The Effect Of Numbers Of Inverters In Photovoltaic Grid Connected System On Efficiency, Reliability And Cost

Aliaa N.Madkor, Dr. Wagdy R.Anis, Dr. Ismail Hafez

Abstract: The DC/AC inverters are used in grid-connected PV energy production systems as the power processing interface between the PV energy source and the electric grid. The energy injected into the electric grid by the PV installation depends on the amount of power extracted from the PV power source and the efficient processing of this power by the DC/AC inverter. The main target of this paper is to determine the principle that achieves high reliability and efficiency with the low cost of the photovoltaic grid-connected system. Accordingly, we are considering the inverter as it represents the important part of the system, by a comparison among the following three systems: The system has one inverter with the power of 100 (kw); The system has two inverters each has the power of 50 (kw); and The system has twenty inverters each has the power of 5 (kW). We will check the effect of number of inverters in photovoltaic grid-connected system on efficiency, reliability and cost taking into account the fixed system, one axis tracking system and two axes tracking system. Also, in order to validate the accuracy of the proposed control strategy, grid-connected PV system is simulated based on MATLAB/Simulink.

Index Terms: Photovoltaic (PV) System – (PV) Inverters – (PV) Reliability – (PV) Efficiency– (PV) Design- (PV) Economical analysis – (PV) Tracking system.

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1 INTRODUCTION

Egypt is experiencing one of its most serious energy crises for decades, with parts of the country facing around six power cuts a day for up to two hours at a time, The blackouts have created widespread frustration, with business reporting a downturn in production and citizens complaining about the disruption to everyday life. Electricity demand hit a daily high record of 27,700 megawatts, i.e. 20% more than power stations could provide. State media reported, Egypt needs to add 12,000 megawatts to its grid over the next five years at a capital cost of about $12 billion. It is ironic that this is happening in a country blessed with so much solar power. In 1913, it was chosen as the site of the world's first solar power station by. American and British engineers, and that is why we suggest solar energy as a cheap and available alternative. PV system installation has played an important role worldwide based on the fact that solar energy is clean, environment friendly and a secure energy source. However, the drawback of PV system is the energy sources, however it is running cost is two low compared with conventional plants. Currently, many research works are carried out focusing on optimization of PV systems so that the number of PV modules, capacity of storage battery, capacity of inverter and PV array tilted angle can be optimally selected [1]. However, the rated power of a PV array must be optimally matched with inverter's rated power in order to achieve maximum PV array output power [2]. The optimal inverter sizing depends on local solar radiation, ambient temperature and inverter performance [3], [4]. PV array efficiency is also affected adversely when an inverter's rated capacity is much lower than the PV rated capacity. On the other hand, under overloading condition, excess PV output power which is greater than the inverter rated capacity is lost [5], [6]. This to say that optimal sizing of PV inverter plays a significant role in increasing PV system efficiency and feasibility. As known, that the cost of Photovoltaic (PV) System depends mainly on both the cost of the inverters and PV array. Therefore, when we talk about the inverters we have to consider the efficiency and reliability of the systems as they affect the energy produced from the system.

1.1 Tracking system

It follows the sun's movement throughout the day, enabling PV modules to capture more available sunlight, resulting in energy gains. "Tracker" is a generic term used to describe devices that orient various payloads toward the sun. In the case of photovoltaic (PV) systems, the payload is the PV module. By maintaining consistent direct exposure from the sun to the module, trackers can improve a PV system's output by up to 40 percent [7] over a fixed-tilt array. The increment of production improvement over a fixed system depends on the project's latitude and the type of tracker. The benefits of trackers vary between the different categories of trackers (one-axis and dual-axis) as shown in "table 1".

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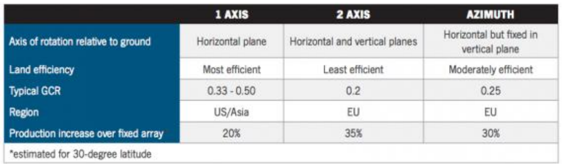
Table 1 *Tracker Technology Comparison*



	1 AXIS	2 AXIS	AZIMUTH
Axis of rotation relative to ground	Horizontal plane	Horizontal and vertical planes	Horizontal but fixed in vertical plane
Land efficiency	Most efficient	Least efficient	Moderately efficient
Typical GCR	0.33 - 0.50	0.2	0.25
Region	US/Asia	EU	EU
Production increase over fixed array	20%	35%	30%

*estimated for 30-degree latitude

By virtue of having moving machinery and requiring a less-dense configuration than fixed-tilt systems, trackers virtually always come at an added cost relative to fixed systems. In order for a tracker to make economic sense, the increased energy harvest must exceed the added cost of installing and maintaining trackers over the lifetime of the system. An additional factor to be considered in the decision to use trackers or fixed systems is land use; tracking systems tend to use additional land because they must be spaced out in order to avoid shading one another as they track the sun. This means that panels must be spaced farther apart, thus increasing land use and land costs for the developer. The other downside to trackers is the operations and maintenance (O&M) cost, which tends to be higher for this category of systems relative to fixed-tilt systems. Given the system's expected operating life of at least twenty years, O&M costs can add up to a meaningful share of total system costs.

1.2 The inverter

The inverter is the key component for successful operation of the grid connected PV system. Inverters are used for DC voltage to AC voltage conversion as seen in ''fig. 1.''. According to output voltage form, they could be rectangle, trapezoid or sine shaped. The most expensive, yet at the same time the best quality inverters, output voltage in sine wave. Inverter input voltage depends on inverter power, for small power of some 100 W the voltage is 12 or 24 V, and 48 V or even more for higher powers. Large inverters could be connected in parallel when higher powers are required.
For large systems, 3-phase inverters are available in the market. Inverters connecting a PV system and the public grid are purposefully designed, allowing energy transfers to and from the public grid. According to working principle, we have many different types of inverters such as central inverters for wide power range from 1 kW to up to 100 kW or even more, string inverters and module inverters. Central inverters are used in large applications, they can be connected according to the "master-slave" criteria, the succeeding inverter switches on only when enough solar radiation is available or in case of main inverter malfunction. Inverters connected to module strings are used in wide power range applications allowing for more reliable operation. Module inverters are used in small photovoltaic systems [8].

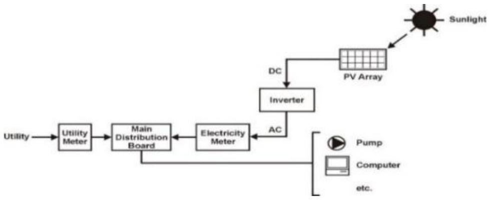


Fig. 1. *Grid-connected PV systems*

Inverters designed for grid-connection applications are called grid-connected inverters, grid-tie inverters, grid-interactive inverters, or utility-interactive inverters. One important feature of grid-connected inverter is the anti-islanding function. Grid-connected inverters manufactured in different countries usually comply with the respective national standards. For example in the US, grid-tie inverters usually comply with UL 1741 and IEEE 929. Small grid-connected PV systems are usually built as single-phase systems. With larger systems, sometimes the PV system is arranged into three arrays, with one single-phase inverter for each array, feeding into each of the three phases. For even larger systems, three-phase inverters are used.
Modern grid-connected PV inverters for PV systems perform the following functions:

- Convert DC into AC
- Adjust the operating point of the inverter to the maximum power point (MPP) of the PV array (the maximum power point tracking function, MPPT)
- Record operational data
- Provide different protective functions and anti-islanding protection function
- Provide isolation function with an isolating transformer at the AC output

Losses occur in an inverter mainly in the semiconductor switching devices and the magnetic devices. Efficiency of 90% or above is usually achievable. A high efficiency inverter will of course help achieve maximum overall system efficiency. It should be noted that at low loads (at less than 15% rated power), the efficiency significantly drops and in some designs the inverters are switched off during low irradiance periods (from evening to early morning).

1.2.1 Inverter efficiency:

Many inverters for grid-connected PV plants have relatively poor specifications from the manufacturer. Today they often have a relatively wide DC input voltage range, but many manufacturers only indicate a peak (DC/AC-conversion) efficiency η and the European efficiency ηEU. Often a rated DC input voltage is indicated, and the efficiency figures given can then be attributed to this nominal DC voltage. Sometimes also a diagram showing efficiency vs power is indicated, but in most cases such a diagram is not available. The *I-V* Curve and the maximum available power PMPP at the maximum power point (MPP) of a PV array depends on actual in-plane irradiance and module temperature. Depending on actual in-plane irradiance and module temperature, a PV array operates on a certain I-V-curve and a correlated PV curve. At a certain point (maximum power point, MPP), the available power from the array reaches its maximum value PMPP at voltage VMPP. For optimum performance, a grid-connected inverter is equipped with a MPP-tracker that tries to keep the operating point of the inverter always at the MPP despite irradiance and/or module temperature-changes that also influence PMPP and VMPP (MPP-Tracking, MPPT). As measurements of actual MPPT-performance of a PV-inverter are quite difficult and require sophisticated measuring equipment [9]. It is usually assumed by manufacturers, plant designers and simulation programs that a grid-connected PV inverter always operates at the MPP. However, depending on the MPP-tracking algorithm used by the inverter, at certain power and voltage levels more or less significant deviations from the MPP may occur which can reduce energy yield of the whole PV plant up to a few %. If η and η_{MPPT} are known, total efficiency $\eta_{tot} = \eta \times \eta_{MPPT}$ can be calculated. As the actual input quantity to the inverter is P_{MPP} offered by the PV array or PV array simulator, it makes sense to indicate η_{tot} not vs P_{DC}, but η_{tot} vs PMP. A grid-connected inverter consists of two main parts; the MPP-tracker which has to always extract the maximum available power PMPP from the array (varying according to irradiance G and module temperature T), and the DC-AC converter which has to convert the available DC power PDC to AC power PAC as efficiently as possible as shown in “fig. 2.”.

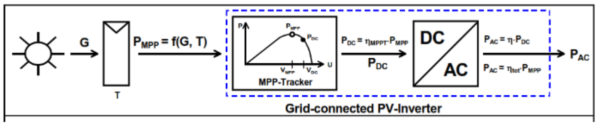


Fig. 2. *Determination of total efficiency ηtot of grid-connected PV inverters*

1.2.2 Efficiency calculation

According to the actual in-plane irradiation G and the module temperature T, a PV array always offers a certain DC-power PMPP. However, under steady-state conditions, the inverter can only extract

$$P_{DC} = \eta_{MPPT} \cdot P_{MPP} \text{ and converts it to } P_{AC} = \eta \cdot P_{DC}$$

Actually the inverter efficiency is a ratio of AC power and DC power. The total efficiency of a grid- connected inverter can be defined as:

$$\eta_{tot} = \eta \cdot \eta_{MPPT} = \frac{\mathbf{PAC}}{\mathbf{PMPP}} \qquad (1)$$

“Fig. 3.” shows the efficiency curve for three given inverters with rated power 100kW, 50 kW, and 5kW consequently.

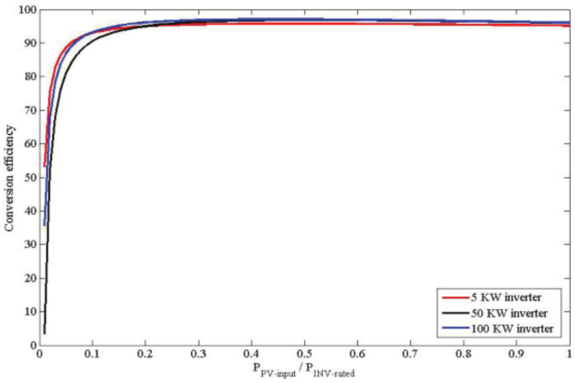


Fig. 3. *Efficiency curves for the three chosen inverters*

From this “fig. 3.” we can clarify the following:

For Fixed System:

I-For system with one inverter with power rated 100(kW):

If $\left(\frac{\text{PDc}}{\text{Prated}}\right) \le 0.1$ so $\eta = \left(\frac{52000}{77} \times \frac{\text{PDc}}{\text{Prated}}\right) + \left(\frac{2250}{77}\right)$
,else η =96.7 (2)

From this equation, Ac power (P_{Ac}) can be defined as follows:

$$P_{Ac} = P_{Dc} \times \eta \quad \text{where } P_{Dc} \text{ is Dc power} \qquad (3)$$

Using this equation, Energy will be calculated by the integration of power and accordingly the effective inverter efficiency will be calculated by:

$$\eta \text{ effective} = \frac{\int (\text{EAcyear})}{\int (\text{EDcyear})} \times 100 \qquad (4)$$

II-For system with two inverter each with power rated 50(kw):

If $\left(\frac{\text{PDc}}{\text{Prated}}\right) \le 0.1$ so $\eta = \left(\frac{21250}{19} \times \frac{\text{PDc}}{\text{Prated}}\right) - \left(\frac{481}{36}\right)$
, else η =98 .4 (2`)

From this equation, Ac power (P_{Ac}) can be defined as follows:

$$P_{Ac} = P_{Dc} \times \eta \quad \text{where } P_{Dc} \text{ is Dc power} \qquad (3`)$$

Again, using this equation, Energy will be calculated by the integration of power and accordingly the effective inverter efficiency will calculated by:

$$\eta \text{ effective} = \frac{\int (\text{EAcyear})}{\int (\text{EDcyear})} \times 100 \qquad (4`)$$

III-For system with twenty inverter each with power rated 5(kW):

If $\left(\frac{\text{PDc}}{\text{Prated}}\right) \le 0.1$ so $\eta = \left(\frac{20000}{39} \times \frac{\text{PDc}}{\text{Prated}}\right) + \left(\frac{596}{13}\right)$
,else η =97 (2″)

From this equation, Ac power (PAc) can be defined as follows:

$$P_{Ac} = P_{Dc} \times \eta \quad \text{where } P_{Dc} \text{ is Dc power} \qquad (3'')$$

Using this equation, Energy will be calculated by the integration of power and accordingly the effective inverter efficiency will be calculated by:

$$\eta \text{ effective} = \frac{\int (\text{EAcyear})}{\int (\text{EDcyear})} \times 100 \qquad (4'')$$

For Tracking System:

We will use the same equations as the Fixed System. However, in the Tracking System the power will be increased and accordingly the energy will be increased.

1.3 System Reliability

To develop a Photovoltaic (PV) module, cell efficiency is not only important, but also improves PV system performance which is the significant technology. The long term reliability is of great importance in PV systems’ performance.

System Reliability is the ability of a system or component to perform its required functions under stated conditions for a specified period of time.

1.3.1 Parameters of Reliability

There are some parameters for reliability [10]. One of these parameters is Mean time between failures (MTBF), which is the predicted elapsed time between inherent failures of a system during operation. Calculations of MTBF, defined by equation (5), assumes that a system is "renewed", i.e. fixed, after each failure and then returned to service immediately after failure. Another parameter is being returned to service, Mean Time to Repair (MTTR), which measures average time to failures with the modeling assumption that the failed system is not repaired (infinite repair time).as defined by equation (6). “Table 2” indicates the values of MTBF and MTTR for different subsystems used in PV system. These values are obtained from field experience for many PV systems in operation. Moreover, failure rate (F.R) is the frequency with which an engineered system or component fails. F.R is simply the inverse of MTBF, expressed for example in hours per failure defined by equation (7). Reliability of the system is another parameter which is the percentage of time when the system is operational. It can be obtained by the equation (8). The life time of PV systems is referred to over 20 years, which is long enough to monitor data.

$$\text{MTBF}= \frac{\text{operation time}}{\text{Number of Failure times}}\ (\text{h}) \qquad (5)$$

$$\text{MTTR} = \frac{\text{Total repair time}}{\text{Number of Failure times}}\ (\text{h}) \qquad (6)$$

$$\text{F.R}= \frac{1}{\text{MTBF}}\ \ (\text{Count/Year}) \qquad (7)$$

$$\text{Reliability} = \frac{MTBF}{\text{MTBF+MTTR}} \qquad (8)$$

We must know that the reliability and the failure rate of the system depend mainly on numbers of subsystems. We also found that (MTBF)ac is less than MTBF of any subsystems, thus as the number of subsystems decreases, the system reliability improves due to enhancement of system MTBF. Hence the simpler the system, the more reliable it is. By the way, and based on the following table 2, MTTR for systems in developing countries equal to 96%:

Table 2 *MTBF and MTTR (in hours) for different subsystems in developed and developing countries*

Subsystem	Developed Countries		Developing Countries	
	MTBF	MTTR	MTBF	MTTR
PV Array	30,000	48	30,000	96
Batteries	43,800	24	43,800	48
BCC	35,040	24	17,520	48
DC/AC Inverter	8,760	24	4,380	48
Motor	100,000	12	100,000	24
Microprocessor	20,000	24	10,000	48
Control unit	17,520	48	8,750	96
Cables	10^7	24	10^7	48

1.3.2 Reliability Calculations

To make Reliability calculations, we have to know the number of subsystems. “Fig. 4.” shows the block diagram of grid-connected system without tracking system. Such systems are coupled to grid utility to share the loads connected to the grid. The Battery Charging Controller (BCC) is used to avoid deep discharging or overcharging of the batteries. The power conditioning unit (PCU) includes the Dc/Ac Inverter as well as voltage, frequency and phase controller. The PCU should be supplied from regulated voltage, this is why BCC and batteries are used

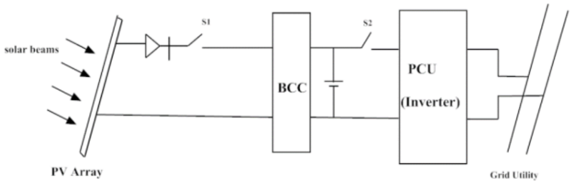


Fig. 4. *PV Grid connected system without tracking*

For Fixed System:

I - For systems with one inverter with power rated 100(kW): According to previous equations we can calculate the reliability of the system shown in “fig. 4.” as follows:

$$\text{F.R} = \frac{1}{\text{(MTBF)Inverter}} + 0.5\left(1+\frac{1}{\text{(MTBF)Array}}\right)\left(\frac{1}{\text{(MTBF)BCC}}\right)$$

$$\text{(MTBF) system}=\frac{1}{F.R}$$

II- For systems with two inverters with power rated 50(kW): According to previous equations we can calculate the reliability of the system shown in “fig. 4.”However, in this case we need to use two inverters and then the failure rate will be calculated as follows:

$$\text{F.R}=\frac{2}{\text{(MTBF)Inverter}} + 0.5\left(1+\frac{1}{\text{(MTBF)Array}}\right)\left(\frac{1}{\text{(MTBF)BCC}}\right)$$

$$\text{(MTBF) system}=\frac{1}{F.R}$$

III- For systems with twenty inverters with power rated 5 (kW): According to previous equations we can calculate the reliability of the system shown in “fig. 4.” However, in this case we need to use twenty inverters and then the failure rate will be calculated as the follows:

$$\text{F.R}=\frac{20}{\text{(MTBF)Inverter}} + 0.5\left(1+\frac{1}{\text{(MTBF)Array}}\right)\left(\frac{1}{\text{(MTBF)BCC}}\right)$$

$$\text{(MTBF) system}=\frac{1}{F.R}$$

For Tracking System:

In tracking system, the number of subsystems will increase because we used motors to track the movement of the sun. In one axis tracking system we will use one motor, but in two axes tracking system we will add two motors. “Fig. 5.” shows the block diagram of grid-connected PV system with tracking motor.

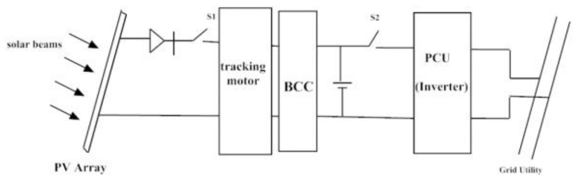


Fig 5. *Block diagram of grid connected PV system with tracking*

One-Axis Tracking System:

I - For systems with one inverter with power rated 100(kW): According to equations (5), (6), (7) and (8) we can calculate the reliability of the system shown in “fig. 5.” as follows:

$$\text{F.R}=\frac{1}{(\text{MTBF})\text{Inverter}}+0.5\left(1+\frac{1}{(\text{MTBF})\text{Array}}\right)\left(\frac{1}{(\text{MTBF})\text{BCC}}+\frac{1}{(\text{MTBF})\text{motor}}\right)$$

$$(\text{MTBF})\ \text{system}=\frac{1}{F.R}$$

II- For systems with two inverters with power rated 50(kW): According to previous equations we can calculate the reliability of the system shown in “fig. 5.” .However, in this case we need to use two inverters and then the failure rate will be calculated as follows:

$$\text{F.R}=\frac{2}{(\text{MTBF})\text{Inverter}}+0.5\left(1+\frac{1}{(\text{MTBF})\text{Array}}\right)\left(\frac{1}{(MTBF)BCC}+\frac{1}{(MTBF)motor}\right)$$

$$(\text{MTBF})\text{system}=\frac{1}{F.R}$$

III- For systems with twenty inverters with power rated 5(kW): According to the previous equations we can calculate the reliability of the system shown in “fig. 5.”. However, in this case we need to use twenty inverters and then the failure rate will be calculated as the follows:

$$\text{F.R}=\frac{20}{(\text{MTBF})\text{Inverter}}+0.5\left(1+\frac{1}{(\text{MTBF})\text{Array}}\right)\left(\frac{1}{(\text{MTBF})\text{BCC}}+\frac{1}{(MTBF)motor}\right)$$

$$(\text{MTBF})\text{system}=\frac{1}{F.R}$$

Two-Axes Tracking System:

I - For systems with one inverter with power rated 100(kW): According to equations (5), (6), (7) and (8) we can calculate the reliability of the system shown in “fig. 5.” as follows:

$$\text{F.R}=\frac{1}{(\text{MTBF})\text{Inverter}}+0.5\left(1+\frac{1}{(\text{MTBF})\text{Array}}\right)\left(\frac{1}{(\text{MTBF})\text{BCC}}+\frac{2}{(\text{MTBF})\text{motor}}\right)$$

$$(\text{MTBF})\text{system}=\frac{1}{F.R}$$

II- For systems with two inverters with power rated 50(kW): According to previous equations we can calculate the reliability of the system shown in “fig. 5.”. However, in this case we need to use two inverters and then the failure rate will be calculated as follows:

$$\text{F.R}=\frac{2}{(\text{MTBF})\text{Inverter}}+0.5\left(1+\frac{1}{(\text{MTBF})\text{Array}}\right)\left(\frac{1}{(MTBF)BCC}+\frac{2}{(MTBF)motor}\right)$$

$$(\text{MTBF})\text{system}=\frac{1}{F.R}$$

III- For systems with twenty inverters with power rated 5 (kW): According to previous equations we can calculate the reliability of the system shown in “fig. 5.” However, in this case we need to use twenty inverters and then the failure rate will be calculated as follows:

$$\text{F.R}=\frac{20}{(\text{MTBF})\text{Inverter}}+0.5\left(1+\frac{1}{(\text{MTBF})\text{Array}}\right)\left(\frac{1}{(\text{MTBF})\text{BCC}}+\frac{2}{(MTBF)motor}\right)$$

$$(\text{MTBF})\text{system}=\frac{1}{F.R}$$

2 DESIGN PROCEDURES

When we make a design in PV systems, we will connect some modules in parallel and other in series. However, to make a good design we have to know the concept of each. The components connected in series are connected along single path and so the same current flows through all of the components. Also, the components connected in parallel are connected so that the same voltage is applied to each component. The same concept in connecting modules. The current produced from modules connected in parallel must not be more than the maximum inverter current. Accordingly, the voltage produced from modules connected in series must not be more than the maximum inverter voltage.

2.1 PV Standard Modules

Our design is based on 200 (W), Vmp=25 (V), Imp=8.04(A) PV modules.

Design Considerations:

Latitude angle Φ = 30

Inverter characteristics:

I-Characteristics of Inverter with power rated 100(KW):

DC Input: Max Dc voltage Vmp =1000 (V), Max Dc current Imp = 245 (A), Input DC voltage range
VDC =450 ~ 825(V), one input.

AC Output: Max AC output power = 100(KW), Phases = 3 phase, nominal ac current (A) = 195(A), nominal Output voltage (V) = 300 (V), Output frequency (Hz) = 50/60(Hz).

II-Characteristics of Inverter with power rated 50(KW):

DC Input: Max Dc voltage Vmp =950 (V), Max Dc current Imp = 110 (A), Input DC voltage range VDC =480 ~ 800(V), have eight input.

AC Output: Max AC output power = 50 (KW), Phases = 3 phase, AC voltage range =320 ~ 480(V), Max Ac output current (A) = 90(A), Output frequency range (Hz)=47~53/57~63(Hz),Rated output frequency(HZ) = 50/60 (Hz)

III-Characteristics of Inverter with power rated 5(KW):

DC Input: Max Dc voltage V_{DC} =600 (V), Max Dc current I_{DC} = 36 (A), Input DC voltage range Vmin-Vmax=145 – 530(V), have two input. AC Output: Max AC output power = 5 (KW), nominal ac current (A) = 27(A), Output voltage range Vmin-Vmax = 183-228 (V), Output frequency (Hz) = 57/60.5(Hz).

2.2 Design Calculations

I - For systems with one inverter with power rated 100(kW):

Number of modules = $\frac{power\ output\ of\ inverter}{power\ of\ module\ used}$ (9)

$=\frac{100\times10^3}{200}$ = 500 modules connected to the inverter
We assume that:
No. of series modules = 25 modules
No. of parallel strings = 20 strings

For check: The total current produced form parallel strings = No. of parallel strings × current produced from one string = 20 × 8.04 = 160.8A < 245A (Max inverter current) that's ok. The total voltage produced form series modules = No. of series modules × voltage produced from one module = 25 × 25 = 625V < 1000V (Max inverter voltage) that's ok Then we have to collect a string in one combiner box, we can divide plant into 20 strings each has 25 modules as shown in "fig. 6."

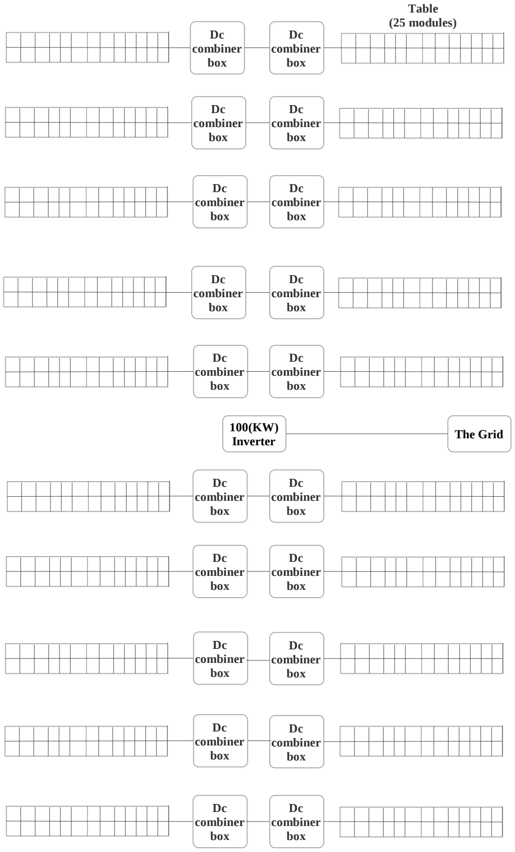


Fig 6. Shows the design of PV system with one inverter with 100 (KW) power rated

II - For systems with two inverters with power rated 50(KW):

Number of modules = $\frac{power\ output\ of\ inverter}{power\ of\ module\ used}$ (9) $=\frac{50\times10^3}{200}$
= 250 modules connected to one inverter
We assume that: We have two groups each is connected to 50KW inverter as shown in "fig. 7." We can divide plant into 10 tables (8 strings) each table has 25 modules, and Inverter has 8 inputs as clarified in details on "table 3" and "fig. 7."

***Table 3** Inputs of the inverter*

	No. of modules in each string	Voltage (V)	Current (A)
input1	32	800	8
input2	32	800	8
input3	32	800	8
input4	32	800	8
input5	32	800	8
input6	30	750	8
input7	30	750	8
input8	30	750	8

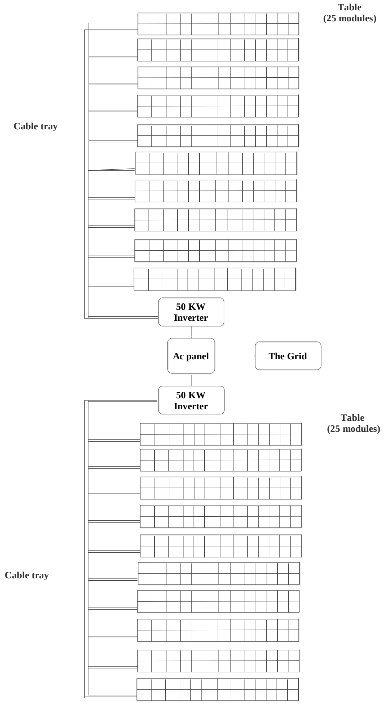


Fig 7. Shows the design of PV system with two inverters with 50 (kW) power rated

III - For systems with twenty inverters with power rated 5 (kW):

Number of modules = $\frac{power\ output\ of\ inverter}{power\ of\ module\ used}$ (9)

$=\frac{5\times10^3}{200}$ = 25 modules connected to one inverter
As shown in "fig. 8." Each inverter is connected to 25 modules, then we need 20 tables each table has 2 strings because the inverter has two inputs. This are clarified in details on "table 4":

Table 4 *Inputs of the inverter*

	Input 1	input 2
No. of modules in each string	12	13
Voltage (V)	300	325
Current (A)	8.04	8.04

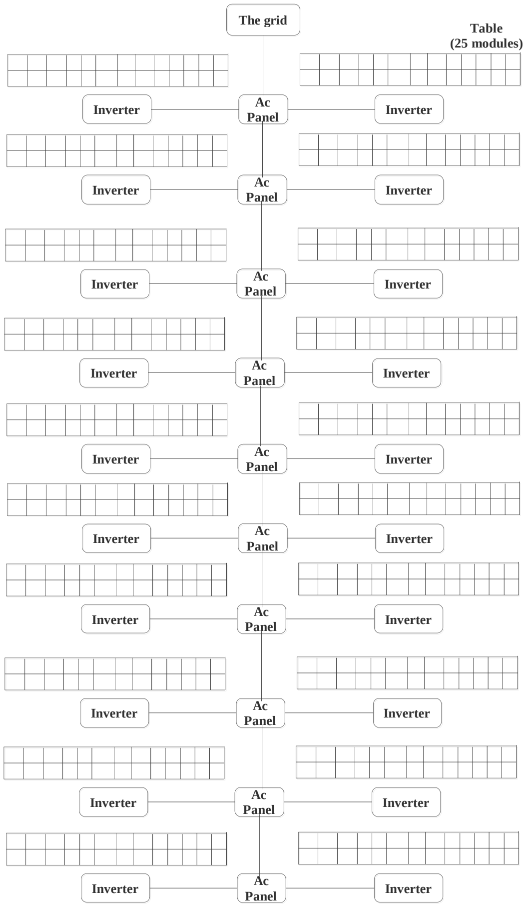


Fig 8. *Shows the design of PV system with twenty inverters with 5 (kW) power rated*

2.3 Simulation Program

- MATLAB Simulation software is used to simulate the dynamic behavior of a system that is represented by a mathematical model. While the model is being simulated, the state of each part of the system is calculated at each step of the simulation using time-based. A detailed simulation program is developed considering climatic conditions of Egypt as shown in “fig. 9.”

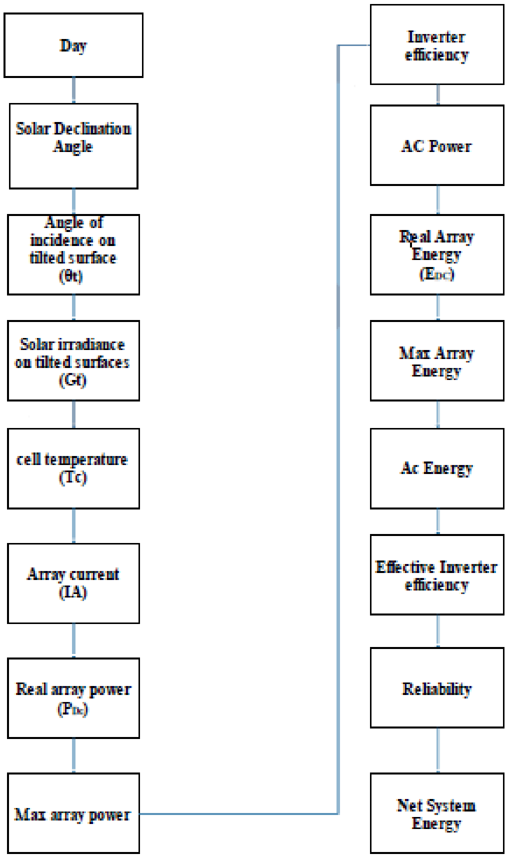


Fig 9*. Simulation program flow chart for the system design*

3.2 System Reliability

To calculate the system reliability we use the following equation:

$$\text{Reliability} = \frac{MTBF}{\text{MTBF+MTTR}} \qquad (8)$$

The following “table 6” will illustrate the results for fixed system, one axis tracking system and two axes tracking system:

Table 6 *the system reliability results*

	One inverter 100 (kw)	Two inverters 50 (kw)	Twenty inverters 5 (kw)
Fixed	0.9759	0.9555	0.6939
One axis tracking system	0.9755	0.9551	0.6937
Two axes tracking system	0.9750	0.9546	0.6935

3.3 System cost

As seen in design’s figures, the system consists of some components like PV arrays, inverters, cables, mounting components. Furthermore, some systems also consist of motors to do tracing. All costs of these components are summed and illustrated it in “table 7”:

***Table 7** Total system cost (EGP)*

	a system that includes One inverter 100 (kw) (EGP)	a system that includes Two inverters 50 (kw) (EGP)	a system that includes Twenty inverters 5 (kw) (EGP)
Fixed	1 200 000	1 250 000	1 302 000
One axis tracking system	1 700 000	1 750 000	1 800 000
Two axes tracking system	1 900 000	1 950 000	2 002 000

3.4 Total System Energy

To calculate the total energy of the system, we have to consider the reliability in our calculations, because reliability affect total system energy as shown in the following equation: Net system energy=Energy during year× Reliability. We use MATLAB to calculate this equation during every month in the year, "fig. 10.", "fig. 11." and "fig. 12." were illustrate the average daily energy during the year for fixed system and for one axis tracing system

One axis tracking system:

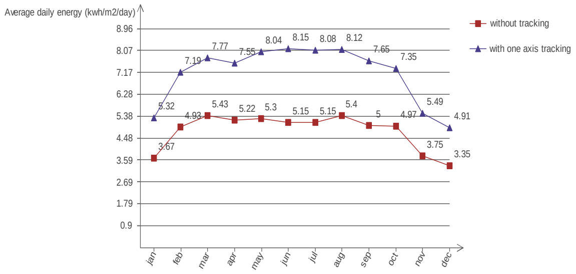


***Fig 10.** The average daily energy during the year for fixed and one axis tracking system using one inverter (100kw)*

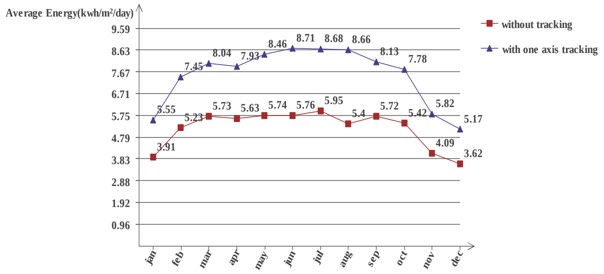


***Fig 11.** The average daily energy during the year for fixed and one axis tracking system using two inverters (50kw)*

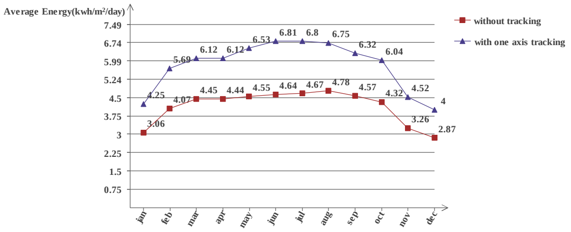


***Fig 12.** The average daily energy during the year for fixed and one axis tracking system using twenty inverters (5kw)*

Two axes tracking system:

We use MATLAB to calculate this equation during every month in the year, "fig. 13.", "fig. 14." and "fig. 15." were illustrate the average daily energy during the year for fixed system and for two axes tracing system

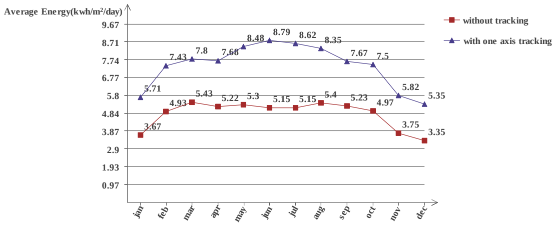


***Fig 13.** The average daily energy during the year for fixed and two axes tracking system using one inverter (100kw)*

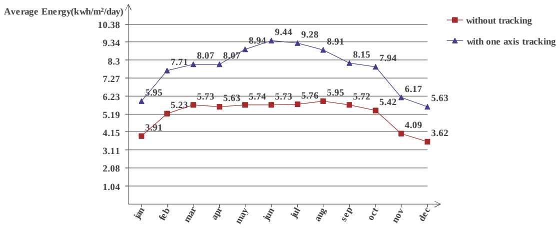


***Fig 14.** The average daily energy during the year for fixed and two axes tracking system using two inverters (50kw)*

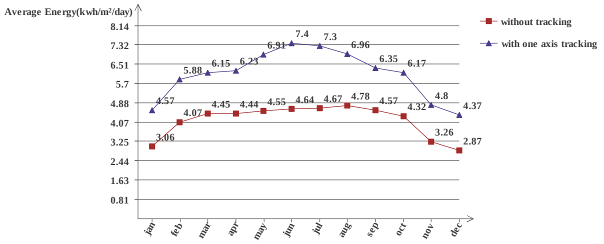


***Fig 15**. The average daily energy during the year for fixed and two axes tracking system using twenty inverters (5kw)*

The following "table 8" illustrate the results to compare between three systems' mean and annual energy

Table 8 *mean and annual energy for every system*

	One inverter 100 (kw)		Two inverters 50 (kw)		Twenty inverters 5 (kw)	
	Mean energy ×10^2 (KWh)	Annual energy ×10^5 (kwh)	Mean energy ×10^2 (kwh)	Annual energy ×10^5 (kwh)	Mean energy ×10^2 (kwh)	Annual energy ×10^5 (kwh)
Fixed	4.7962	1.7506	5.2119	1.90234	4.1396	1.5110
One axis tracking Sys.	7.1364	2.6048	7.3507	2.7487	5.8294	2.12773
Two axes tracking Sys.	7.4333	2.71315	7.8554	2.86722	6.0896	2.2227

4 CONCLUSION

This paper showed the effect of the number of inverters in PV systems. As we have found out that the number of inverters does not affect the efficiency of the system, but it affects the reliability which subsequently affects the total energy of the system and also the cost. The result tables shows that the highest reliability system is the fixed system with one inverter because it has the smallest number of components. So the number of inverter has a reverse proportion with the reliability. However, the highest energy system is the two-axes tracking system with two inverters, because the two-axes tracking system gives the highest energy. Therefore, when we take reliability in our consideration, it gives us the highest system energy. Also, the tables show that the most expensive system is the two-axes system that has twenty inverters. Therefore, the number of inverters has direct proportion with the cost. Finally, when we decide to design the PV system with high energy we mostly use two-axes tracking systems. When we need the most reliable system, we mostly decrease the number of components by using fixed systems with one inverter. Accordingly, when we need the cheap system, we mostly decrease the number of inverters.

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