Palestine Polytechnic University

College of Engineering

Electrical Engineering Department

Competency Investigation of PV Inverters In Palestine

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Submitted to the College of Engineering

in partial fulfillment of the requirements for the

Bachelor degree in Electrical Power Engineering

Hebron, May 2017

Palestine Polytechnic University

Collage of Engineering

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Abstract

Photovoltaic inverter, that is the heart of PV systems, which is take (20 – 25)% of total cost of PV system which is in charge of electric power conversion from DC to AC. Due to the multiplicity types of inverters, which have the same power class and type connection to grid but with gap in their prices. This gap has raised attention to work compared based on several parameters. The project focuses on competency investigation of PV inverters are used in Palestinian houses that have the same power class with prices gap, based on the technical specifications, internal installation evaluation, protection, monitoring, costs and periodic tests under the same condition and circumstances to try to justify this difference in prices and provide scientific comparison study between these inverters.

The study would provide a scientific base for professional and unprofessional interested people to simplify their purchase decision in the manner of reliability/cost relationship.

For this purpose, a studying for Palestinian market is required to give most commonly types of inverters used in Palestinian houses. Whereas by statistical analysis of questionnaire, German and Chinese on grid inverters are the most common types.

As a result, each inverter has different specifications (weakness and strengthen). However, the points on which the comparison was based are insufficient to determine the best of them.

الملخص

يعتبر الانفيرتر قلب الأنظمة الكهروضوئية، حيث يشكل نسبة (٢٠-٢٥)٪ من التكلفة الإجمالية لهذه الأنظمة، وهو المسؤول عن تحويل الطاقة الكهربائية من DC إلى AC . للانفيرترات أنواع تتماثل في قدرتها وموصولة على الشبكة وتختلف في أسعارها، حيث أن هذا الاختلاف أو الفجوة في الأسعار أثارت الاهتمام لعمل مقارنة على أساس عدة معايير حيث يركز المشروع على التحقق من كفاءة الانفيرترات المستخدمة في المنازل الفلسطينية التي لها نفس القدرة والأداء مع وجود فجوة في السعر بينها ، على اساس المواصفات الفنية، وتقييم التركيب الداخلي والحماية والمراقبة الداخلية والتكاليف والاختبارات الدورية تحت نفس الظروف لتبرير هذا الاختلاف في الأسعار وتوفير دراسة علمية مقارنة بين هذه الانفيرترات. ومن شأن هذه الدراسة أن توفر قاعدة علمية للمهنيين المحترفين وغير المهنيين لتبسيط قرار الشراء الخاص بهم بطريقة تحقق الكفاءة وتقلل التكلفة.

حيث ان هذه المقارنة تتطلب دراسة السوق الفلسطيني لإعطاء أكثر أنواع االانفيرترات شيوعا في المنازل الفلسطينية. ومن خلال التحليل الإحصائي للاستبيان، وجدت الانفيرترات الألمانية والصينية هي الأكثر انتشارا وشيوعا في فلسطين.

كنتيجة للدراسة يوجد لكل انفيرتر نقاط قوة ونقاط ضعف مختلفة الا ان النقاط التي تم مناقشتها واجراء التجارب عليها غير كافية لتبرير فرق السعر وتحديد ايهما أفضل.

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1.1 Overview

Using the renewable energy has become a common need for economic and environmental reasons in many countries all over the world. Palestine is one of these countries, which is interested in the renewable energy field, especially the PV system. The PV system has a deep connection with the inverters, so we can get the perfect outcome.

The project based on two principle (research and applied) where it will be compared between two type of inverters from two different manufacturing countries which are available in Palestinian market and used in Palestinian houses. These inverters have the same power class with gap in prices, so the comparison based on the characteristic and technical data such as there efficiencies, protection, installation, and do the appropriate experiments to knowledge the quality of the signal. Which making easier for Palestinian engineer and technical to choose and select the appropriate type for the system who operate on it, and knowing the strengths and weaknesses of these inverters.

1.2 Motivation

- The increasing trend for investment in PV system in Palestinian markets.
- Gap price between inverters that have the same power class and type connection to grid, which manufactured from different companies.
- Offering customers a base for reliability/cost relationship for the inverters available in Palestinian market.

1.3 Objectives

- Provide the consumer scientific comparison study between inverters, which are produced by different companies and have the same class and performance with gap prices.
- Is the gap prices between these types of inverters justified or not?
- Release the strengths and weaknesses of the present types in the Palestinian market.

1.4 Challenges

- The high price of inverters under text sample, which reached to 2500$.
- Find alternative dc source instead the PV modules as input for on grid inverters and the high price of this dc source, which reached to 350$.
- Find a way for connect these inverters as on grid mode.
- Non-disclose the companies about the information for the internal protection devices used on inverters.

1.5 Importance

- Determine the considerations for choose the best type of inverter to consumer's PV system.
- Right choice of inverters reduces the cost of maintenance and increase the reliability of the PV system.

1.6 Time schedule

- For first semester

Week / Tasks	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Task 1	■	■														
Task 2			■	■	■											
Task 3					■	■	■	■								
Task 4									■	■	■					
Task 5											■	■	■	■		
Task 6															■	■

- **Task 1**: Collection of general information about inverters.
- **Task 2**: Collection data and information on the subject of the project.
- **Task 3**: Work a questionnaire about the types of inverters that used in Palestine and visit the companies to fill it.
- **Task 4:** Analysis the questionnaire and choose two inverters, which will used in project.
- **Task 5**: Work comparison between inverters depending on their datasheets.
- **Task 6**: Prepare the presentation.

- For second semester

Week / Tasks	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Task 1	■	■	■	■	■											
Task 2				■	■	■	■	■								
Task 3									■	■	■	■				
Task 4													■	■	■	
Task 5																■

Task 1: Collection offer prices and buy the chosen inverters.

Task 2: Install and study the datasheet and catalog for the chosen inverters.

Task 3: Running the inverters and do the experiment in renewable energy lab.

Task 4: Disassembling inverters and examination the internal component.

Task 5: Write the document and prepare the presentation.

2

Chapter Two PV Inverters

2.1 Introduction

2.2 PV Inverters Components

2.3 Function of PV Inverters

2.4 PV Inverter In Palestine Market

2.1 Introduction

DC to AC converters are known as inverters. Inverters convert DC input power into grid synchronized AC output power.

The Key element of PV system is the inverter. The inverter developed parallel with development of PV system where the first grid-connected PV plants were introduced in the 1980s as thyristor based central inverters. After that The first series-produced transistor-based PV inverter was PV-WR in 1990 by SMA [1]. Since the mid-1990s, IGBT and MOSFET technology has been extensively used for all types of PV inverters except module-integrated ones, where MOSFET technology is dominating.

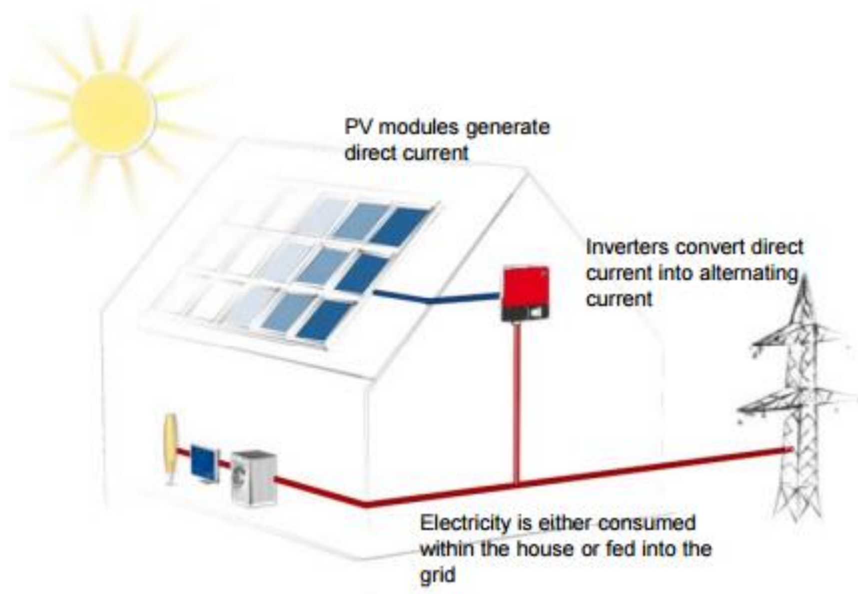


Fig 2.1: On Grid PV System With On Grid Inverter.

2.2 PV Inverters Components

The major component of the modern PV inverter is:

1- Microcontroller
2- Power electronic switches (IGBT, MOSFT,…etc.)
3- Filters.
4- Measuring and monitoring components.
5- Protection and devices.

2.2.1 Microcontroller

The microcontroller is main part of inverter, which performs multiple functions (e.g.) generating PWM for switching; controlling the protection systems etc. for inverters it used for control the switching of signals according to requirements.

There are many types and families of microcontroller available in the market such as PIC family, AVRs (ATMEGA series), Atmel and Arduino etc. Which can use depending on the design specifications.

2.2.2 Power Electronic Switches

2.2.2.1 H-Bridge

An H-Bridge is a set of four switches that are assembled in such a way that arbitrary load impedance is separated from a direct current (DC) power rail and ground. These switches can then be used to control the direction of current running from the DC source to ground in either direction across the connected impedance.

In inverters, an H-Bridge is being utilized to create an Alternating Current (AC) waveform from a high voltage DC Rail. This is done by reversing the direction of current flow across the load impedance at a frequency of 50 Hz, which in turn results in an alternating current signal at the same frequency of typical line current in the Palestine. [2]

For inverters most switches used are a transistor such as IGBT and MOSFET; which is act as current and voltage controlled switches.

2.2.2.2 MOSFET

Metal-Oxide-Semiconductor-Field-Effect-Transistor (MOSFET) is a voltage-controlled device and requires a very small input current, it is mainly used for switching of electronic signals as its switching speed is very high.

2.2.2.3 IGBT

Insulated-gate bipolar transistor (IGBT) is a minority-carrier device with high input impedance and large bipolar current-carrying capability. Benefits of IGBT are high current density and low power dissipation resulting in higher efficiency and smaller heat sink to allow lower overall system cost.

2.2.3 Filters

At times, it is desirable to have circuits capable of selectively filtering one frequency or range of frequencies out of a mix of different frequencies in a circuit. The output of the inverter is "chopped AC voltage with zero DC components" contain harmonics. Therefore, an LC low-pass filter is normally fitted at the inverter output to reduce the high frequency harmonics; which has easy passage for low-frequency signals.

2.3 Function of PV Inverters

The old inverters used motor-generator sets, but were costly, heavy and inefficient. [3] Modern inverters use solid-state designs and microprocessor controls to produce high quality AC power very efficiently. also Modern inverters doesn't only perform the converting of DC current produced by the PV cells into AC current for our home appliances, it also perform another functions; which makes it differs from old inverters. Such as:

1. Monitoring and Protection.
2. Power Optimization.
3. Reliable Operation.

2.3.1 Monitoring and Protection

PV systems produce energy yields data, which collect by the inverters i.e. used this data to monitors the PV generator's electrical activity, and signals disturbances if they occur. The yields data can be read directly from the device. The inverter also monitors the power distribution grid it feeds into. If the specified voltage and frequency limits are exceeded, it will disconnect the PV system from the grid to ensure safety. However, if there is a slight increase in the frequency the inverter will reduce its power accordingly to guarantee grid specifications are met. Typically an inverter shuts down for about 5-minutes if it senses the grid going down. [4]

This is a safety precaution but not the only one that prevents inverters from sending power into the grid if the grid fails. Inverters carry several anti-islanding features that are of paramount importance for safety reasons. [5]

The most faults that occur on the PV inverter include:

1- Overvoltage fault, which occur on the two sides (AC and DC) of the inverter due to lightning.

2- Short circuit fault (overcurrent), which occur on the two sides (AC and DC) of the inverter.

3- Leakage current fault, which also occur on the AC and DC sides of the inverter due to faulty insulation between current and ground conductors.

2.3.2 Power Optimization

Another importance function of the inverter is to make sure the PV modules are always working at their optimum power levels. At any given temperature and irradiation intensity, there is exactly one voltage-to-current-strength ratio that allows a PV module to achieve its maximum power, which is called maximum power point tracker (MPPT). Because both temperature and irradiation intensity are constantly changing, the inverter must continuously monitor the MPP to ensure the PV modules are generating as much energy as possible. The inverter relies on the MPP tracker software for monitoring. [5]

2.3.3 Reliable Operation

Inverter is a high-tech device with sensitive electronics inside that must function reliably in all kinds of weather, So that the modern inverter is fixed (not movable) and isolated part from an external effect. That means their internal components have to be robust and long lasting.

2.4 PV Inverter In Palestinian Market

With a wide range of models and options, selecting the right inverter has become complex task. With some basic knowledge, you can narrow down the choices to select the right one for your application. The most basic choices are whether your system will be grid-tied or off-grid.

According to the project targets which requires a close study to the Palestinian market to identify the types and the categories of the inverters, which are mostly sale in the Palestinian market. For this purpose, we gave a questionnaire to Palestinian companies; which are specialized in building-up and maintaining the PV system and interested of the inverters types, categories and efficiency. The sample included the companies from Bethlehem, Hebron and Ramallah. The results of statistical analysis were as following:

Table 2.1: The Percentage of The Most Type Inverters Existing In Palestinian Market.

Type of inverter	On grid	Off grid
Percentage	69%	31%

Table 2.2: The Percentage of The Most Class Used In Household Loads.

Class (KW)	1	2	3	4	5	6
Percentage	0%	0%	37.5%	0%	62.5%	0%

Table 2.3: The Percentage of The Most Inverters Used In Household PV System.

Most inverter used	KACO	SMA	ABB	SHENT	OMNIC	SOLAREDG	EXPERT
Percentage	4.5%	30%	30%	0%	17.4%	0%	13.4%

Based on the mentioned statistical analysis, we conclude that the most selling in the Palestinian market is on grid PV inverter class 5KW systems for household applications, where the types of the inverters that are mostly used are: SMA, ABB and OMNIC. [Appendix A].

3

Chapter Three General Comparison

3.1 Samples under Comparison

3.2 Parameters to Be Comparison

3.3 After Selling Service

3.1 Samples under Comparison

After studying the Palestinian markets, we decide to compare two inverters with the specific shown in table 3.1 below. The comparison results will be based on studying and analysis of the datasheets and manuals. such details which we compare between those inverters is in physical structure such as (assembly system, isolation, cooling, dimensions and weight) and protection devices that are exist or not; these protection devices used to protect from the overvoltage, leakage current and over current.

Note that, for legal reasons and not completing the study we decided not to mention the names of inverters.

Table3.1: samples under test.

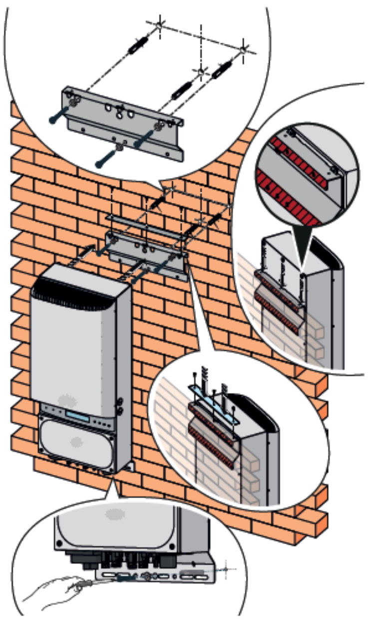
	Sample 1(European**)**	**Sample 2(**Asian**)**
Price	**1300$**	**1000$**
Class	5KW	5KW
Topology Structure	transformer less	transformer less
On/off grid	On grid	On grid
Number of MPPT	2 MPPT	2 MPPT
Origin	German	China

3.2 Parameters to Be Comparison

3.2.1 Physical Structure

3.2.1.1 Assembly System

Through install the European and Asian inverters, we notes that to install European inverter need bracket for wall fastening and Safety bar to guarantee durability of inverter, however; Asian inverter need only Wall mounting bracket as shown in figure 3.1 and 3.2 respectively below.



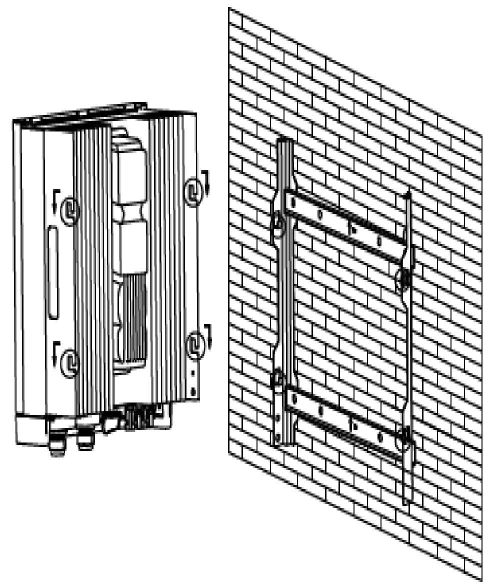
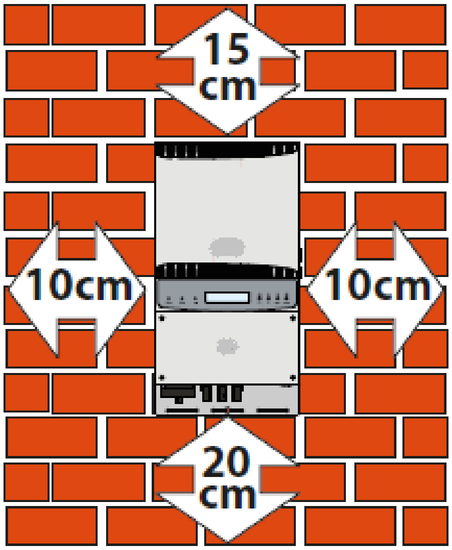


Fig 3.1: European Install.   Fig 3.2: Asian Install.

The installation of European inverter harder than Asian due to need more Screws, but the European more fixity.

3.2.1.2 Dimensions

When install the inverters, it must consider the safety distance from a wall or other inverters in the same system that will allow the normal control and maintenance operations to carry out as shown below in figure 3.3 and 3.4 respectively.



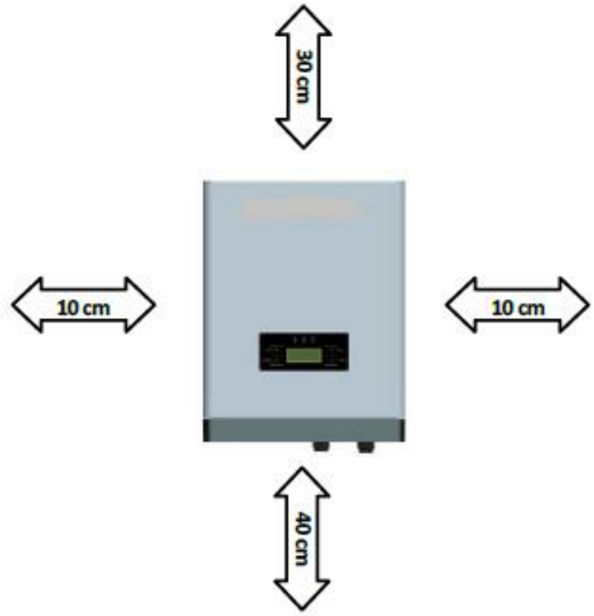


Fig 3.3: Safety Distance For European. Fig 3.4: Safety Distance For Asian.

From the datasheets European dimensions is (32.5cm x 81cm); however, Asian dimension is (35.2cm x 42.1cm); i.e. the occupied area will be different in both inverters.

$$\text{Area} = \text{Width x length} \tag{3.1}$$

By equation 3.1

Area of European inverter = 32.5 x 81 = 2632.5 cm^2

However, the occupied area for European inverter = ((10+10+32.5) x (20+81+15)) = 6090 cm^2.

Area of Asian inverter = 35.2 x 42.1 = 1481.92 cm^2.

However, the occupied area for Asian inverter = ((10+10+35.2) x (30+40+42.1)) = 6188 cm^2.

As we notice, the area of the Chinese inverter is less than that of the European inverter, however consider the required distance from the manuals between neighboring inverters, we find that the total occupied area for the European is less than Asian.

According to fig 3.3 and 3.4, we find that the lower and upper distance of the European is less than Asian. Based on this, we assume that the cooling system of the European inverter is better than Asian inverter. This is also supported by the internal structure of the cooling system. However, the cooling of the European depends only on natural cooling through the heat sink, and the Asian depends on cooling on the presence of heat sink and internal fan.

3.2.1.3 Cooling system

In comparison based on cooling system of the two types, the cooling of the European depends only on natural cooling through the heat sink, and the Asian depends on cooling on the presence of heat sink and internal fan. We assumed the reason for dispensing internal fan in European inverter is the heat sink provide good cooling which put on the front interface of the inverter not as Asian inverter, which put on background interface as fig3.5 and 3.6 shown below. In addition, the presence of an internal fan means have additional possible faults in the inverter, which is a fan failure.

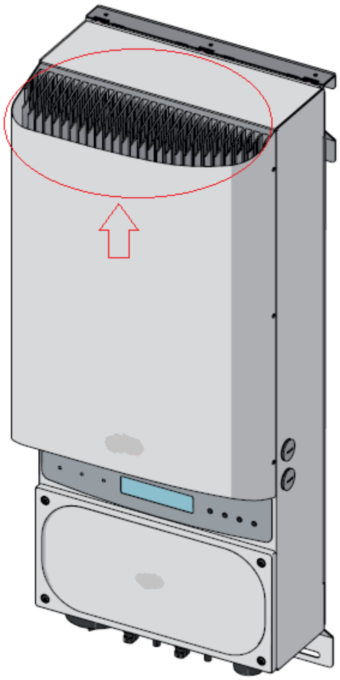


Fig 3.5: European Heat Sink.

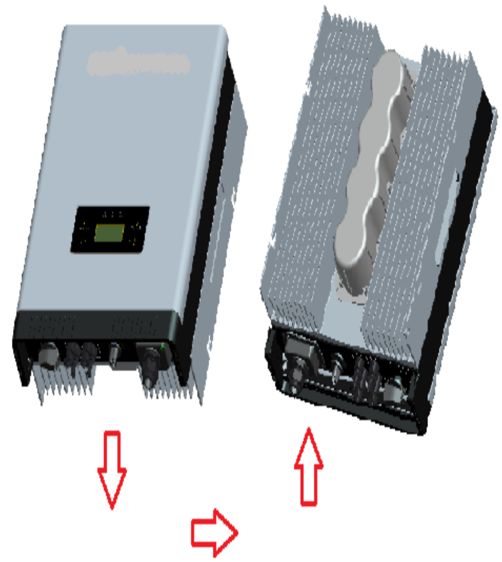


Fig 3.6: Asian Heat Sink with Internal Fan.

3.2.1.4 Weight

Considering the two types, we find the weight of European inverter more than Asian inverter, whereas the weight of the first is 26kg and the second is 16.5kg. Therefore, we assumed the weight difference is justified due to design material of out cover. Which making the European more bearable to mechanical stress.

3.2.1.5 Enclosures

According to datasheets, the two inverters have the same standard for isolation, which represent in standard ingress protection 65 (IP65) which relate to the level of protection provided by an enclosure or housing. The first number (6) relates to protection from solids (against Dust tight) and the second number (5) relates to protection from liquids (against water jet spray).

3.2.2 Protection Devices

3.2.2.1 Overvoltage Protection Devices

There are always a chance of suffering an electrical power system from abnormal over voltages. These abnormal over voltages; may be caused due to various reason such as, sudden interruption of heavy load, lightening impulses, switching impulses etc. for this purpose using varistors as protection against overvoltage.

Varistors are manufacture from a non-homogeneous material, giving a rectifying action at the contact points of two particles. Where when a transient occurs, the varistor resistance changes from a very high stand-by value to a very low conducting value. The transient is thus absorbed and clamped to a safe level, protecting sensitive circuit components. The features is:

- Wide voltage range selection - from 14 VRMS to 680 VRMS. This allows easy selection of the correct component for the specific application.
- High energy absorption capability with respect to size of component.
- Response time of less than 20 ns, clamping the transient the instant it occurs.
- Low stand-by power - virtually no current used in the stand-by condition.
- Low capacitance values, making the varistors suitable for the protection of digital switching circuitry.
- High body insulation - an ochre coating provides protection up to 2500 V, preventing short circuits to adjacent components or tracks.

• Available on tape with accurately defined dimensional tolerances, making the varistors ideal for automatic insertion.

• Completely nonflammable, in accordance with IEC, even under severe loading conditions.

• Nonporous lacquer making the varistors safe for use in humid or toxic environments. [6].

Asian inverters have protection devices according to the international electrotechnical commission (IEC) 62109-1 which is a safety standard for solar power converters, where equipment falls in tow category, category II before the inverter in the DC side and category III after the inverter in AC side [appendix A]. The provided manual does not contain any information about the overvoltage protection devices used, so we assumed there is no varistors on it.

European inverters have varistors protection device in both AC and DC side and the overvoltage rating based on IEC 62109-1 standard. [Appendix B]

3.2.2.2 Protection Against Leakage Current

The currents that flow from or between insulated conductors from earth and from each other called leakage currents, and are normally small. However, since the amount of current required to produce adverse physiological effects is also small, such currents must be limit by the design of equipment to safe values.

For this purpose uses residual current device (RCD) and residual current monitoring device (RCM). Used RCM for monitoring the leakage current and send a massage about it before RCD make the interruption as the figure 3.5 below describe.

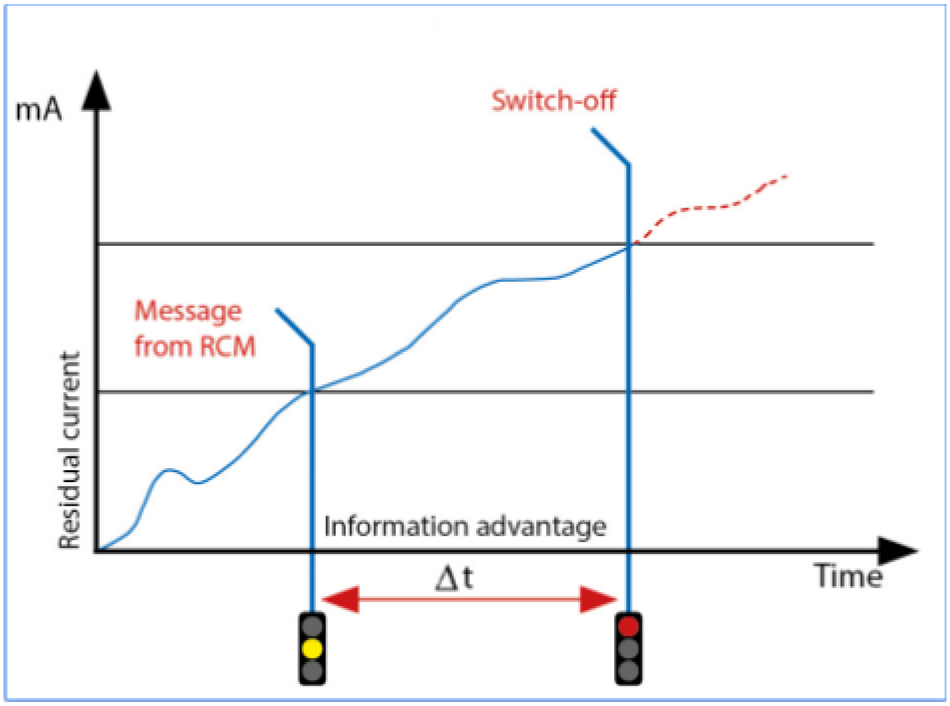


Fig 3.7: RCM Operation.

Both Asian and European have RCD and RCM in the AC side, where the current sensor will detect the volume of the leakage current and compare it with the pre-set value, if the leakage current exceeds the permitted range, the RCD will disconnect the inverter from the AC load.

To protect the AC connection line of the inverter, European inverter recommend installing a device for protection against leakage current with the following characteristics as table 3.1 shown below.

Table 3.2: Characteristic Recommend For Leakage Current Protection In AC Side.

Type of differential protection	A/AC
Differential sensitivity	300 mA

European declares that the European transformerless inverter, in terms of their construction, do not inject continuous ground fault currents and therefor is no requirement that the differential protection installed downstream of the inverter be type B in accordance with IEC 60755/A2.

3.2.2.3 Overcurrent protection

Overcurrent is abnormal current flow higher than the normal value of current flow in an electrical circuit. Uncorrected “overcurrent” can cause serious safety hazards and costly damage to electrical equipment and property.

There are three basic types of current flow in an electrical circuit:

1. Normal intended current flow to operate electrical equipment.
2. Abnormal overcurrent flow with a value of up to 10 times normal current flow.
3. Abnormal overcurrent flow with a value more than 10 times the normal current flow. It is known as “short-circuit” or “fault” current flow.

Fuses and most circuit breakers are installed in electrical circuits to open and stop the flow of overcurrent. They respond and open for both low and high values of overcurrent flow. “Limiters” and “magnetic only” circuit breakers respond only to high values of overcurrent flow. [7]

European does not give any information about this. However, To protect the AC connection line of the inverter, European inverter recommend installing a device for protection against overcurrent with the following characteristics as table 3.3 shown below.

Table 3.3: Characteristic Recommend For Overcurrent Protection In AC Side.

Type	Automatic circuit breaker with differential thermal magnetic protection
Voltage rating	230 Vac
Current rating	32 A
Magnetic protection characteristic	B/C

For Asian inverter, the fuse from littlefuse brand is used as overcurrent protection device. [Appendix C]. In addition, it does not provide any recommend about the overcurrent protection used to protect the AC connection side, which is as disadvantage.

3.2.3 Internal structure

3.2.3.1 European inverter's internal structure

Figure 3.6 shown below summarizes the internal structure of this inverter.

The main blocks are the DC-DC input converters (called "boosters") and the output inverter. The DC-DC converter and the output inverter both work at a high switching frequency, and so are small and relatively light. Each of the input converters is dedicated to a separate array, with independent maximum power point tracking (MPPT) control. This means that the two arrays may be installed with various positions or orientations. Each array is controlled by an MPPT control circuit. The two trackers can be configured (where required) in parallel to handle power levels and/or current higher than those that a single tracker can handle.

This inverter version is of the type without transformer, that is without galvanic insulation between the input and the output. This allows ultimately an increase in conversion efficiency. The inverter is already equipped with all the protections necessary for safe operation and compliance with the norms, even without the insulating transformer. The inverter is controlled by two independent DSPs (Digital Signal Processors) and a central microprocessor.

The connection to the power grid is thus kept under control by two independent computers, in full compliance with the electric field norms both for power supply to the systems as well as security. The operating system carries out the task of communicating with its components in order to carry out data analysis.

The European inverter does not explain the type of power electronic device, which is used in inverter.

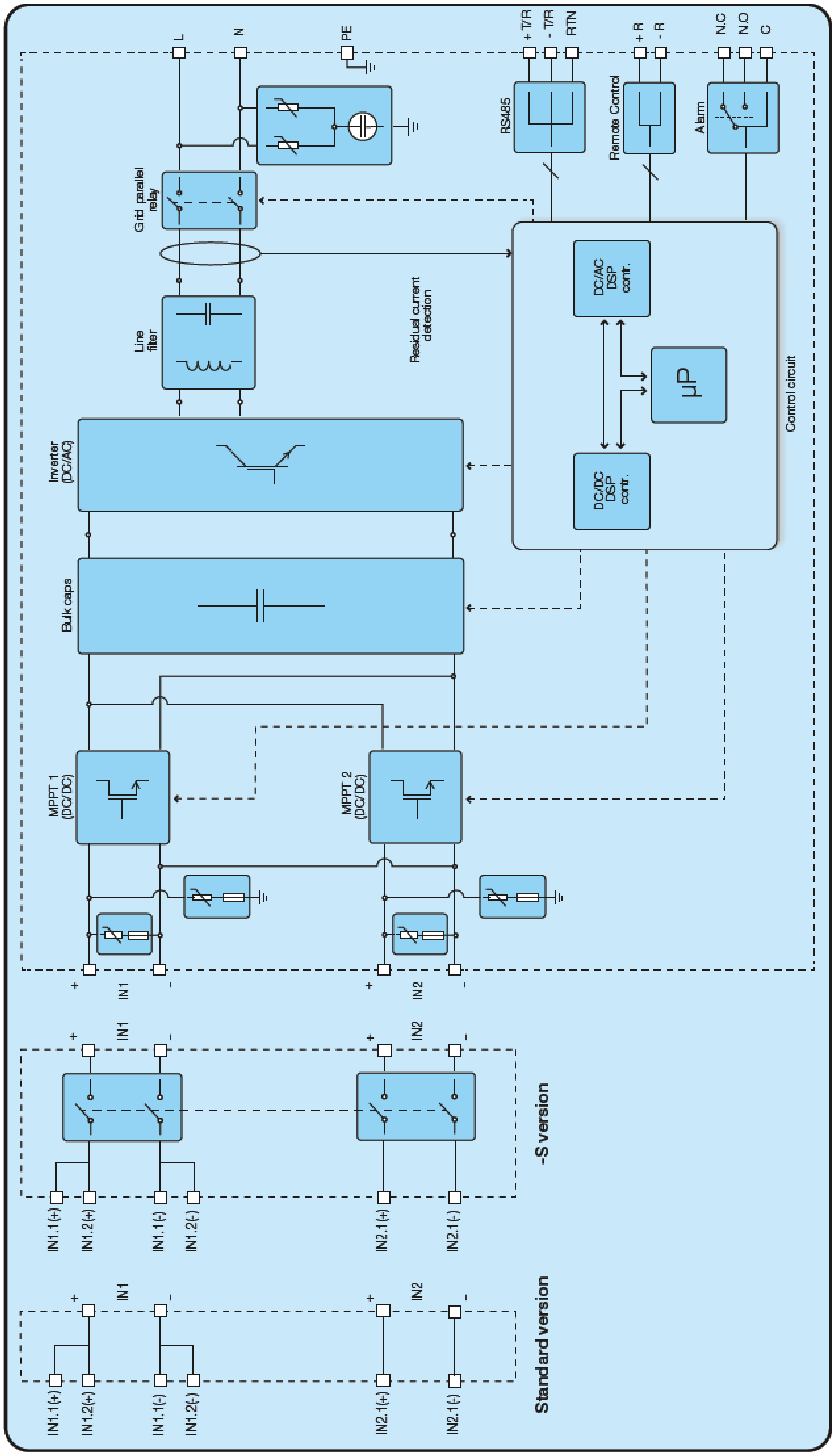


Fig3.8:Internal Structure For European Inverter.

3.2.3.2 Asian inverter's internal structure

The manual of Asian inverter does not give any information about the internal structure as the European's manual, however Asian provide key component list. [Appendix C]

The brand of used IGBT in Asian inverter is INFINEON, which is one of the worldwide leader in manufacturer and developing of power electronic device. [10]

3.2.4 Quality of the output signal

In this section, we want to talk about THD and the efficiency, which is as an importance parameter in the PV inverters.

3.2.4.1 Total Harmonic Distortion (THD)

Harmonics are the integer multiples of the fundamental frequency of any periodical waveform are called e.g. Acoustic waves and Electrical waves as shown in figure 3.7 below. The harmonics come from Non-linear loads such as Variable speed drives; Uninterruptible power supplies (UPS), Industrial rectifiers and welding machines. [8]

The total harmonic distortion can be find by the following equations:

$$\mathrm{THD_V} = \frac{\sqrt{V_2^2 + V_3^2 + V_4^2 + \cdots + V_n^2}}{V_1} * 100\% = \frac{\sqrt{\sum_{k=2}^{n} V_k^2}}{V_1} * 100\% \tag{3.2}$$

$$THD_I = \frac{\sqrt{I_2^2 + I_3^2 + I_4^2 + \cdots + I_n^2}}{I_1} * 100\% = \frac{\sqrt{\sum_{k=2}^{n} I_k^2}}{I_1} * 100\% \tag{3.3}$$

The Effects of Harmonic Distortions:

- Harmonic Currents mainly effect the power distribution system up to the rectifier:

  - Additional losses in wires and cables.

- Extra heating of transformers.

- Circuit breaker malfunctioning.

- Harmonic Voltage can affect other equipment's connected to the electrical system:

  - Resonance with power factor correction capacitors.

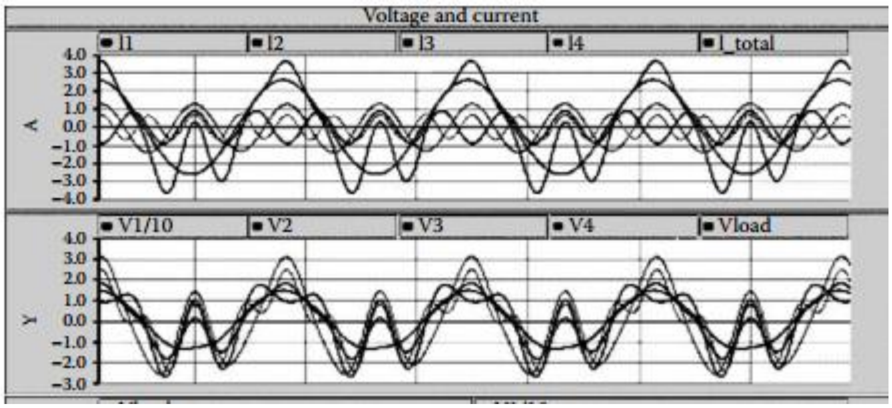


Fig 3.9: Voltage and Current Harmonic Distortion.

For European inverter the THD < 3.5%, while Asian inverter THD < 2% Where it is considered an advantage for this inverter.

3.2.4.2 Efficiency

Efficiency signifies a level of performance that describes a process that uses the lowest amount of inputs to create the greatest amount of outputs. Efficiency, in terms of PV inverters, is a percent measure of the conversion of DC electricity from solar panels (or batteries) to AC electricity. [9]

There are two Types of PV inverter efficiency:

1- European inverter efficiency:

   It called weighted efficiency, which measure inverter performance across the range of the inverter's capacity. This give a better idea about the inverter's operating profile over the course of the day. Calculating weighted efficiency requires first selecting a few DC input levels relative to the inverter's rated capacity, there are 6 efficiency points in the calculation according to the following equation:

$$\eta_{EU} = 0.03 \times \eta_{5\%} + 0.06 \times \eta_{10\%} + 0.13 \times \eta_{20\%} + 0.1 \times \eta_{30\%} + 0.48 \times \eta_{50\%} + 0.2 \times \eta_{100\%}. \quad \textbf{(3.4)}$$

2- California Energy Commission efficiency (CEC):

This type as the European inverter efficiency, the difference between the CEC and EU type, is in how each input level is weighted. The calculation according to the following equation:

$$\eta_{CEC} = 0.04 \times \eta_{10\%} + 0.05 \times \eta_{20\%} + 0.12 \times \eta_{30\%} + 0.21 \times \eta_{50\%} + 0.53 \times \eta_{75\%} + 0.05 \times \eta_{100\%}. \quad \textbf{(3.5)}$$

For European inverter:

- Maximum Efficiency (η_{max}) = 97.0%.
- Weighted Efficiency (EURO/CEC) = 96.4%.

For Asian inverter:

- Maximum Efficiency (η_{max}) = 98.2%.
- Weighted Efficiency (EURO/CEC) = 97.5%.

According to the above information, Asian inverter have an advantage where it have higher efficiencies then European inverter.

3.3 After Selling Service

Both companies provide websites for any enquiries about their inverters, we contact with them to get information about the internal protection devices. However, The European Company responded to our emails Within 7 days. In contrast, The Asian Company did not responded to our emails until now.

In view of those two websites, both provide the same information need for contact i.e. there no any difference between those websites.

4

Chapter Four Experiment Results and Analysis

4.1 Introduction

4.2 Cooling Efficiency

4.3 Analysis of The Output Signal

4.4 Anti-Islanding Protection

4.1 Introduction

After the general comparison according to datasheet, need for Practical experiments which put the two samples under the same condition and circumstances to prove these information which relate to cooling efficiency, analysis of the output signal and Anti-Islanding Protection for each inverter, which will be support the theory result in chapter 3. Table 4.1 shown below the main device that are used to set up the circuit for inverters in the experiments.

Table 4.1: Devices Used In Experiments.

VEGA -78 Power Quality Analyzer
Thermometer
SP-750-48 Four Power supplies as DC input connected in series Each Volts 48-60 Each Amps 15
LINI-T Digital Multimeter Model UT33C

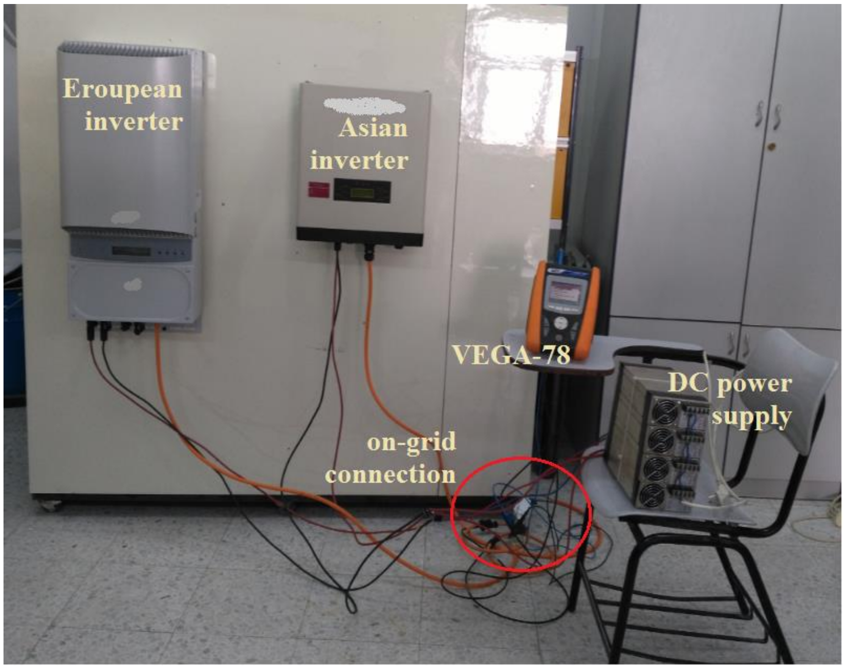


Fig 4.1: Test Circuit with Devices.

4.2 Cooling Efficiency

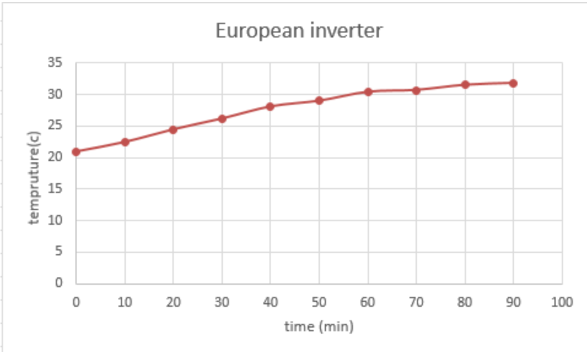
In this experiment, we use the thermometer and put it in the middle of the heat sink as figure 4.2 and 4.3 shown below.

Fig 4.2: Thermometer with European Inverter.

Fig 4.3: Thermometer with Asian Inverter.

In this experiment, we turn on the two inverters at temperature room (21c^{o}), input dc voltage 206V and dc current 15A for 90 minutes. The study depend on divide the time into intervals, which will be 10 minutes and take the reading from the thermometer after each interval to reach the steady state temperature. [Appendix D]

As a result, the European and Asian inverters have the same steady state temperature as figure 4.4 and 4.5 shown below, so the cooling efficiency for each inverter are the same. However, the Asian efficiency will be decreased when fan failure, which is considered as disadvantage for it, on the other hand, European cooling system will conserve its efficiency due to doesn't have internal fan and depend on good physical structure of the heat sink as the previous chapter describe.



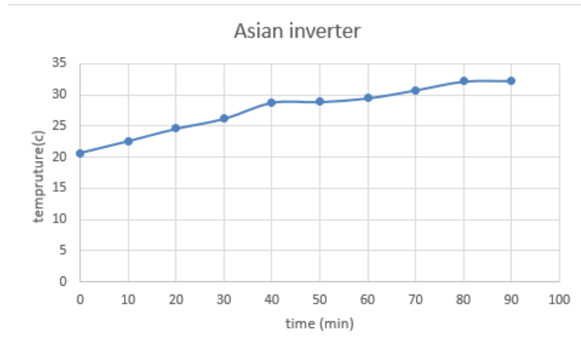


Fig 4.4: Temperature vs Time For European.

Fig 4.5: Temperature vs Time For Asian.

4.3 Analysis of The Output Signal

Analysis the output signal is achieved according to total harmonic distortion, current and voltage waveforms and efficiency. For this purpose connect the VEGA-78 device to inverters under the same conditions and circumstances where the input dc voltage is 206V and the input dc current is 15A and turn on the inverters for 30 second, then take the reading from the VEGA-78 for each second and after that we take the average of these. The readings include all of the above details.

4.3.1 Analysis The Output Signal of European Inverter

After doing the experiment, the taken result according to our measurement is in appendix E. the input power is calculated as the following equation:

$$P_{in} = I_{dc} \,.\, V_{dc} \tag{4.1}$$

$= 15 \,.\, 206 = 3090$ W, which represent 60% of the rated power of the inverter.

The average output power that taken from appendix E is 2968.5W and the current 13.137A. So the efficiency is calculated as the following equation:

$$\eta = \frac{p_{out}}{p_{in}}.100\% \tag{4.2}$$

$$= \frac{2968.5}{3090}.100\% = 96.07\%.$$

By comparison with datasheet, the calculated efficiency is nearly to given efficiency where is equal 97.0% at rated power, so that we assume the efficiency is the same and have no different between them.

The second part of the experiment concerns the measurement of the Total harmonic distortion (THD). At this case, the harmonic currents (THD_i) and voltages (THD_v) injected into grid by the inverter were further recorded at appendix E.

After taking the results every second according to our measurement, we take the average value for THD_v, which is equal 3.02% and the THD_i injected from the inverter where it is equal 4.85%. However according to datasheet the THD_i <3.5%, so we assume this difference in values is according due to different between our measurement conditions and Circumstances and laboratory conditions of manufacturer, so we recommend that it should do deeper investigation through further work in future.

4.3.2 Analysis The Output Signal of Asian Inverter

After doing the experiment, the taken result due to our measurement is in appendix F. the input power is calculated as equation 4.1 above:

P_{in} = 3090 W, which represent 60% of the rated power of the inverter.

The average output power that taken from appendix F is 2870.7W and the current is 13.451A. So the efficiency is calculated as equation 4.2 above is:

$\eta = \frac{2870.7}{3090} . 100\% = 92.9\%$.

By comparison with datasheet, the calculated efficiency is different to given efficiency where is equal 98.2% at rated power, so that we assume this difference in values is according due to different between our measurement conditions and Circumstances and laboratory conditions of manufacturer, so we recommend that it should do deeper investigation through further work in future.

The second part of the experiment concerns the measurement of the Total harmonic distortion (THD). At this case, the harmonic currents (THD_i) and voltages (THD_v) injected into grid by the inverter were further recorded at appendix F. After taking the results every second according to our measurement, we take the average value for THD_v , which is equal 3.52% and the THD_i injected from the inverter where it is equal 5.46%. However according to datasheet the THD_i <2.0%, so we assume this difference in values is according due to different between our measurement conditions and Circumstances and laboratory conditions of manufacturer, so we recommend that it should do deeper investigation through further work in future.

As results for our comparison, European inverter datasheet agree with our measurement, which have a small difference in values between them. However, Asian inverter datasheet disagree with our measurement due to difference in values.

4.4 Anti-Islanding protection

Anti-islanding protection is very important in case when we have on grid inverters, which needed for safety resonance, where when we have falling down grid the inverters must shutdown, according to chapter 2, which tell us that the modern inverters have this protection approach. However, the datasheets for our inverters do not give the time of shutting down so we do this experiment to know that. In this experiment we apply the idea of falling down grid by disconnect the output cable from the socket, which connected to the grid.

For European inverter when grid falling down, it give an alarm and shutting down the output through milliseconds. However, the LCD of the inverter will not turn off, which is advantage as they tell the users about this error.

For Asian inverter when grid falling down, it does not give an alarm and shutting down the output through milliseconds. However, the LCD of the inverter will turn off after three seconds, which is disadvantage for it as they dose not tell users about this error.

5

Chapter Five Results and Recommendation

The project based on comparison between two inverters with the same class and performance, which are manufactured from different companies with gap prices under the same Circumstances. As discussed in the previous chapters, we find that each inverter has different specifications (weakness and strengthen). However, the points on which the comparison was based are insufficient to determine the best of them. Table 5.1 shown below the results of our comparison, for more results and details read chapter 3 and 4.

Table 5.1: Results of Comparison Study.

	European	Asian
Cooling system	Natural cooling	Natural cooling with internal fan
Agree the measurement with datasheet	Yes	No
Occupied area	Smaller	Greater
Information is provided by company	More details	Less details
Reaction of Anti-islanding protection equipment	Within milliseconds	Within milliseconds

Therefore, to make project's results more accurate and for further works, we recommend the following:

1- The inverters should fed by solar panels to investigate accurate performance.
2- Open the outer casing of the inverter and identify the types of internal components used.
3- The reliable of the electronic devices (power electronic, varistors, etc…) should be investigate by cycling test.

Conclusion

The inability to determine which is better and justify the price difference between them based on the tests performed and the points that were compared through the Datasheet. However, we find that each inverter has different specifications (weakness and strengthen).

Appendix A

Datasheet for Asian inverter

Type	3kw	4kw	5kw
Input (DC)			
Max. PV Power	3400W	4500W	5000W
Max DC Voltage	590V	590V	590V
Nominal DC Voltage	360V	360V	360V
Operating MPPT Voltage Range	120 - 550V	120 - 550V	120 - 550V
MPPT Voltage Range at Nominal Power	150 - 500V	200 - 500V	200 - 500V
Start up DC Voltage	150V	150V	150V
Turn off DC Voltage	120V	120V	120V
Max. DC Current	12A/12A	16A/16A	18A/18A
Max. Short Circuit Current for each MPPT	16A/16A	20A/20A	20A/20A
Number of MPP trackers	2	2	2
Max. Input Power for each MPPT	2000W	2600W	3000W
Number of DC Connection for each MPPT	1/1	1/1	1/1
DC Connection Type	MC4 connector	MC4 connector	MC4 connector
Output (AC)			
Max. AC Apparent Power	3300VA	4400VA	5000VA*
Nominal AC Power(cos phi = 1)	3000W	4000W	5000W**
Nominal Grid Voltage	220V/230V/240V	220V/230V/240V	220V/230V/240V
Nominal Grid Frequency	50Hz/60Hz	50Hz/60Hz	50Hz/60Hz
Max. AC Current	14.4A	19.0A	22.0A
Grid Voltage Range*	185-276V	185-276V	185-276V
Grid Frequency Range*	45-55Hz/55-65Hz	45-55Hz/55-65Hz	45-55Hz/55-65Hz
Power Factor	0.95 capacitive…0.95 inductive	0.95 capacitive…0.95 inductive	0.95 capacitive…0.95 inductive
Total Harmonic Distortion (THD)	<2%	<2%	<2%
Feed in Starting Power	30W	30W	30W
Night time Power Consumption	<1W	<1W	<1W
Standby Consumption	6W	6W	6W
AC Connection Type	Plug-in connector	Plug-in connector	Plug-in connector
Efficiency			
Max. Efficiency (at 360Vdc)	98.2%	98.2%	98.2%
Euro Efficiency (at 360Vdc)	97.3%	97.5%	97.5%
MPPT Efficiency	99.9%	99.9%	99.9%
Safety and Protection			
DC Insulation Monitoring	Yes		
DC Switch	Optional		
Residual Current Monitoring Unit (RCMU)	Integrated		
Grid Monitoring with Anti-islanding	Yes		
Protection Class	I (According to IEC 62103)		
Overvoltage Category	PV II / Mains III (According to IEC 62109-1)		

Type	3kw	4kw	5kw
Reference Standard			
Safety Standard	EN 62109, AS/NZS 3100		
EMC Standard	EN 61000-6-1, EN 61000-6-3, EN 61000-6-2, EN 61000-6-4, EN61000-3-2, EN61000-3-3, EN61000-3-11, EN61000-3-12		
Grid Standard	VDE-AR-N-4105, VDE 0126-1-1, RD1699, CEI0-21, C10/11, G83/2, UTE C15-712-1, AS4777, CQC		
Physical Structure			
Dimensions (WxHxD)	352x421x162.5mm		
Weight	16.5kg		
Environmental Protection Rating	IP 65 (According to IEC 60529)		
Cooling Concept	Internal fan convection		
Mounting Information	Wall bracket		
General Data			
Operating Temperature Range	-20°C to +60°C(derating above 45℃)		
Relative Humidity	0% to 98%, no condensation		
Max. Altitude (above sea level)	2000m		
Noise Level	< 40dB		
Isolation Type	Transformerless		
Display	3 LED, Backlight,20 x 4 Character LCD		
Data Communication Interfaces	RS485(WiFi, GPRS, intergrated)		
Computer Communication	USB		
Standard Warranty	10 Years (15 years optional)		

*The AC voltage and frequency range may vary depending on specific country grid

**4600VA, 4600W with VDE-AR-N-4105

Appendix B
Datasheet of European inverter

Table: Technical Data	MODEL1(5000)	MODEL2(6000)
Input		
Absolute Maximum Input Voltage ($V_{max,abs}$)	600 V	
Rated Input Voltage (V_{dcr})	360 V	
Input start-up voltage (V_{start})	200 V (adj. 120...350 V)	
Input operating interval (V_{dcmin}...V_{dcmax})	0.7 x Vstart...580 V	
Input Nominal Power(P_{dcr})	5150 Wp	6200 Wp
Number of Independent MPPT	2	
Maximum input power for Each MPPT ($P_{MPPTmax}$)	4000 W	
Input voltage interval ($V_{MPPTmin}$ ... $V_{MPPTmax}$) to P_{acr} (parallel MPPT configuration)	150…530 V	180...530 V
DC Power limiting for each MPPT with Independent MPPT Configuration to P_{acr}, maximum unbalance example	4000 W [220V≤V_{MPPT}≤530V] other channel: P_{dcr}-4000W [90V≤V_{MPPT}≤530V]	4000 W [220V≤V_{MPPT}≤530V] other channel: P_{dcr}-4000W [120V≤V_{MPPT}≤530V]
Maximum DC Input Current (Idcmax) / for each MPPT (IMPPTmax)	36.0 A / 18.0 A	
Maximum Return current (AC side vs DC side)	Negligible	
Number of DC Connection Pairs in Input for each MPPT	2 pair	
DC Input Connector type (components indicated or equivalents)	Quick Fit PV Connector (3)	
Type of photovoltaic panels that can be connected at input according to IEC 61730	Class A	
Input protection		
Reverse Polarity Protection	Yes, from current limited source	
Input Overvoltage protection for each MPPT - Varistors	Yes	
Maximum short-circuit current for each MPPT	22.0 A	
Insulation Check	Complying with the local standard	
DC Disconnect Switch rating (-S Version)	Max. 25 A / 600 V	
Output		
AC Connection to the grid	Monophase	
Nominal AC output voltage (V_{acr})	230 V	
Output voltage range (V_{acmin}...V_{acmin})	180...264 V (1)	
Nominal AC Output Power (P_{acr} @cosφ=1)	5000 W (4)	6000 W
Maximum apparent Output power (S_{max})	5560 VA	6670 VA
Maximum output current (I_{acmax})	25.0 A	30.0 A
Contribution to short-circuit current	32.0 A	40.0 A
Inrush current	Negligible	
Maximum fault current	<40 A rms (100ms)	
Rated Output Frequency (f_r)	50 Hz / 60 Hz	
Output Frequency Range (f_{min}...f_{max})	47...53 Hz / 57…63 Hz (2)	
Nominal Power Factor	> 0.995, adj. ± 0.9 with P_{acr} =5.0 Kw	> 0.995, adj. ± 0.9 with Pacr =6.0 kW
Total Current Harmonic Distortion	< 3.5%	
AC Connections Type	Terminal block (max cross-section 10 mm²); cable gland M32	
Output protection		
Anti-islanding Protection	Complying with the local standard	
Maximum AC Overcurrent External protection	32.0 A	40.0 A
Output overvoltage protection - Varistors	2 (L - N / L - PE)	

Table: Technical Data	MODEL1(5000)	MODEL2(6000)
Operating performance		
Maximum Efficiency (η_{max})	97.0%	
Weighted Efficiency (EURO/CEC)	96.4% / -	
Power Supply Threshold	10.0 W	
Night-time Consumption	< 1.0 W	
Communication		
Wired Local Monitoring (opt.)	PVI-USB-RS232_485 (opt.)	
Remote Monitoring (opt.)	VSN300 Wifi Logger Card (opt.), PVI-AEC-EVO (opt.), VSN700 Data Logger (opt.)	
Wireless Local Monitoring (opt.)	VSN300 Wifi Logger Card (opt.)	
User Interface	LCD Display with 16 characters x 2 line	
Environmental		
Ambient temperature	-25...+60°C -13...140°F with derating above 60°C / 140°F	-25...+60°C -13...140°F with derating above 50°C / 131°F
Storage temperature	-40...80°C (-40...+176°F)	
Relative Humidity	0...100% condensing	
Typical noise emission pressure	50 db(A) @ 1 m	
Maximum operating altitude	2000 m / 6560 ft	
Environmental pollution classification for external environment	3	
Environmental Category	External	
Physical		
Environmental Protection Rating	IP 65	
Cooling System	Natural	
Overvoltage rating as per IEC 62109-1	II (DC input) III (AC output)	
Dimensions (H x W x D)	810mm x 325mm x 222mm / 31.9" x 12.8" x 8.7"	
Weight	< 26 kg / 57.3 lb	
Assembly System	Wall bracket	
Safety		
Safety class	I	
Insulation level	Without transformer (TL)	
Marking	CE (50Hz only)	
Safety and EMC Standards	EN62109-1, EN62109-2, AS/NZS3100, AS/NZS 60950, EN61000-6-1, EN61000-6-3, EN61000-3-11, EN61000-3-12	
Grid Standard	CEI 0-21, VDE 0126-1-1, G59/3, EN 50438 (not for all national appendices), RD1699, AS 4777, C10/11, IEC 61727, ABNT NBR 16149, CLC/FprTS 50549, PEA, MEA	CEI 0-21, VDE 0126-1-1, G59/3, EN 50438 (not for all national appendices), RD1699, AS 4777, C10/11, IEC 61727, ABNT NBR 16149, CLC/FprTS 50549

Appendix C

ASIAN Key Component List

NO	BRAND	NAME	MADE FROM
1	TI	DSP	US
2	Microchip	MCU	US
3	FAIRCHILD	IGBT/ MOSFET	US
4	VAC	Current sensor/Core	GERMANY
5	INFINEON	IGBT	GERMANY
6	APT	Diode	US
7	NCC	Capacitor	JAPAN
8	EPCOS	Film capacitors	GERMANY
9	Panasonic	RELAY	JAPAN
10	Panasonic	Film capacitors	JAPAN
11	MURATA	Chip capacitors	JAPAN
12	OMRON	Connector	JAPAN
13	Littlefuse	Fuse	US
14	VISHAY	Diode	US
15	CREE	Diode	US

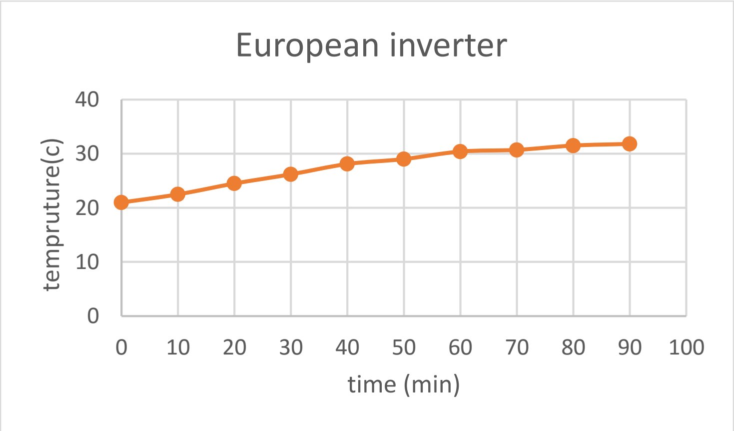
Asian Commitment

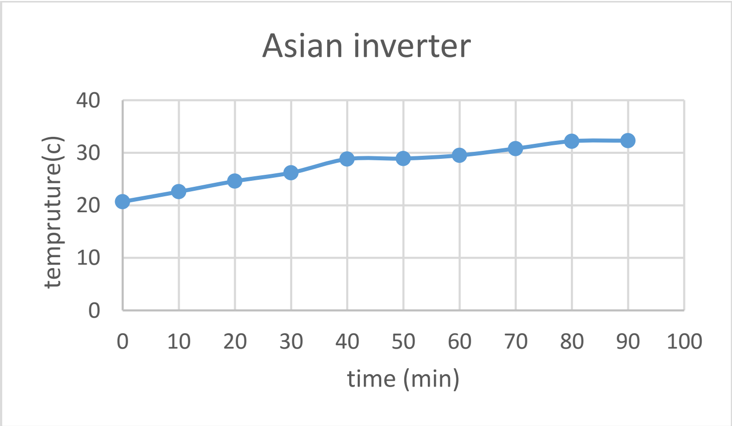
Asian commits to use these listed key components for the specific models and shall not substitute these parts with other unqualified components without customers' consent.

Appendix D

Temperature vs time

Time (min)	Temp AS		Time (min)	Temp Eu
0	20.7		0	21
10	22.6		10	22.5
20	24.6		20	24.5
30	26.2		30	26.2
40	28.8		40	28.1
50	28.9		50	29
60	29.5		60	30.4
70	30.8		70	30.7
80	32.2		80	31.5
90	32.3		90	31.8





الحمد لله رب العالمين والصلاة والسلام على أشرف الخلق والمرسلين
نبينا محمد صل الله عليه وسلم وعلى آله وصحبه أجمعين
نشكر الله العلي القدير الذي أحاطنا برعايته الإلهية ويسر لنا كل عسير وألهمنا الصبر والقوة في شق الطريق وأنار لنا درب العلم والمعرفة

تتبعثر الاحرف ،، وعبثا نحاول تجميعها في سطور لنشكر كل من أضاء بعلمه عقل غيره أو هدى بالجواب الصحيح حيرة سائليه فأظهر بسماحته تواضع العلماء وبرحابته سماحة العارفين

بعد الانتهاء من هذا البحث بكل الحب والاحترام نتقدم بجزيل الشكر وعظيم العرفان

الى الدكتور رائد عمروالذي تفضل بالإشراف على هذا البحث

وبالتأكيد الشكر الجزيل لمن ساعدنا وأرشدنا في أولى الخطوات نحو كتابة المشروع الدكتور فؤاد الزرو

ولا ننسى الشركات التي ساهمت بكل حب في تعبئة الاستبيان وهي : شركة كهرباء الخليل ، شركة نور سولار ، شركة الجدع ، شركة الاخرس للخدمات الكهربائية ، شركة **sun energy** ، شركة الاخوة الهندسية ، شركة **pal power** .

الزملاء والاصدقاء الذين زرعوا التفاؤل في دربنا وقدموا لنا المساعدات والتسهيلات والافكار والمعلومات لهم منا كل الشكر .

ومن خلف الكواليس الذين كانوا عوناً لنا في السراء والضراء والعافية والمرض نورٌ يضيئ الظلمات عائلاتنا .

شكر من النوع الخاص نتوجه به لكل من لم يقف الى جانبنا ومن وقف في طريقنا وزرع الشوك أمامنا ، فلولاهم لما شعرنا بحلاوة المنافسة ولما وصلنا الى ما نحن عليه الان لهم منا كل الشكر

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