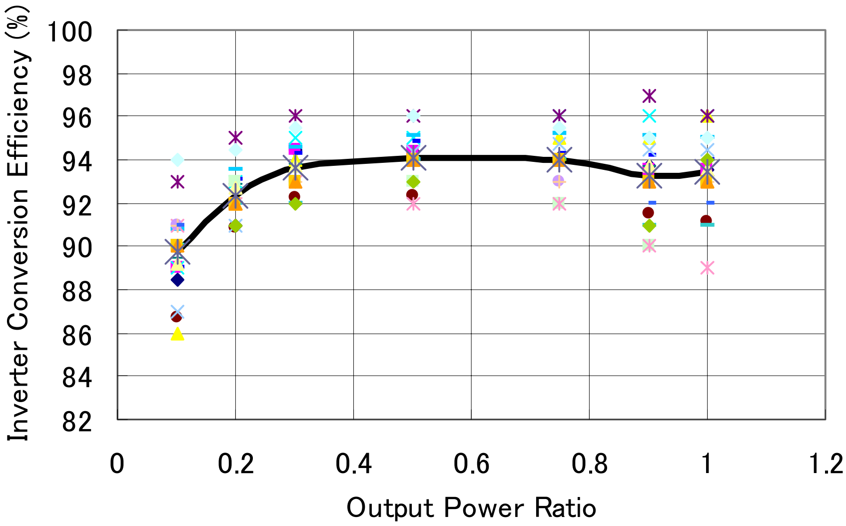

Fig. 3.3 Inverter Conversion Efficiency

3.7 Isolation between AC and DC

It is necessary to prevent the direct current from flowing at the AC side. This can be done for example by isolating the DC circuit at the PV array side and the AC circuit at the utility distribution system side. If the direct current flows at the AC side, a transformer in the power distribution system could be saturated and overheat, or a large harmonic current would occur.

To isolate the DC circuit and the AC circuit, a simple method is to install an isolating transformer at the output side of the inverter. However, in this case, a transformer of a commercial frequency is required, raising the problem that the volume and the weight of the entire inverter system are increased. Accordingly, a system is employed in which a high frequency AC circuit is provided for the inverter circuit between the direct current and the commercial AC system, and a transformer is installed at this high-frequency part to isolate the DC circuit and the commercial AC circuit. In this case, although a high-frequency circuit is required, the higher the frequency is the smaller the capacity and the weight of the transformer are, so the size and the weight of the transformer are reduced. In addition, an inverter of a transformer-less system can be provided in which no isolating transformer is used. In this case, a circuit for detecting the DC component superposed on the AC circuit, and a grounding detection circuit in the DC circuit is required. However, capacity and weight can be minimized because the transformer is omitted.

The results of this survey include the inverter system using a commercial transformer or high-frequency transformer, as well as a transformer-less inverter system. The high-frequency transformer and the transformer-less inverter constitute the majority.

3.8 Inverter power control scheme

Most of the power control schemes of inverters follow the maximum output of the PV array determined by the level of solar radiation at the DC side, and most employ the Maximum Power Point Tracking Control capable of constantly obtaining the maximum output according to the quantity of solar radiation. In addition, a very small number of power control schemes control the DC voltage to be constant.

Constant control of the power factor at the AC side is usually performed by output current control, while output voltage control or output power control are performed in some examples.

3.9 Inverter start-up and stop operation condition for normal operation

To start-up the grid interconnected photovoltaic power system, voltage and frequency at the AC side must be within the specified range, and the PV array must generate power in the presence of solar radiation. At night time without any solar radiation, the inverter must automatically stop operation and must automatically start operation when there is solar radiation. The conditions for stopping the operation of the inverter are summarized below in the survey. As a result, most inverters start operation after checking that the voltage condition at the AC side is within the operational range, monitoring that the DC voltage or the DC output power is generated, and then performing the check and waiting for from 10 seconds to several minutes. In addition, most inverters stop operation immediately if the voltage condition at the AC side deviates from the operational range, or after waiting for a maximum of 20 minutes after the DC voltage or the DC power drops below the specified value if the voltage condition at the AC side is within the operational range.

3.10 Power source for inverter control circuit

Connection of control power source of the inverter to the DC side or to the AC system side is determined by the design philosophy of the total system. As shown in Fig. 3.4, the results of this survey show that many of the control power sources are connected to the DC side, and a small number are connected to the AC side. Some are connected to both in case the capacity is relatively large, and the reliability of the control circuit must be improved.

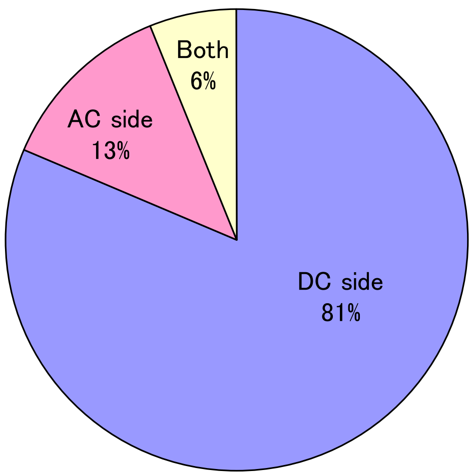

Fig. 3.4 Power source for inverter control circuit

When the control power source is connected to the DC side, the control circuit is operated normally if the quantity of solar radiation is increased, and operation of the inverter is started. When the quantity of solar radiation is reduced, and the output of the PV array is reduced, the control power source becomes powerless, and the inverter stops normally. This system is characterized in that that operation is automatically started and stopped. In addition, if photovoltaic power generation gives no output at nighttime, the power for the control circuit is not required. Conversely, if the control power source is obtained from the AC side, it is characterized in that operation is continuous even when the quantity of solar radiation is low. However, it is necessary to supply power to the control power source from the utility system side even at nighttime.

3.11 Operational environment

It is also important to grasp the installation environment of the inverter for the photovoltaic power system, and to take into consideration the influence of the inverter on the surrounding environment. The installation conditions of the inverter (the indoor installation specification or the outdoor installation specification), the ambient temperature condition, the requirements for waterproofness and dusproofness, actual audible noise level of the inverter, and applicable regulations for EMC (electro-magnetic compatibility), etc. are summarized below.

Comparing indoor installation specification and outdoor installation specification, the indoor installation specification occupies about 80%. This is considered to be attributable to the fact that many photovoltaic power systems for grid interconnection are installed in general houses, and the inverters are often installed indoors. The inverters may be installed on external walls. However, even in such cases, many inverters might install in external boxes. For the outdoor installation specification, waterproof and dustproof performance is requested. However, even for the indoor installation specification, waterproof and dustproof performance is often requested. In some outdoor installation specifications, waterproof and dustproof performance is not requested. These are cases in which the inverters are installed in external boxes even if they are of the indoor installation specification. Fig. 3.5 shows the breakdown.

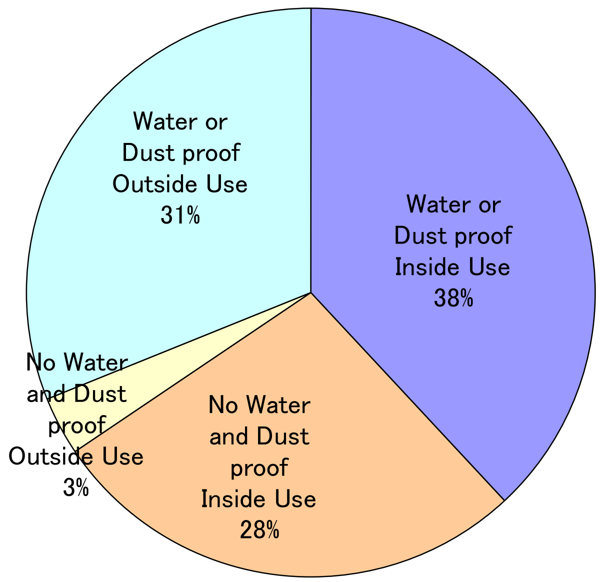

Fig. 3.5 Breakdown of installation environment

Regarding ambient temperature condition, minimum temperatures for the indoor installation specification are –25°C, -15°C, -10°C and 0°C, while the maximum temperatures are 40°C, 50°C, and 85°C. The minimum temperature and the maximum temperature for outdoor installation specification are –25°C to 60°C, and –10°C to 50°C. Generally, it is considered that an extensive temperature range is required for the outdoor installation specification. However, no significant results are obtained in the results of the survey.

The audible noise level of the inverter is as lows as 35 to 40 dBA at a distance of about 1 m from an inverter with a rated capacity of 10 kW or under. However, in some inverters having a power capacity exceeding 10 kW, the audible noise level exceeds 50 dBA. This is considered attributable to the audible noise caused by the cooling fan of the inverter.

Regarding the EMC standard, the standard value of each country based on the IEC standard is applied to most inverters.

4. Survey Results for Inverter Protective Functions

The inverters of the photovoltaic power system for grid interconnection have a function for performing output control and safely disconnecting and stopping of the inverter if any abnormality in the system or at the utility grid side occurs. Here, the protective function of the inverter for grid interconnection is summarized.

4.1 Required Protection Devices or Functions

Protective functions include protection for the DC side, protection for the AC side, and others. The protective functions for the DC side include those for DC overpower, DC overvoltage, DC undervoltage, DC overcurrent, and detection of DC grounding faults. Protective functions for the AC side include AC overvoltage, AC undervoltage, AC overcurrent, frequency increase, frequency drop, and detection of AC grounding, and further include protective functions such as detecting any superposition of the direct current in some systems employing transformer-less inverters. Other protective functions include those for temperature rise. These functions are performed using detection results of voltage and current in the control circuit, and information from various kinds of sensors, and protection is performed integrally with the control circuit.
These protections are accompanied by operation of the inverter system, and protection against lightning and surge voltage is required separately. These transient overvoltage protections are performed by a surge arrester (zinc oxide element etc.) and a varistor, both at DC and AC sides, in some cases a filter is used at the AC side.

4.2 Protective Functions for Islanding Phenomena

Regarding an islanding operation of the photovoltaic power system, it has been proved that the probability of islanding is low, and the risk of islanding operation is also low (refer to the Report of Task 5 “Probability of islanding in utility networks due to grid connected photovoltaic power systems” Report IEA-PVPS T5-07: 2002, February 2002., and “Risk analysis of islanding of photovoltaic power systems within low-voltage distribution networks” Report IEA-PVPS T5-08: 2002, February 2002). Nevertheless, to prevent islanding operation more reliably manner, it is considered that the islanding operation detection function should be incorporated in the control circuit of the inverter. The islanding operation detecting method is described in the Report of Task 5: “Evaluation of islanding detection methods for photovoltaic utility-interaction power systems” Report IEA-PVPS T5-09: 2002, February 2002. Here, the actual employment status of the islanding operation detection function for the inverter products in photovoltaic power generation is summarized.

Most inverters have a detection function for voltage and frequency window to limit the islanding operation generation range. In addition, many inverters have a islanding operation detection function, besides those for detecting of voltage and frequency window, which is incorporated in the control circuit of an inverter. Islanding operation detection includes detecting rate of change of frequency, voltage phase jump, and monitoring three-phase voltage drop for the passive method. Further, in an active method, schemes including frequency shift, active frequency drift (AFD), ENS (impedance measurement), and reactive power fluctuation are employed.
Among these systems, a separate device from the control circuit must be fitted for ENS. In other systems, detection can be performed in the control circuit using software without any increase of cost. As described in the Report of Task 5, it is necessary to note that each islanding operation detection system has a non-detectable range (dead zone).

4.3 Disconnection and Restarting Procedure for Protection

If the protective circuit of the inverter for the grid interconnection is operated, the inverter must be disconnected rapidly from the utility distribution system. However, the inverter is preferably automatically restarted after any accident or a problem is eliminated. Further, in some cases, it is considered that the protective device reacted so sensitively due to switching of distribution system side or instantaneous voltage sag, and the inverter is preferably rapidly restored, even when disconnected once. Survey was carried out on the stopping and re-starting method during protection.

Regarding actions when the protective device is operated, all switching devices for the inverter circuit are turned off (by the gate blocking), and the circuit breaker or the relay contact is turned off. In some inverters, only gate blocking is performed when a passive islanding detection that has high detection sensitivity is activated, and the circuit breaker is not opened. This takes into consideration that inverters can be re-started rapidly when operation of the protective device is activated unnecessary.
Re-starting methods after recovery from an fault include using an automatic re-starting function after checking that the conditions at DC and AC sides are restored in every inverter. The conditions at the DC and AC sides are the same as the normal starting conditions.

The waiting times before re-starting after the conditions at the DC and AC sides are restored are from 5 seconds (minimum) to 4 minutes (maximum).

4.4 Location of Inverter Protective Functions

In a case in which the protective function of the inverter is integrated with that of the control circuit, a special protective device need not be added, and protection can be provided simply by changing the software for the control circuit, which does not increase cost. The results of this survey show that most inverters are built into the control circuit. The exception is active islanding detection method by ENS described in 4.2 above. In this case, a detector must be added. This detector may be incorporated in the inverter hardware as well as installed as a separate unit.

5. Inverter System Cost, Size and Weight

Finally, the results of the survey are shown for cost, volume, and weight of the inverter system including controller, protection device, etc.

5.1 Inverter System Cost

The cost of the inverter system is an important element when considering the economy of a photovoltaic power system. Here, the cost of the inverter system including the control device and the protective device is summarized. The cost of the inverter system was also summarized in the survey of 1998. According to the results of the previous survey, the difference in the cost was large by country and manufacturer, even when the power capacity of the inverter system was the same, and the cost varied greatly. However, the cost is substantially stabilized in this revised survey. Fig. 3.6 shows the results of the cost survey in the previous survey (old survey) and the revised survey (new survey) at the same time. Cost is indicated in USD when survey replies were in the currency of each country. The currency exchange rate was based on the values in 2001; 1 German Mark was 0.46 US dollar, 1 Yen was 0.0075 USD, and 1 Euro was 1.07 USD.

As a result, it is shown that the cost of the inverter system is reduced more in the present survey than in the previous survey on the whole, and the cost for 1 kW is 800 USD or less in the present survey. It is also shown that the cost per kW decreases as inverter power capacity increases. Differences by country and manufacturer are also reduced, and the cost level becomes similar worldwide. It is expected that the cost of the inverter system will be further reduced.

Fig. 5.1 shows a summary of the inverter system cost with a capacity from 1 kW to 6 kW. The cost of the inverter for the AC module with a capacity as low as 100 W to 300 W was 1 USD/W in the previous survey, while it is 1.2 to 1.9 USD/W in the present survey, showing that the cost has slightly increased. In addition, for the system with a large capacity exceeding 10 kW, cost per kW is apt to be reduced when capacity is increased. However, this cannot be concluded uniquely because cost depends on the number of production, and cost per kW increases if the number manufactured is small.

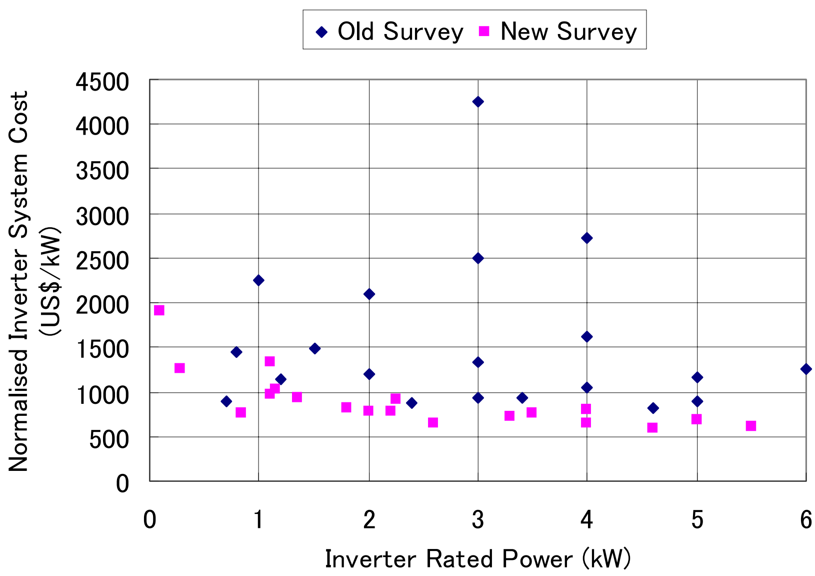

Fig. 5.1 Inverter system cost

5.2 Inverter System Size

Fig. 5.2 shows the result of the survey on the volume of inverter systems per kW against inverter system power capacity. The inverter system volume, which is normalized in terms of kW decreases as the capacity of the inverter increases. This is because the semiconductor switching device stack, the control device, etc., determines the volume of the inverter while the volume differs less when the power capacity is changed.

In any case, the volume of an inverter system with a capacity up to 6 kW is in the range between 10 and 30 liters, and is permissible even when the inverter system is installed indoors in residential houses.

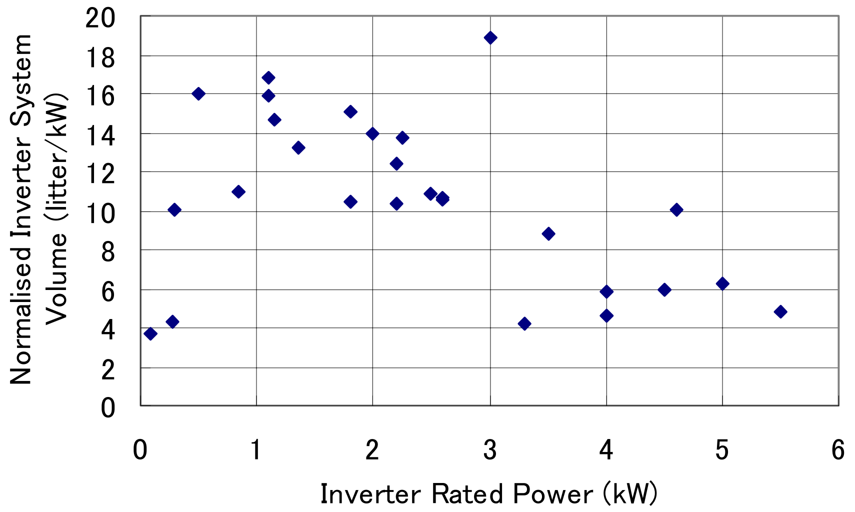

Fig. 5.2 Volume of Inverter Systems

5.3 Inverter System Weight

The weight of the inverter system differs considerably according to presence/absence of the isolating transformer (in particular, an isolating transformer of a commercial frequency). Fig. 3.8 shows the inverter system weight normalized in terms of kW for inverter system power capacity. The transformer-less inverter or inverter using a high-frequency isolating transformer has a constant weight of about 5 kg per kW. When an isolating transformer of a commercial frequency is used, the weight per kW increases, especially when the rated output power decreases. This is because the ratio of the weight of the transformer to the total inverter system weight is large if a transformer of a commercial frequency is used. In the inverter for a household photovoltaic power system, weight reduction is important when the inverter is installed indoors or is mounted on an external wall. Accordingly, employment of a system without an isolating transformer of a commercial frequency is recommended.

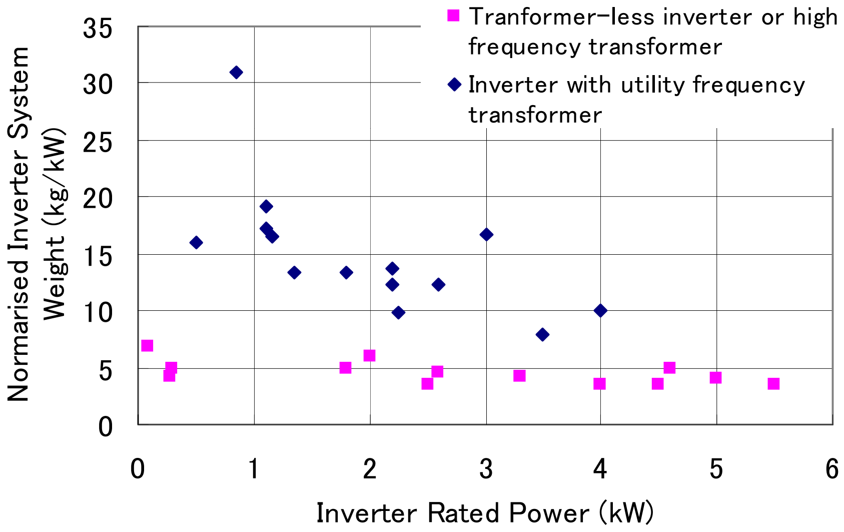

Fig. 5.3 Inverter System Weight

6. Conclusions

According to the survey, PV grid interconnection inverters have fairly good performance. They have high conversion efficiency and a power factor exceeding 90% over a wide operational range, while maintaining current harmonics THD less than 5%.

Cost, size, and weight of a PV inverter have been reduced recently, because of technical improvements and advances in the circuit design of inverters and integration of required control and protection functions into the inverter control circuit. The control circuit also provides sufficient control and protection functions such as maximum power tracking, inverter current control, and power factor control.

There are still some subjects as yet unproven. Reliability, life span, and maintenance needs should be certified through long-term operation of a PV system. Further reductions of cost, size, and weight are required for the diffusion of PV systems. In the future, if PV systems are widely diffused, EMC could be the one subject for consideration.

ANNEX A List of Survey Results

AUSTRIA

INVERTER (1)

Manufacture	Type	Power Capacity	Type of Conversion	Switching Devices	Nominal AC and DC Voltage	Operational AC Voltage and Frequency Ranges	Operational DC Voltage Ranges and DC Voltage Ripple	Applicable PV module size
Fronius International GmbH	FRONIUS IG 20 Ordinary Inverter	1,8 kW	Self-commutated PWM Current Control	IGBT 20kHz	AC: 230V 50Hz DC: 150 to 500V	Voltage: 230 V +10% -15% Frequency: 50 Hz +/- 0,2 Hz	150 to 500 V	2,5 kWp
Fronius International GmbH	FRONIUS IG 30 Ordinary Inverter	2,5 kW	Self-commutated PWM Current Control	IGBT 20kHz	AC: 230V 50Hz DC: 150 to 500V	Voltage: 230 V +10% -15% Frequency: 50 Hz +/- 0,2 Hz	150 to 500 V	3,4 kWp

INVERTER (2)

Manufacture	Type	Grid Electrical System	Harmonic Current	Power Factor At rated Power	Availability of power factor control	Inverter Conversion Efficiency	Isolation Transformer	DC Injection Countermeasures
Fronius International GmbH	FRONIUS IG 20 Ordinary Inverter	1 phase/ 3 wires	THD: 5% Each: 3%	100%	No(Fixed)	0,1Pn: 88,5% 0,2 Pn: 91% 0,3Pn: 94,5% 0,5Pn: 94,4% 0,75Pn:94,1% 0,9Pn: 93,7%	Not mandatory But used (High frequency transformer)	
Fronius International GmbH	FRONIUS IG 30 Ordinary Inverter	1 phase/ 3 wires	THD: 5% Each: 3%	100%	No(Fixed)	0,1Pn: 89% 0,2 Pn: 92% 0,3Pn: 94,5% 0,5Pn: 94,4% 0,75Pn:94% 0,9Pn: 93,5%	Not mandatory But used (High frequency transformer)	

INVERTER (3)

Manufacture	Type	Inverter Power Control		Normal Startup and Stop Condition		Control Power Source	Operational Environment			
		DC side	AC side	Startup	Stop		Tempera-ture Range	Installation Requirements	Audible Noise	EMC Standards
Fronius International GmbH	FRONIUS IG 20 Ordinary Inverter	Maximum Power Tracking	AC Current Control	DC Voltage and AC Voltage in Operating Windows for 20 sec.	AC voltage and frequency outside windows for 0,2 sec. Impedance jump> 0,5ohm; 5 sec	DC side	-20 to +50 °C reference 20 °C	Both Inside and Outside Use Water proof required but no dust proof need		EN-50081-1 EN-50082-1
Fronius International GmbH	FRONIUS IG 30 Ordinary Inverter	Maximum Power Tracking	AC Current Control	DC Voltage and AC Voltage in Operating Windows for 20 sec.	AC voltage and frequency outside windows for 0,2 sec. Impedance jump> 0,5ohm; 5 sec	DC side	-20 to +50 °C reference 20 °C	Both Inside and Outside Use Water proof required but no dust proof need		EN-50081-1 EN-50082-1

PROTECTIVE DEVICES OR FUNCTIONS

Manufacture	Type	Protective Functions		Transient Overvoltage Protection/Devices		Islanding Protection	Disconnection Procedure for Protection	Restart Procedure after Fault Clearance
		DC side	AC side	DC side	AC side			
Fronius International GmbH	FRONIUS IG 20 Ordinary Inverter	OV Grounding: warning indication	OV: +10% 0,2 sec UV: -15% 0,2 sec OC: 1,2 Inom OF/UF: +/-0,2 Hz Grounding: <1MOhm	Passive protection network	Metal Oxide surge arrester	Included Active: impedance measurement, frequency shift	Gate blocking and opening of circuit breaker	Automatic Restart 20 sec. after AC and DC side conditions restored; can be changed by software
Fronius International GmbH	FRONIUS IG 30 Ordinary Inverter	OV Grounding: warning indication	OV: +10%0,2 sec UV: -15% 0,2 sec OC: 1,2 times OF/UF: +/-0,2 Hz Grounding: <1MOhm	Passive protection network	Metal Oxide surge arrester	Included Active: impedance measurement, frequency shift	Gate blocking and opening of circuit breaker	Automatic Restart 20 sec. after AC and DC side conditions restored; can be changed by software

OTHERS

Manufacture	Type	Location of Protective Functions (Relays)	Price of Inverter and Protective Devices	Size and Weight of Inverter and Transformer	Comments	Date of Information
Fronius International GmbH	FRONIUS IG 20 Ordinary Inverter	All included in inverter	Not available	Total 366x338x220 mm 9 kg	-Multifunctional custom-specific LC Display with information about operating parameters and error messages in case of problem	2002/01
Fronius International GmbH	FRONIUS IG 30 Ordinary Inverter	All included in inverter	Not available	Total 366x338x220 mm 9 kg	-Multifunctional custom-specific LC Display with information about operating parameters and error messages in case of problem	2002/01

GERMANY

INVERTER (1)

Manufacture	Type	Power Capacity	Type of Conversion	Switching Devices	Nominal AC and DC Voltage	Operational AC Voltage and Frequency Ranges	Operational DC Voltage Ranges and DC Voltage Ripple	Applicable PV module size
Kaco Gerätetechnik GmbH	PVI 2600-2,0 kW String Inverter	2 kW	Self-commutated PWM Current Control	IGBT 20kHz	AC: 230V 50Hz DC: 350 to 750V	Voltage: 230 V +15% -30% Frequency: 50 Hz	350 to 750 V Ripple: No Limit	2,56 kWp
Kaco Gerätetechnik GmbH	PVI 2600-2,6 kW String Inverter	2,6 kW	Self-commutated PWM Current Control	IGBT 20kHz	AC: 230V 50Hz DC: 350 to 750V	Voltage: 230 V +15%, -30 % Frequency: 50 Hz	350 to 750 V Ripple: No Limit	3,2 kWp
Kaco Gerätetechnik GmbH	PVI 5000 String Inverter	4,6 kW	Self-commutated PWM Current Control	IGBT 20kHz	AC: 230V 50Hz DC: 350 to 750V	Voltage: 230 V +15%, -30 % Frequency: 50 Hz	350 to 750 V Ripple: No Limit	6,4 kWp
Karschny	Solwex 1065E String Inverter	1,1 kW			AC: 230V 50Hz DC: 65V			
G&H Elektronik GmbH	SB 1500 String Inverter	1,15 kW (Ta=40°C)	Self-commutated PWM Voltage Control	MOSFET 16kHz	AC: 230V 50Hz	Voltage: 196 to 253 V Frequency: 49,8 to 50,2 Hz	125 to 375 V	1,9 kWp
G&H Elektronik GmbH	SB 2000 String Inverter	1,8 kW (Ta=40°C)	Self-commutated PWM Voltage Control	MOSFET 16kHz	AC: 230V 50Hz	Voltage: 196 to 253 V Frequency: 49,8 to 50,2 Hz	125 to 375 V	2,5 kWp
G&H Elektronik GmbH	SB 2500 String Inverter	2,2 kW (Ta=40°C)	Self-commutated PWM Voltage Control	MOSFET 16kHz	AC: 230V 50Hz	Voltage: 196 to 253 V Frequency: 49,8 to 50,2 Hz	125 to 375 V	3,2 kWp

Manufacture	Type	Power Capacity	Type of Conversion	Switching Devices	Nominal AC and DC Voltage	Operational AC Voltage and Frequency Ranges	Operational DC Voltage Ranges and DC Voltage Ripple	Applicable PV module size
Borsig Solar / skytron energy	NEG 500 String Inverter	0,5 kW	Self-commutated PWM Current Control	MOSFET 20-25kHz	AC: 230V 50Hz DC: 70 V	Voltage: 230 V +10 %, -15 % Frequency: 50 Hz +/- 0,4 %	55 to 110 V Ripple: 1% of DC current	0,6 kWp
SMA Regelsysteme GmbH	Sunny Boy 1100E String Inverter	1,1 kW	Self-commutated PWM Current Control	IGBT 20kHz	AC: 230V 50Hz (60Hz Optional) DC: 180 V	Voltage: 230 V +10 %, -15 % Frequency: 50 Hz +/- 0,4 %	139 to 400 V Ripple: 10%	1,5 kWp
SMA Regelsysteme GmbH	Sunny Boy 2500 String Inverter	2,2 kW	Self-commutated PWM Current Control	IGBT 16kHz	AC: 230V 50Hz (60Hz Optional) DC: 350 V	Voltage: 230 V +10 %, -15 % Frequency: 50 Hz +/- 0,4 %	250 to 600 V Ripple: 10%	3,45 kWp
SMA Regelsysteme GmbH	Sunny Boy 3000 String Inverter	2,6 kW	Self-commutated PWM Current Control	IGBT 16kHz	AC: 230V 50Hz (60Hz Optional) DC: 350 V	Voltage: 230 V +10 %, -15 % Frequency: 50 Hz +/- 0,4 %	250 to 600 V Ripple: 10%	4,1 kWp
Sunways	Sunways 5.02 String Inverter	5 kW	Self-commutated PWM (bang-bang) Current control	IGBT 13kHz	AC: 230V 50Hz DC: 350 to 650 V	Voltage: 230 V +10 %, -20 % Frequency: 50 Hz +/- 0,5 %	350 to 750 V	6,3 kWp
UfE GmbH	NEG 4 Grid connected Inverter	4 kW	Self-commutated PWM Current control	MOSFET 25kHz	AC: 230V 50Hz DC: 48 V	Voltage: 230V +10 %, -15 % Frequency: 50Hz +/- 0,5 %	40 to 95 V	5 kWp
Würth-Solargy	WE 500 NWR Parallel Inverter	0,84 kW	Self-commutated PWM Current control	MOSFET 30kHz	AC: 230V 50Hz DC: 34 V	Voltage: 230V +10 %, -15 % Frequency: 50Hz +/- 10 %	27 to 48 V Ripple: 5%	0,84 kWp

INVERTER (2)

Manufacture	Type	Grid Electrical System	Harmonic Current	Power Factor At rated Power	Availability of power factor control	Inverter Conversion Efficiency	Isolation Transformer	DC Injection Countermeasures
Kaco Gerätetechnik GmbH	PVI 2600-2,0 kW String Inverter	3 phase/ 4 wires	THD: 3% Max: 5%	99%	No (Fixed)	At Rated Power Pn: 96 % 0,1Pn: 86% 0,2 Pn: 92% 0,3Pn: 94% 0,5Pn: 94% 0,75Pn:95% 0,9Pn: 95%	Not mandatory	
Kaco Gerätetechnik GmbH	PVI 2600-2,6 kW String Inverter	3 phase/ 4 wires	THD: 3% Max: 5%	99%	No (Fixed)	At Rated Power Pn: 96 % 0,1Pn: 89% 0,2 Pn: 93% 0,3Pn: 95% 0,5Pn: 95% 0,75Pn:96% 0,9Pn: 96%	Not mandatory	
Kaco Gerätetechnik GmbH	PVI 5000 String Inverter	3 phase/ 4 wires	THD: 3% Max: 5%	99%	No (Fixed)	At Rated Power Pn: 96 % 0,1Pn: 93% 0,2 Pn: 95% 0,3Pn: 96% 0,5Pn: 96% 0,75Pn:96% 0,9Pn: 97%	Not mandatory	
Karschny	Solwex 1065E String Inverter	3 phase/ 4 wires	THD: Less Than 5%	100%		At Rated Power Pn: 93 %	Transformer	
G&H Elektronik GmbH	SB 1500 String Inverter	1 phase/ 3 wires		100%	No (Fixed)		Integrated Transformer	
G&H Elektronik GmbH	SB 2000 String Inverter	1 phase/ 3 wires		100%	No (Fixed)		Integrated Transformer	
G&H Elektronik GmbH	SB 2500 String Inverter	1 phase/ 3 wires		100%	No (Fixed)		Integrated Transformer	

Manufacture	Type	Grid Electrical System	Harmonic Current	Power Factor At rated Power	Availability of power factor control	Inverter Conversion Efficiency	Isolation Transformer	DC Injection Countermeasures
Borsig Solar / skytron energy	NEG 500 String Inverter	1 phase/ 3 wires	THD: 3% Each: 3%	99% (Inductive)	No (Fixed)	At Rated Power Pn: 92,5 % 0,1Pn:85,4% 0,3Pn:93,4% 0,5Pn:94,1% 0,9Pn: 93%	Mandatory Line Frequency Transformer	
SMA Regelsysteme GmbH	Sunny Boy 1100E String Inverter	1 phase/ 3 wires	THD: Less Than 4%	99,9%	No (Fixed)	At Rated Power Pn: 91,1 % 0,1Pn:86,7% 0,2 Pn:90,9% 0,3Pn:92,2% 0,5Pn:92,3% 0,75Pn:92% 0,9Pn: 91,5%	Not mandatory Integrated Transformer	
SMA Regelsysteme GmbH	Sunny Boy 2500 String Inverter	1 phase/ 3 wires	THD: Less Than 4%	99,9%	No (Fixed)	At Rated Power Pn: 93,3 % 0,1Pn:89,5% 0,2 Pn:92,9% 0,3Pn:93,8% 0,5Pn:94,1% 0,75Pn:94% 0,9Pn: 93,7%	Not mandatory Integrated Transformer	
SMA Regelsysteme GmbH	Sunny Boy 3000 String Inverter	1 phase/ 3 wires	THD: Less Than 4%	99,9%	No (Fixed)	At Rated Power Pn: 94 % 0,1Pn:89% 0,2 Pn:93,1% 0,3Pn:94,3% 0,5Pn:94,8% 0,75Pn:94,3% 0,9Pn: 94,2%	Not mandatory Integrated Transformer	
Sunways	Sunways 5.02 String Inverter	1 phase/ 3 wires	THD: Less Than 3%	96,1%	No (Fixed)	At Rated Power Pn: 95 % 0,1Pn:90,8% 0,2 Pn:93,5% 0,3Pn:94,6% 0,5Pn:95,1% 0,75Pn:95,2% 0,9Pn: 95,1%	Not mandatory	
UfE GmbH	NEG 4 Grid connected Inverter	1 phase/ 2 wires	THD: 5% Each: 3%	100%	No (Fixed)	At Rated Power Pn: 95 % 0,1Pn: 94% 0,2 Pn: 94,5% 0,3Pn: 95,5% 0,5Pn: 96% 0,75Pn:95,5% 0,9Pn: 95%	Mandatory High frequency isolation	
Würth-Solargy	WE 500 NWR Parallel Inverter	1 phase/ 2 wires		100%	Controllable	At Rated Power Pn: 93 % 0,1Pn: 90% 0,2 Pn: 93% 0,3Pn: 93% 0,5Pn: 93% 0,75Pn:92% 0,9Pn: 90%	Transformer isolated till 3,5kV	Galvanize Security System between DC and AC

INVERTER (3)

Manufacture	Type	Inverter Power Control		Normal Startup and Stop Condition		Control Power Source	Operational Environment			
		DC side	AC side	Startup	Stop		Tempera-ture Range	Installation Requirements	Audible Noise	EMC Standards
Kaco Gerätetechnik GmbH	PVI 2600-2,0 kW String Inverter	Maximum Power Tracking	AC Current Control	DC Voltage >410V and AC Voltage in Operating Windows for 4 min.	Pin ≤ 10 W	DC side	0 to +50 °C	Inside Use No Water and Dust Proof Need	35 dBA at 1 m	EN-50081-1 EN-50082-1 EN55014
Kaco Gerätetechnik GmbH	PVI 2600-2,6 kW String Inverter	Maximum Power Tracking	AC Current Control	DC Voltage >410V and AC Voltage in Operating Windows for 4 min.	Pin ≤ 10 W	DC side	0 to +50 °C	Inside Use No Water and Dust Proof Need	35 dBA at 1 m	EN-50081-1 EN-50082-1 EN55014
Kaco Gerätetechnik GmbH	PVI 5000 String Inverter	Maximum Power Tracking	AC Current Control	DC Voltage >410V and AC Voltage in Operating Windows for 4 min.	Pin ≤ 10 W	DC side	0 to +50 °C	Inside Use No Water and Dust Proof Need	35 dBA at 1 m	EN-50081-1 EN-50082-1 EN55014
Karschny	Solwex 1065E String Inverter	Maximum Power Tracking		Pin ≥ 8 W	Pin ≤ 8 W		0 to +35 °C		Less Than 35 dBA	
G&H Elektronik GmbH	SB 1500 String Inverter	Maximum Power Tracking	AC Current Control			AC side	-10 to +50 °C (ref 40°C)	Inside Use Water and Dust Proof	Less Than 30 dBA	EN-50081-1 EN-50081-2
G&H Elektronik GmbH	SB 2000 String Inverter	Maximum Power Tracking	AC Current Control			AC side	-10 to +50 °C (ref 40°C)	Inside Use Water and Dust Proof	Less Than 30 dBA	EN-50081-1 EN-50081-2
G&H Elektronik GmbH	SB 2500 String Inverter	Maximum Power Tracking	AC Current Control			AC side	-10 to +50 °C (ref 40°C)	Inside Use Water and Dust Proof	Less Than 30 dBA	EN-50081-1 EN-50081-2

Manufacture	Type	Inverter Power Control		Normal Startup and Stop Condition		Control Power Source	Operational Environment			
		DC side	AC side	Startup	Stop		Tempera-ture Range	Installation Requirements	Audible Noise	EMC Standards
Borsig Solar / skytron energy	NEG 500 String Inverter	Maximum Power Tracking				DC side	Nominal: +4 to +40 °C (ref 25°C) Extended (reduced warranty and power): -25 to +60 °C (ref 25°C)	Inside and Outside Use IP54 Protection need for direct water	Less Than 35 dBA at 1 m	EN-50081-1 EN-55014 EN55022 EN-50082-1 IEC 801-2 IEC 801-3 IEC 801-4 EN61000-4-5 EN 60 95 0 EN 61 01 0
SMA Regelsysteme GmbH	Sunny Boy 1100E String Inverter	Maximum Power Tracking	AC Current Control	DC and AC Voltage in Operating Windows for 10 sec. Pin ≥ 4 W	DC and AC Voltage out of Operating Windows for 0,1 sec. Pin ≤ 4 W	DC side	-25 to +60 °C (ref 25°C)	Outside Use Protection class IP65	40 dBA at 1 m	EN-50081-1 EN-50082-2 EN61000-3-2 DIN VDE 0126 EN 50178 EN60146-1-1
SMA Regelsysteme GmbH	Sunny Boy 2500 String Inverter	Maximum Power Tracking	AC Current Control	DC and AC Voltage in Operating Windows for 10 sec. Pin ≥ 4 W	DC and AC Voltage out of Operating Windows for 0,1 sec. Pin ≤ 4 W	DC side	-25 to +60 °C (ref 25°C)	Outside Use Protection class IP65	40 dBA at 1 m	EN-50081-1 EN-50082-2 EN61000-3-2 DIN VDE 0126 EN 50178 EN60146-1-1
SMA Regelsysteme GmbH	Sunny Boy 3000 String Inverter	Maximum Power Tracking	AC Current Control	DC and AC Voltage in Operating Windows for 10 sec. Pin ≥ 4 W	DC and AC Voltage out of Operating Windows for 0,1 sec. Pin ≤ 4 W	DC side	-25 to +60 °C (ref 25°C)	Outside Use Protection class IP65	40 dBA at 1 m	EN-50081-1 EN-50082-2 EN61000-3-2 DIN VDE 0126 EN 50178 EN60146-1-1

Manufacture	Type	Inverter Power Control		Normal Startup and Stop Condition		Control Power Source	Operational Environment			
		DC side	AC side	Startup	Stop		Tempera-ture Range	Installation Requirements	Audible Noise	EMC Standards
Sunways	Sunways 5.02 String Inverter	Maximum Power Tracking	AC Current Control	Uoc>420V	DC Voltage <340V	DC side	-25 to +40 °C (ref 30°C)	Inside Use No Water and Dust Proof Need	50 dBA at 3 m	EN-50082-2 EN-50081 EN55014-1 EN55011 EN61003-3 EN6100-3-2
UfE GmbH	NEG 4 Grid connected Inverter	Maximum Power Tracking	AC Current Control	Pin ≥ 10 W	Pin ≤ 10 W	AC side	-15 to +50 °C	Inside Use No Water and Dust Proof Need		
Würth-Solargy	WE 500 NWR Parallel Inverter	Maximum Power Tracking	AC Current Control AC Voltage Control	Pin ≥ 7 W	Pin ≤ 5 W	DC side 1,5 W	-25 to +60 °C		Less Than 40 dBA at 1 m	EN-50081-1 EN-50081-2

PROTECTIVE DEVICES OR FUNCTIONS

Manufacture	Type	Protective Functions		Transient Overvoltage Protection/Devices		Islanding Protection	Disconnection Procedure for Protection	Restart Procedure after Fault Clearance
		DC side	AC side	DC side	AC side			
Kaco Gerätetechnik GmbH	PVI 2600-2,0 kW String Inverter	Over Power 2,6 kW	OV: +15% UV: -30% 0,2 sec	Metal Oxide surge arrester	Metal Oxide surge arrester	Included Over/Under voltage		Automatic Restart 4 min. after AC and DC side conditions restored
Kaco Gerätetechnik GmbH	PVI 2600-2,6 kW String Inverter	Over Power 3 kW	OV: +15% UV: -30% 0,2 sec	Metal Oxide surge arrester	Metal Oxide surge arrester	Included Over/Under voltage		Automatic Restart 4 min. after AC and DC side conditions restored
Kaco Gerätetechnik GmbH	PVI 5000 String Inverter	Over Power 6,5 kW	OV: +15% UV: -30% 0,2 sec	Metal Oxide surge arrester	Metal Oxide surge arrester	Included Over/Under voltage		Automatic Restart 4 min. after AC and DC side conditions restored
Karschny	Solwex 1065E String Inverter							
G&H Elektronik GmbH	SB 1500 String Inverter		Over current:: 16A	Metal Oxide surge arrester	Metal Oxide surge arrester	Included ENS	Opening of Contactor	Automatic
G&H Elektronik GmbH	SB 2000 String Inverter		Over current:: 16A	Metal Oxide surge arrester	Metal Oxide surge arrester	Included ENS	Opening of Contactor	Automatic
G&H Elektronik GmbH	SB 2500 String Inverter		Over current:: 16A	Metal Oxide surge arrester	Metal Oxide surge arrester	Included ENS	Opening of Contactor	Automatic

Manufacture	Type	Protective Functions		Transient Overvoltage Protection/Devices		Islanding Protection	Disconnection Procedure for Protection	Restart Procedure after Fault Clearance
		DC side	AC side	DC side	AC side			
Borsig Solar / skytron energy	NEG 500 String Inverter	Only for information	OV/UV: +/-10% of nominal voltage, 0,2 sec waiting time OF/UF	Transil Diode	250 V Metal Oxide surge arrester	Not included	Opening of circuit breaker	Automatic Restart 5 sec. after AC and DC side conditions restored
SMA Regelsysteme GmbH	Sunny Boy 1100E String Inverter	Over voltage Ground fault	OV/UV OF/UF Over Current	Varistors	Filters	Included Passive: frequency change rate Active: grid impedance detection	Gate Blocking and opening of relay contacts	Automatic Restart 30 sec. after AC and DC side conditions restored
SMA Regelsysteme GmbH	Sunny Boy 2500 String Inverter	Over voltage Ground fault	OV/UV OF/UF Over Current	Varistors	Filters	Included Passive: frequency change rate Active: grid impedance detection	Gate Blocking and opening of relay contacts	Automatic Restart 30 sec. after AC and DC side conditions restored
SMA Regelsysteme GmbH	Sunny Boy 3000 String Inverter	Over voltage Ground fault	OV/UV OF/UF Over Current	Varistors	Filters	Included Passive: frequency change rate Active: grid impedance detection	Gate Blocking and opening of relay contacts	Automatic Restart 30 sec. after AC and DC side conditions restored

Manufacture	Type	Protective Functions		Transient Overvoltage Protection/Devices		Islanding Protection	Disconnection Procedure for Protection	Restart Procedure after Fault Clearance
		DC side	AC side	DC side	AC side			
Sunways	Sunways 5.02 String Inverter	Over voltage: >750 V Ground fault: FI300mA	OV: +20% UV: -10% 0,2 sec Each OC: 25A OF/UF: +/- 0,5 Hz	Varistors (internal) Metal Oxide Surge Arrestor (outside)	Varistors	Included Passive: three phase undervoltage monitoring	Gate Blocking for Passive Islanding detection Opening of Circuit Breaker for other Protection	Automatic Restart 10 sec. after AC and DC side conditions restored
UfE GmbH	NEG 4 Grid connected Inverter	Over current: 2x63 A Ground fault: only indicated	OV: +20% UV: -20% 0,2 sec Each OC: 20A	Metal Oxide Surge Arrestor (2 times of DC Nominal Voltage)	Metal Oxide Surge Arrestor (2,5 times of AC Nominal Voltage)	Included Nearly Passive: impedance step detection	Gate Blocking + Opening of Contactor	Automatic Restart 30 sec. after AC and DC side conditions restored
Würth-Solargy	WE 500 NWR Parallel Inverter	OV: >48VDC UV: <27VDC Over current: 28 A	OV: +10% UV: -15% 0,2 sec Each Over Temp: 70 °C OF/UF: 5Hz	Metal Oxide Varistor (60VDC)	Metal Oxide Varistor (60VAC)	Not Included	Two relays for disconnecting	Automatic Restart 5 sec. after AC and DC side conditions restored

OTHERS

Manufacture	Type	Location of Protective Functions (Relays)	Price of Inverter and Protective Devices	Size and Weight of Inverter and Transformer	Comments	Date of Information
Kaco Gerätetechnik GmbH	PVI 2600-2,0 kW String Inverter	Over/Under Voltage Protection are Separate from Inverter Control Circuit	Total DM 3.435,-	Total 505x355x155 mm 12 kg		2001/08
Kaco Gerätetechnik GmbH	PVI 2600-2,6 kW String Inverter	Over/Under Voltage Protection are Separate from Inverter Control Circuit	Total DM 3.675,-	Total 505x355x155 mm 12 kg		2001/08
Kaco Gerätetechnik GmbH	PVI 5000 String Inverter	Over/Under Voltage Protection are Separate from Inverter Control Circuit	Total DM 6.000,-	Total 555x355x235 mm 23 kg		2001/08
Karschny	Solwex 1065E String Inverter		Total DM 3.190,-	Total 430x220x185 mm 19 kg		2001/09
G&H Elektronik GmbH	SB 1500 String Inverter	All Included in Inverter	Total US$ 1.174,-	Total 280x335x180 mm 19 kg		2001/08
G&H Elektronik GmbH	SB 2000 String Inverter	All Included in Inverter	Total US$ 1.493,-	Total 280x375x180 mm 24 kg		2001/08
G&H Elektronik GmbH	SB 2500 String Inverter	All Included in Inverter	Total US$ 1.708,-	Total 280x455x180 mm 27 kg		2001/08

Manufacture	Type	Location of Protective Functions (Relays)	Price of Inverter and Protective Devices	Size and Weight of Inverter and Transformer	Comments	Date of Information
Borsig Solar / skytron energy	NEG 500 String Inverter	All Included in Inverter		Total 400x256x78 mm 8 kg	-Metering Interface RS485	2001/02
SMA Regelsysteme GmbH	Sunny Boy 1100E String Inverter	All Included in Inverter	Total DM 2.333,-	Total 320x322x180 mm 21 kg		2001/08
SMA Regelsysteme GmbH	Sunny Boy 2500 String Inverter	All Included in Inverter		Total 434x295x214 mm 30 kg		2001/08
SMA Regelsysteme GmbH	Sunny Boy 3000 String Inverter	All Included in Inverter		Total 434x295x214 mm 32 kg		2001/08
Sunways	Sunways 5.02 String Inverter	All Included in Inverter	Total DM 7.540,-	Total 500x320x195 mm 20 kg		2001/09
UfE GmbH	NEG 4 Grid connected Inverter	All Included in Inverter	Total US$ 3.200,-	Total 580x270x150 mm 40 kg	-The new islanding protection system will be available in 2002	2001/11
Würth-Solargy	WE 500 NWR Parallel Inverter	All Included in Inverter Separated ENS System for Germany	Total DM 1.400,-	Inverter: 320x240x120 mm, 21 kg Transformer: 120 mm, 5 kg	-Low DC voltage level lower than 42VDC -Easy connection without DC switch	2001/08

ITALY

INVERTER (1)

Manufacture	Type	Power Capacity	Type of Conversion	Switching Devices	Nominal AC and DC Voltage	Operational AC Voltage and Frequency Ranges	Operational DC Voltage Ranges and DC Voltage Ripple	Applicable PV module size
ELETTRONICA SANTERNO	SUNWAY-M Stand Alone/ Grid Connected Inverter	1,5 to 3 kW	Self-commutated PWM	MOSFET 16kHz	AC: 230V 50Hz /60Hz DC: 120 V	Voltage: 230 V +/-20% Frequency: +/- 10%		2 to 4 kWp
ELETYRONICA SANTERNO	SUNWAY-T Central Inverter	Max. 320 kW	Self-commutated PWM	IGBT 3kHz	AC: On Request DC: 480 V Usually	Voltage: +/-20% Frequency: +/- 10%		On Request

INVERTER (2)

Manufacture	Type	Grid Electrical System	Harmonic Current	Power Factor At rated Power	Availability of power factor control	Inverter Conversion Efficiency	Isolation Transformer	DC Injection Countermeasures
ELETTRONICA SANTERNO	SUNWAY-M Stand Alone/ Grid Connected Inverter	1 phase/ 2 wires	THD: 3% Each: 2%		On Request	At Rated Power Pn: 89 % 0,3Pn: 95% 0,75Pn:92%	Line frequency transformer isolation	
ELETTRONICA SANTERNO	SUNWAY-T Central Inverter	3 phase/ 3 wires	THD: 5% Each: 3%		On Request	0,1Pn: 89,5% 0,2 Pn: 92% 0,3Pn: 93,5% 0,5Pn: 95% 0,75Pn:95%	Line frequency transformer isolation	

INVERTER (3)

Manufacture	Type	Inverter Power Control		Normal Startup and Stop Condition		Control Power Source	Operational Environment			
		DC side	AC side	Startup	Stop		Temperature Range	Installation Requirements	Audible Noise	EMC Standards
ELETTRONICA SANTERNO	SUNWAY-M Stand Alone/ Grid Connected Inverter	Maximum Power Tracking DC Constant Voltage		PV Voltage	PV Voltage	DC side				EN61000-4-2 EN61000-4-4 EN61000-4-5 EN55011 Class B
ELETTRONICA SANTERNO	SUNWAY-T Central Inverter	Maximum Power Tracking DC Constant Voltage		On Request	On Request	DC side				EN55011 Class B

PROTECTIVE DEVICES OR FUNCTIONS

Manufacture	Type	Protective Functions		Transient Overvoltage Protection/Devices		Islanding Protection	Disconnection Procedure for Protection	Restart Procedure after Fault Clearance
		DC side	AC side	DC side	AC side			
ELETTRONICA SANTERNO	SUNWAY-M Stand Alone/ Grid Connected Inverter			Varistor	Varistor	Included: Impedance Changing Measurement	Gate Blocking and Opening Contactor	Automatic Restart 1 sec. (Programmable)
ELETTRONICA SANTERNO	SUNWAY-T Central Inverter			Varistor	Varistor		Gate Blocking and Opening Contactor	Automatic Restart

OTHERS

Manufacture	Type	Location of Protective Functions (Relays)	Price of Inverter and Protective Devices	Size and Weight of Inverter	Comments	Date of Information
ELETTRONICA SANTERNO	SUNWAY-M Stand Alone/ Grid Connected Inverter	Included in Inverter		Total 340x520x320 mm 50 kg	-Isolated operation -PC interface -Modem interface	1999/12
ELETTRONICA SANTERNO	SUNWAY-T Central Inverter					1999/12

JAPAN

INVERTER (1)

Manufacture	Type	Power Capacity	Type of Conversion	Switching Devices	Nominal AC and DC Voltage	Operational AC Voltage and Frequency Ranges	Operational DC Voltage Ranges and DC Voltage Ripple	Applicable PV module size
Japan Kyocera Corporation	Econoline 401 Ordinary Inverter	4 kW	Self-commutated PWM Current Control	IGBT 18kHz	AC: 202V 50/60Hz DC: 236V	Voltage: +/- 6 V Frequency: +/- 2 Hz	100 to 350 V	4,5 kWp
Japan Kyocera Corporation	Econoline 550 Ordinary Inverter	5,5 kW	Self-commutated PWM Current Control	IGBT 16.5kHz	AC: 202V 50/60Hz DC: 236V	Voltage: +/- 6 V Frequency: +/- 2 Hz	100 to 350 V	6,0 kWp
Japan Storage Battery Co., Ltd	LINE BACK FX Ordinary Inverter	4,5 kW	Self-commutated PWM Current Control	IGBT 20kHz	AC: 200V 50/60Hz DC: 220V	Voltage: +/-10 % Frequency: +/- 1%	100 to 350 V	5,0 kWp
Japan Storage Battery Co., Ltd	LINE BACK ALPHA Ordinary Inverter	10 kW	Self-commutated PWM Current Control	IGBT 8,88kHz	AC: 200V 50/60Hz DC: 220V	Voltage: +/-10 % Frequency: +/- 1%	200 to 500 V	11 kWp
Japan Storage Battery Co., Ltd	LINE BACK SIGMA Ordinary Inverter	10 to 50 kW	Self-commutated PWM Current Control	IGBT 17kHz	AC: 200V 50/60Hz DC: 300V	Voltage: +/-10 % Frequency: +/- 1%	200 to 480 V	11 to 55 kWp
Mitsubishi Electric Corp.	PV-PN04B3 Ordinary Inverter	3,3 kW	Self-commutated PWM Current Control	IPM(IGBT) 17kHz	AC: 202V 50/60Hz DC: 236V	Voltage: +19%, -20% Frequency: +/- 3%	115 to 350 V	4,2 kWp

INVERTER (2)

Manufacture	Type	Grid Electrical System	Harmonic Current	Power Factor At rated Power	Availability of power factor control	Inverter Conversion Efficiency	Isolation Transformer	DC Injection Countermeasures
Japan Kyocera Corporation	Econoline 401 Ordinary Inverter	1 phase/ 3 wires	THD: <5% Each: <3%	95%	Controllable Synchronizing current phase with line voltage	At Rated Power Pn: 93,5% 0,1Pn: 89,2% 0,2Pn: 92,7% 0,3Pn: 93,7% 0,5Pn: 94,2% 0,75Pn:94,0% 0,9Pn: 93,7%	Not mandatory Transformer-less	DC injection current sensor
Japan Kyocera Corporation	Econoline 550 Ordinary Inverter	1 phase/ 3 wires	THD: <5% Each: <3%	95%	Controllable Synchronizing current phase with line voltage	At Rated Power Pn: 95,1%	Not mandatory Transformer-less	DC injection current sensor
Japan Storage Battery Co., Ltd	LINE BACK FX Ordinary Inverter	1 phase/ 3 wires	THD: <5% Each: <3%	100%	Controllable when AC voltage rise by AC current reference phase shift	At Rated Power Pn: 93,5 % 0,1Pn: 91% 0,5Pn: 94%	Not mandatory Transformer-less	DC injection current control and detection DC grounding fault detection
Japan Storage Battery Co., Ltd	LINE BACK ALPHA Ordinary Inverter	3 phase/ 3 wires	THD: <5% Each: <3%	100%	Controllable when AC voltage rise by AC current reference phase shift	At Rated Power Pn: 92,5 %	Not mandatory Transformer-less	DC injection current control and detection DC grounding fault detection
Japan Storage Battery Co., Ltd	LINE BACK SIGMA Ordinary Inverter	3 phase/ 3 wires	THD: <5% Each: <3%	100%	Controllable when AC voltage rise by AC current reference phase shift	At Rated Power Pn: 91,5 %	Not mandatory Transformer-less	DC injection current control and detection DC grounding fault detection
Mitsubishi Electric Corp.	PV-PN04B3 Ordinary Inverter	1 phase/ 3 wires	THD: <5% Each: <3%	99%	Controllable when AC voltage exceeds specific value by Automatic control	At Rated Power Pn: 94,5% 0,1Pn: 87,0% 0,2Pn: 91,0% 0,3Pn: 93,6% 0,5Pn: 94,4% 0,75Pn:94,7% 0,9Pn: 94,5%	Not mandatory Transformer-less	DC injection current monitoring and compensation DC grounding fault detector

INVERTER (3)

Manufacture	Type	Inverter Power Control		Normal Startup and Stop Condition		Control Power Source	Operational Environment			
		DC side	AC side	Startup	Stop		Temperature Range	Installation Requirements	Audible Noise	EMC Standards
Japan Kyocera Corporation	Econoline 401 Ordinary Inverter	Maximum Power Tracking	AC Current Control	DC Voltage >125V	DC Voltage <100V	DC side	-10 to 40 °C (ref 25°C)	Inside Use Water and Dust Proof Need	40 dBA at 1 m	VCCI-II
Japan Kyocera Corporation	Econoline 550 Ordinary Inverter	Maximum Power Tracking	AC Current Control	DC Voltage >125V	DC Voltage <100V	DC side	-10 to 40 °C (ref 25°C)	Inside Use Water and Dust Proof Need	35 dBA at 1 m	VCCI-II
Japan Storage Battery Co., Ltd	LINE BACK FX Ordinary Inverter	Maximum Power Tracking	AC Current Control	DC Voltage >Setting Value for 10 seconds	DC Voltage <Setting value for 20 min.	DC side	-10 to 40 °C (ref 25°C)	Inside Use	<40 dBA at 1 m	
Japan Storage Battery Co., Ltd	LINE BACK ALPHA Ordinary Inverter	Maximum Power Tracking	AC Current Control	DC Voltage >Setting Value for 10 seconds	DC Voltage <Setting value for 20 min.	DC and AC side	-10 to 50 °C (ref 25°C)	Outside Use No Water and Dust Proof Need	50 dBA at 1 m	
Japan Storage Battery Co., Ltd	LINE BACK SIGMA Ordinary Inverter	Maximum Power Tracking	AC Current Control	DC Voltage >Setting Value for 10 seconds	DC Voltage <Setting value for 20 min.	DC and AC side	-10 to 40 °C (ref 25°C)	Inside Use No Water and Dust Proof Need		
Mitsubishi Electric Corp.	PV-PN04B3 Ordinary Inverter	Maximum Power Tracking	AC Current Control/ AC Voltage Control	DC Voltage >130V	DC Voltage <115V	DC side	0 to 40 °C (ref 25°C)	Inside Use Water and Dust Proof Need	<36 dBA at 1m (less than 15kHz)	VCCI-II

PROTECTIVE DEVICES OR FUNCTIONS (1)

Manufacture	Type	Protective Functions		Transient Overvoltage Protection/Devices	
		DC side	AC side	DC side	AC side
Japan Kyocera Corporation	Econoline 401 Ordinary Inverter	OV: 350V UV: 100V OC: 40A Grounding Fault:: DC100mA	OV/UV: +115V/ -80V of nominal voltage 1.0 sec. OC: 24A OF/UF: 51/ 48,5 Hz (50Hz), 61/58 Hz (60Hz)	Metal Oxide surge arrester 3 times of AC nominal rms voltage: 680V	Metal Oxide surge arrester 3 times of DC nominal voltage: 680V
Japan Kyocera Corporation	Econoline 550 Ordinary Inverter	OV: 350V UV: 100V OC: 32A Grounding Fault:: DC90mA	OV/UV: +115V/ -80V of nominal voltage 1.0 sec. OC: 31A OF/UF: 51/ 48,5 Hz (50Hz), 61/58 Hz (60Hz)	Metal Oxide surge arrester 4 times of AC nominal rms voltage: 820V	Metal Oxide surge arrester 2,8 times of DC nominal voltage: 680V
Japan Storage Battery Co., Ltd	LINE BACK FX Ordinary Inverter	OV: 360V 10ms UV: 65V 10ms Grounding Fault: 100mA	OV/UV: 110-125%/ 80-90% 0,5-2,0 sec OF/UF: 50,5-52 Hz/48-49.5 Hz (50Hz) 60,5-62 Hz/58-59,5 Hz (60Hz) 0,5-2,0 sec. OC: 150%, 0,3 sec. DC injection: 180mA 0,4 sec.		
Japan Storage Battery Co., Ltd	LINE BACK ALPHA Ordinary Inverter	OV: 515V 0,4 sec. UV: 170V 10ms Grounding Fault: 100mA	OV/UV: 110-125%/ 80-90% 0,5-2,0 sec OF/UF: 50,5-52 Hz/48-49.5 Hz (50Hz) 60,5-62 Hz/58-59,5 Hz (60Hz) 0,5-2,0 sec.. OC: 140%, 0,3 sec. DC injection: 230mA 0,4 sec.		
Japan Storage Battery Co., Ltd	LINE BACK SIGMA Ordinary Inverter	OV: 480V 10ms UV: 160V 10ms Grounding Fault: 100mA	OV/UV: 110-125%/ 80-90% 0,5-2,0 sec OF/UF: 50,5-52 Hz/48-49.5 Hz (50Hz) 60,5-62 Hz/58-59,5 Hz (60Hz) 0,5-2,0 sec. OC: 140%, 0,3 sec. DC injection: 230mA 0,4 sec. (10kW)		
Mitsubishi Electric Corp.	PV-PN04B3 Ordinary Inverter	OV: 350V <0,5 sec. UV: 115V <0,5 sec. Grounding Fault: <DC100mA <0,1 sec.	OV/UV: up to +/- 20% of nominal voltage 0,5 to 2,0 sec. OC: 106% <0,5 sec. OF/UF: up to +/- 3% of nominal frequency 0,5 to 2,0 sec.	Metal Oxide surge arrester 2,4 times of AC nominal rms voltage	Metal Oxide surge arrester 2,6 times of DC nominal voltage

PROTECTIVE DEVICES OR FUNCTIONS (2)

Manufacture	Type	Islanding Protection	Disconnection Procedure for Protection	Restart Procedure after Fault Clearance
Japan Kyocera Corporation	Econoline 401 Ordinary Inverter	Included Passive: Frequency change rate Active: Reactive power perturbation	Gate Blocking for passive islanding detection, opening of circuit breaker for other protection	Automatic Restart 0,3 s after AC and DC side conditions restored
Japan Kyocera Corporation	Econoline 550 Ordinary Inverter	Included Passive: Voltage phase jumping Active: Reactive power perturbation	Gate Blocking for passive islanding detection, opening of circuit breaker for other protection	Automatic Restart 0,3 s after AC and DC side conditions restored
Japan Storage Battery Co., Ltd	LINE BACK FX Ordinary Inverter	Included Passive: Voltage phase jumping Active: Reactive power variation	Gate Blocking and opening of contactor	Automatic Restart 0,3 s after AC and DC side conditions restored
Japan Storage Battery Co., Ltd	LINE BACK ALPHA Ordinary Inverter	Included Passive: Voltage phase jumping Active: Reactive power variation	Gate Blocking and opening of contactor	Automatic Restart 0,3 s after AC and DC side conditions restored
Japan Storage Battery Co., Ltd	LINE BACK SIGMA Ordinary Inverter	Included Passive: Voltage phase jumping Active: Reactive power variation	Gate Blocking and opening of contactor	Automatic Restart 0,3 s after AC and DC side conditions restored
Mitsubishi Electric Corp.	PV-PN04B3 Ordinary Inverter	Included Passive: Voltage phase jumping Active: Frequency shift	Gate Blocking for passive islanding detection, gate blocking and opening of circuit breaker for other protection	Automatic Restart 0,15 to 0,3 s after AC and DC side conditions restored

OTHERS

Manufacture	Type	Location of Protective Functions (Relays)	Price of Inverter and Protective Devices	Size and Weight of Inverter and Transformer	Comments	Date of Information
Japan Kyocera Corporation	Econoline 401 Ordinary Inverter	All Included in Inverter	Total JP\ 350.000,-	Total 460x142x280 mm 14 kg	-Transformer-less Inverter	2001/05
Japan Kyocera Corporation	Econoline 550 Ordinary Inverter	All Included in Inverter	Total JP\ 450.000,-	Total 580x162x280 mm 19.8 kg	-Transformer-less Inverter	2001/05
Japan Storage Battery Co., Ltd	LINE BACK FX Ordinary Inverter	All Included in Inverter		Total 580x160x290 mm 16.2 kg	-Ability of isolated operation	2001/06
Japan Storage Battery Co., Ltd	LINE BACK ALPHA Ordinary Inverter	All Included in Inverter		Total 600x285x550 mm 55 kg	-Remote monitoring function	2001/06
Japan Storage Battery Co., Ltd	LINE BACK SIGMA Ordinary Inverter	All Included in Inverter		Total 550x7005x1250 mm 150 kg (10kW)	-Ability of isolated operation -Remote monitoring function	2001/06
Mitsubishi Electric Corp.	PV-PN04B3 Ordinary Inverter	All Included in Inverter	Total JP\ 320.000,-	Total 430x230x140 mm 14 kg	-Ability of isolated operation -Small size	2001/06

THE NETHERLANDS

INVERTER(1)

Manufacture	Type	Power Capacity	Type of Conversion	Switching Devices	Nominal AC and DC Voltage	Operational AC Voltage and Frequency Ranges	Operational DC Voltage Ranges and DC Voltage Ripple	Applicable PV module size
NKF Electronics	OK4E-100 OK4U-100 OK4J-100 AC module	Depending on V-AC: nominally 86/90 WAC at 230/120 VAC	Self-commutated PWM Current Control	MOSFET 400kHz	AC: 230V or 120V, Freq. 50 or 60Hz DC: 33V (72 crystalline cells)	Voltage: +/- 17,4 % at 230V +0,87% -20,8% at 120V Frequency: +/- 2% at 50Hz +/- 1,7% at 60Hz (Software adjustable)	27 to 50 V Ripple: 1% of MPP voltage	80 to 120 Wp
NKF Electronics	OK5E-LV OK5U-LV Semi AC module	Depending on V-AC: nominally 281 WAC at 230/120 VAC	Self-commutated PWM Current Control	MOSFET 800kHz	AC: 230V or 120V, Freq. 50 or 60Hz DC: 16,5V (36 crystalline cells)	Voltage: +/- 17,4 % at 230V +10% -18,3% at 120V Frequency: auto detect +/- 2% at 50Hz +/- 1,7% at 60Hz (Software adjustable)	14 to 25 V Ripple: 1% of MPP voltage	200 to 500 Wp
NKF Electronics	OK5E-MV OK5U-MV Mini-string inverter	Depending on V-AC: nominally 281 WAC at 230/120 VAC	Self-commutated PWM Current Control	MOSFET 800kHz	AC: 230V or 120V, Freq. 50 or 60Hz DC: 66V (144 crystalline cells)	Voltage: +/- 17,4 % at 230V +10% -18,3% at 120V Frequency: auto detect +/- 2% at 50Hz +/- 1,7% at 60Hz (Software adjustable)	48 to 120 V Ripple: 1% of MPP voltage	200 to 500 Wp
Philips	PSI-300 String Inverter	300 W	Self-commutated PWM Current Control	MOSFET, IGBT 30-300 kHz	AC: 230V, 50 Hz DC: 90V	Voltage: +/- 15 % Frequency: +/- 2%	45 to 100 V	360 Wp

INVERTER (2)

Manufacture	Type	Grid Electrical System	Harmonic Current	Power Factor At rated Power	Availability of power factor control	Inverter Conversion Efficiency	Isolation Transformer	DC Injection Counter-measures
NKF Electronics	OK4E-100 OK4U-100 OK4J-100 AC module	1 phase/ 2 wires (OK4E-100, OK4J-100) 1 phase/ 3 wires (OK4U-100)	THD: Less than 3% Each: 1%	99%	No (Fixed)	At Rated Power Pn: 89 % 0,1Pn: 91% 0,2 Pn: 92% 0,3Pn: 93% 0,5Pn: 92% 0,75Pn: 92% 0,9Pn: 90%	Not mandatory High frequency transformer in inverter	
NKF Electronics	OK5E-LV OK5U-LV Semi AC module	1 phase/ 2 wires (OK5E-LV) 1 phase/ 3 wires (OK5U-LV)	THD: Less than 3% Each: 1%	99%	No (Fixed)	At Rated Power Pn: 93 % 0,1Pn: 91% 0,2 Pn: 92% 0,3Pn: 93% 0,5Pn: 94% 0,75Pn: 93% 0,9Pn: 93%	Not mandatory High frequency transformer in inverter	
NKF Electronics	OK5E-MV OK5U-MV Mini-string inverter	1 phase/ 2 wires (OK5E-MV) 1 phase/ 3 wires (OK5U-MV)	THD: Less than 3% Each: 1%	99%	No (Fixed)	At Rated Power Pn: 93 % 0,1Pn: 91% 0,2 Pn: 92% 0,3Pn: 93% 0,5Pn: 94% 0,75Pn: 93% 0,9Pn: 93%	Not mandatory High frequency transformer in inverter	
Philips	PSI-300 String Inverter	1 phase/ 2 wires	THD: 10% Each: 3%	95%	No (Fixed)		Not Mandatory	-Symmetry measurement -Residual current detection (optional with ENS)

INVERTER (3)

Manufacture	Type	Inverter Power Control		Normal Startup and Stop Condition		Control Power Source
		DC side	AC side	Startup	Stop	
NKF Electronics	OK4E-100 OK4U-100 OK4J-100 AC module	Maximum Power Tracking	AC Current control, always in phase with AC voltage	Startup when DC voltage, AC voltage and frequency is in operating windows for 1-600 seconds (software adjustable)	Stop operation when AC voltage, AC frequency or phase jump is out of operating windows for 0,01 seconds	DC side
NKF Electronics	OK5E-LV OK5U-LV Semi AC module	Maximum Power Tracking	AC Current control, always in phase with AC voltage	Startup when DC voltage, AC voltage and frequency is in operating windows for 1-600 seconds (software adjustable)	Stop operation when AC voltage, AC frequency or phase jump is out of operating windows for 0,01 seconds	DC side
NKF Electronics	OK5E-MV OK5U-MV Mini-string inverter	Maximum Power Tracking	AC Current control, always in phase with AC voltage	Startup when DC voltage, AC voltage and frequency is in operating windows for 1-600 seconds (software adjustable)	Stop operation when AC voltage, AC frequency or phase jump is out of operating windows for 0,01 seconds	DC side
Philips	PSI-300 String Inverter	Maximum Power Tracking	AC current control	Startup when DC voltage and AC voltage is in operating windows for 60 seconds	Stop operation when DC voltage or AC voltage is out of operating windows for 0,1 seconds	DC side

INVERTER (4)

Manufacture	Type	Operational Environment			
		Temperature Range	Installation Requirements	Audible Noise	EMC Standards
NKF Electronics	OK4E-100 OK4U-100 OK4J-100 AC module	-40 to 85 °C	Both Inside and Outside Use Water and dust proof: No (IP67)	Less than 30 dBA at 1 m	EN-50081-1 EN-50081-2 IEC/EN 61000-6-2 IEC61000-6-3
NKF Electronics	OK5E-LV OK5U-LV Semi AC module	-40 to 85 °C	Both Inside and Outside Use Water and dust proof: No (IP67)	Less than 30 dBA at 1 m	EN-50081-1 EN-50081-2 IEC/EN 61000-6-2 IEC61000-6-3
NKF Electronics	OK5E-MV OK5U-MV Mini-string inverter	-40 to 85 °C	Both Inside and Outside Use Water and dust proof: No (IP67)	Less than 30 dBA at 1 m	EN-50081-1 EN-50081-2 IEC/EN 61000-6-2 IEC61000-6-3
Philips	PSI-300 String Inverter	-10 to 45 °C (ref 20°C)	Inside Use		EN55014 EN61000

PROTECTIVE DEVICES OR FUNCTIONS

Manufacture	Type	Protective Functions		Transient Overvoltage Protection/Devices		Islanding Protection	Disconnection Procedure for Protection	Restart Procedure after Fault Clearance
		DC side	AC side	DC side	AC side			
NKF Electronics	OK4E-100 OK4U-100 OK4J-100 AC module	Minimum voltage 26V (Shut down)	OV/UV: +/-17,4% at 230V +0,87/-20,8% at 120V for 1-600 sec. (Software adjustable) OF/UF: 49-51Hz at 50Hz 59-61Hz at 60Hz OC: 0,375A (230V model) 0,75A (120V model) Fuse: 2.5A	By large capacitor	Metal oxide surge arrester: 1kV at 1,2/50 µs	Included Passive: frequency and voltage window, frequency change rate detection (phase jump) Active: frequency shift	Gate blocking for all islanding detection	Automatic Restart 1-600 sec. after AC and DC side conditions restored (software adjustable)
NKF Electronics	OK5E-LV OK5U-LV Semi AC module	Minimum voltage 13V (Shut down) Grounding fault: detection in OK5U-LV	OV/UV: +/-17,4% at 230V +10/-18,3% at 120V for 1-600 sec. (Software adjustable) OF/UF: 49-51Hz at 50Hz 59-61Hz at 60Hz OC: 1,22A (230V model) 2,34A (120V model) Fuse: 5A	By large capacitor	Metal oxide surge arrester: 6kV at 1,2/50 µs	Included Passive: frequency and voltage window, frequency change rate detection (phase jump)	Gate blocking for all islanding detection	Automatic Restart 1-600 sec. after AC and DC side conditions restored (software adjustable)

Manufacture	Type	Protective Functions		Transient Overvoltage Protection/Devices		Islanding Protection	Disconnection Procedure for Protection	Restart Procedure after Fault Clearance
		DC side	AC side	DC side	AC side			
NKF Electronics	OK5E-MV OK5U-MV Mini-string inverter	Minimum voltage 48V (Shut down) Grounding fault: detection and interrupt in OK5U-MV	OV/UV: +/-17,4% at 230V +10/-18,3% at 120V for 1-600 sec. (Software adjustable) OF/UF: 49-51Hz at 50Hz 59-61Hz at 60Hz OC: 1,22A (230V model) 2,34A (120V model) Fuse: 5A	By large capacitor	Metal oxide surge arrester: 6kV at 1,2/50 µs	Included Passive: frequency and voltage window, frequency change rate detection (phase jump)	Gate blocking for all islanding detection	Automatic Restart 1-600 sec. after AC and DC side conditions restored (software adjustable)
Philips	PSI-300 String Inverter		VDE 0126	Fast forward diode	Fast forward diode	Included Passive Active (optional: ENS)	Gate blocking is included Opening of circuit breaker is optional	Automatic Restart 60 sec. after AC side conditions restored

OTHERS

Manufacture	Type	Location of Protective Functions (Relays)	Price of Inverter and Protective Devices	Size and Weight of Inverter and Transformer	Comments	Date of Information
NKF Electronics	OK4E-100 OK4U-100 OK4J-100 AC module	All Included in Inverter	Total EUR 160	Total 93x120x30 mm 0,625 kg (Transformer 0,05kg)	-Standard data interface -Built-in kWh meter -Extremely reliable (less than 1% failure)	2002/03
NKF Electronics	OK5E-LV OK5U-LV Semi AC module	All Included in Inverter	Total EUR 333	Total 510x80x30 mm 1,2 kg (Transformer 0,02kg)	-Standard data interface over AC line -OK5 Energy Monitor option -Built-in kWh meter -Compact: very much suited for BIPV	2002/03
NKF Electronics	OK5E-MV OK5U-MV Mini-string inverter	All Included in Inverter	Total EUR 333	Total 510x80x30 mm 1,2 kg (Transformer 0,02kg)	-Standard data interface over AC line -OK5 Energy Monitor option -Built-in kWh meter -Compact: very much suited for BIPV	2002/03
Philips	PSI-300 String Inverter	Some functions are separated from inverter control circuit like optional ENS		Total 176x71x242,5 mm 1,5 kg	-System is modular -Additional wireless remote control unit is available	2001/04

SWITZLAND

INVERTER(1)

Manufacture	Type	Power Capacity	Type of Conversion	Switching Devices	Nominal AC and DC Voltage	Operational AC Voltage and Frequency Ranges	Operational DC Voltage Ranges and DC Voltage Ripple	Applicable PV module size
ASP	TopClass Grid 2500 Central Inverter	2,25 kW	Self-commutated PWM Current Control	MOSFET 30kHz	AC: 230V 50Hz DC: 72 to 145V	Voltage: +10% -15% Frequency: +/- 2%	72 to 145 V Ripple: 4%	2,5 kWp
ASP	TopClass Grid 4000/6 Central Inverter	3,5 kW	Self-commutated PWM Current Control	MOSFET 30kHz	AC: 230V 50Hz DC: 72 to 145V	Voltage: +10% -15% Frequency: +/- 2%	72 to 145 V Ripple: 4%	4 kWp
ASP	TopClass Grid Spark String Inverter	1,35 kW	Self-commutated PWM Current Control	MOSFET 30kHz	AC: 230V 50Hz DC: 75 to 225V	Voltage: +10% -15% Frequency: +/- 2%	75 to 225 V Ripple: 4%	1,5 kWp
Sputnik Engineering AG	Solarmax DC10 20, 30, 30+, 60 Central Inverter	10kW 20 kw 25 kW 25 kW 50 kW	Self-commutated PWM Voltage Control	IGBT 12.8kHz	AC: 400V 50Hz DC: 450 to 800V	Voltage: +10% -15% Frequency: +/- 2%	450 to 800 V Ripple: 4%	12 kWp 24 kWp 30 kWp 33 kWp 66 kWp
Sputnik Engineering AG	Solarmax DC 100 Central Inverter	75 kW	Self-commutated PWM Voltage Control	IGBT 12.8kHz	AC: 400V 50Hz DC: 450 to 800V	Voltage: +10% -15% Frequency: +/- 2%	450 to 800 V Ripple: 4%	100 kWp

INVERTER (2)

Manufacture	Type	Grid Electrical System	Harmonic Current	Power Factor At rated Power	Availability of power factor control	Inverter Conversion Efficiency	Isolation Transformer	DC Injection Counter-measures
ASP	TopClass Grid 2500 Central Inverter	1 phase/ 3 wires	THD: 4% Each: 2%	100%	No (Fixed)	At Rated Power Pn: 92 % 0,1Pn: 91% 0,2 Pn: 92% 0,3Pn: 92% 0,5Pn: 94% 0,75Pn:94% 0,9Pn: 92%	Not mandatory 50Hz toroidal transformer	
ASP	TopClass Grid 4000/6 Central Inverter	1 phase/ 3 wires	THD: 4% Each: 2%	100%	No (Fixed)	At Rated Power Pn: 91 % 0,1Pn: 90% 0,2 Pn: 92% 0,3Pn: 92% 0,5Pn: 94% 0,75Pn:94% 0,9Pn: 91%	Not mandatory 50Hz toroidal transformer	
ASP	TopClass Grid Spark String Inverter	1 phase/ 3 wires	THD: 4% Each: 2%	100%	No (Fixed)	At Rated Power Pn: 94 % 0,1Pn: 90% 0,2 Pn: 91% 0,3Pn: 92% 0,5Pn: 93% 0,75Pn:94% 0,9Pn: 91%	Not mandatory 50Hz toroidal transformer	
Sputnik Engineering AG	Solarmax DC 10 20, 30, 30+, 60 Central Inverter	3 phase/ 3 wires	THD: 4% Each: 2%	99%	No (Fixed)	At Rated Power Pn: 93 % 0,1Pn: 90% 0,2 Pn: 92% 0,3Pn: 93% 0,5Pn: 94% 0,75Pn:94% 0,9Pn: 93%	Mandatory 50Hz Transformer	
Sputnik Engineering AG	Solarmax DC 100 Central Inverter	3 phase/ 3 wires	THD: 4% Each: 2%	99%	No (Fixed)	At Rated Power Pn: 93 % 0,1Pn: 90% 0,2 Pn: 92% 0,3Pn: 93% 0,5Pn: 94% 0,75Pn:94% 0,9Pn: 93%	Mandatory 50Hz Transformer	

INVERTER (3)

Manufacture	Type	Inverter Power Control		Normal Startup and Stop Condition		Control Power Source
		DC side	AC side	Startup	Stop	
ASP	TopClass Grid 2500 Central Inverter	Maximum Power Tracking	AC Current control AC Voltage control AC Output power control Constant power factor	10 sec. after AC grid is within tolerance and stable DC Voltage is above minimum MPPT voltage Ramp control startup (soft start)	DC voltage below MPP limit, AC parameters are out of limit	DC side
ASP	TopClass Grid 4000/6 Central Inverter	Maximum Power Tracking	AC Current control AC Voltage control AC Output power control Constant power factor	10 sec. after AC grid is within tolerance and stable DC Voltage is above minimum MPPT voltage Ramp control startup (soft start)	DC voltage below MPP limit, AC parameters are out of limit	DC side
ASP	TopClass Grid Spark String Inverter	Maximum Power Tracking	AC Current control AC Voltage control AC Output power control Constant power factor	10 sec. after AC grid is within tolerance and stable DC Voltage is above minimum MPPT voltage Ramp control startup (soft start)	DC voltage below MPP limit, AC parameters are out of limit	DC side
Sputnik Engineering AG	Solarmax DC 10 20, 30, 30+, 60 Central Inverter	Maximum Power Tracking	AC current control AC power control (Limiting overload) Constant power factor	DC voltage test with an internal load	DC voltage and AC power test	DC side
Sputnik Engineering AG	Solarmax DC 100 Central Inverter	Maximum Power Tracking	AC current control AC power control (Limiting overload) Constant power factor	DC voltage test with an internal load	DC voltage and AC power test	DC side

INVERTER (4)

Manufacture	Type	Operational Environment			
		Temperature Range	Installation Requirements	Audible Noise	EMC Standards
ASP	TopClass Grid 2500 Central Inverter	0 to 50 °C (ref 25°C)	Inside Use Water and Dust Proof Need	32 dBA at 2 m	EN-50081-1 EN-50082-1 EN55014
ASP	TopClass Grid 4000/6 Central Inverter	0 to 50 °C (ref 25°C)	Inside Use Water and Dust Proof Need	32 dBA at 2 m	EN-50081-1 EN-50082-1 EN55014
ASP	TopClass Grid Spark String Inverter	-25 to 85 °C (ref 25°C)	Inside Use Water and Dust Proof Need	32 dBA at 2 m	EN-50081-1 EN-50082-1 EN55014
Sputnik Engineering AG	Solarmax DC 10 20, 30, 30+, 60 Central Inverter	0 to 40 °C (ref 25°C)	Inside Use Water and Dust Proof Need	57 dBA at 3 m	EN-50081-1 EN-50082-1 EN55014
Sputnik Engineering AG	Solarmax DC 100 Central Inverter	0 to 40 °C (ref 25°C)	Inside Use Water and Dust Proof Need	57 dBA at 3 m	EN-50081-1 EN-50082-1 EN55014

PROTECTIVE DEVICES OR FUNCTIONS

Manufacture	Type	Protective Functions		Transient Overvoltage Protection/Devices		Islanding Protection	Disconnection Procedure for Protection	Restart Procedure after Fault Clearance
		DC side	AC side	DC side	AC side			
ASP	TopClass Grid 2500 Central Inverter					Included Passive: frequency and voltage window Active: impedance measurement	First gate blocking then the main relay will open	Automatic Restart 20 sec. after AC and DC side conditions restored
ASP	TopClass Grid 4000/6 Central Inverter					Included Passive: frequency and voltage window Active: impedance measurement	First gate blocking then the main relay will open	Automatic Restart 20 sec. after AC and DC side conditions restored
ASP	TopClass Grid Spark String Inverter					Included Passive: frequency and voltage window Active: impedance measurement	First gate blocking then the main relay will open	Automatic Restart 20 sec. after AC and DC side conditions restored
Sputnik Engineering AG	Solarmax DC 10 20, 30, 30+, 60Central Inverter	OV/UV OC Grounding fault	OV/UV: +/- 20% of nominal voltage 0,2 sec OC, OF/UF Grounding fault	Not necessary	Not necessary	Included Passive: frequency and voltage window Active: active frequency drift (AFD)	Gate blocking and opening of circuit breaker (relay)	Automatic Restart 20 sec. after AC and DC side conditions restored
Sputnik Engineering AG	Solarmax DC 100 Central Inverter	OV/UV OC Grounding fault	OV/UV: +/- 20% of nominal voltage 0,2 sec OC, OF/UF Grounding fault	Not necessary	Not necessary	Included Passive: frequency and voltage window Active: active frequency drift (AFD)	Gate blocking and opening of circuit breaker (relay)	Automatic Restart 20 sec. after AC and DC side conditions restored

OTHERS

Manufacture	Type	Location of Protective Functions (Relays)	Price of Inverter and Protective Devices	Size and Weight of Inverter and Transformer	Comments	Date of Information
ASP	TopClass Grid 2500 Central Inverter	All Included in Inverter	Total sFr 3.400,- incl. VAT	Total 320x210x460 mm 22 kg		2001/04
ASP	TopClass Grid 4000/6 Central Inverter	All Included in Inverter	Total sFr 4.500,- incl. VAT	Total 320x210x460 mm 28 kg		2001/04
ASP	TopClass Grid Spark String Inverter	All Included in Inverter	Total sFr 2.100,- incl. VAT	Total 260x180x380 mm 18 kg		2001/04
Sputnik Engineering AG	Solarmax DC 10 20, 30, 30+, 60 Central Inverter	All Included in Inverter	Total sFr 20.000,- (DC 20 type)-	Total 600x800x2100 mm 150 kg	-Monitoring system Max Talk via Modem: daily data reading and comparison -Warranty possible over 20 years	2001/04
Sputnik Engineering AG	Solarmax DC 100 Central Inverter	All Included in Inverter	Total sFr 88.000,-	Total 600x800x2100 mm 450 kg	-Monitoring system Max Talk via Modem: daily data reading and comparison -Warranty possible over 20 years	2001/04

LISTS OF MANUFACTURES

Followings are the lists of manufactures that send response to the Questionnaire.

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