Instituto Tecnológico y de Estudios Superiores de Monterrey

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School of Engineering and Sciences

Operation of a Photovoltaic System in the Mexican Electricity Market

A thesis presented by

Carlos Alberto Gutiérrez Andrews

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in

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Declaration of Authorship

I, Carlos Alberto Gutiérrez Andrews declare that this thesis titled, "Operation of a Photovoltaic System in the Mexican Electricity Market" and the work presented in it are my own. I confirm that:

- This work was done wholly or mainly while in candidature for a research degree at this University.
- Where any part of this thesis has previously been submitted for a degree or any other qualification at this University or any other institution, this has been clearly stated.
- Where I have consulted the published work of others, this is always clearly attributed.
- Where I have quoted from the work of others, the source is always given. With the exception of such quotations, this thesis is entirely my own work.
- I have acknowledged all main sources of help.
- Where the thesis is based on work done by myself jointly with others, I have made clear exactly what was done by others and what I have contributed myself.

Carlos Alberto Gutiérrez Andrews

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Dedication

To Mom and Dad, for give me a place to stand to move my world.

To Carina and Cristina, "what" is not as important as "who".

To God, for being my shepherd, therefore, I lack nothing.

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Operation of a Photovoltaic System in the Mexican Electricity Market

by

Carlos Alberto Gutierrez Andrews

Abstract

Taking as a study case a Photovoltaic (PV) System installed in the Development and Innovation Center of Schneider Electric a whole study was realized. The main objective was to analyze the operation of a PV system in the Mexican Electricity Market and develop tools that can make easier to evaluate the performance of the installation. It produces less than 0.5 MW, in the current regulation is consider as Distributed Generation (DG). This kind of Power Plants (PP) can be interconnected to the grid and the owner has three contract options: Net Metering, Net Billing and Total Sale of Energy. In this case the better is Net Metering because the building consumes all the energy produced, but by having a contract with a supplier this field could earn Clean Energy Certificates (CEL).

Three tools were developed to evaluate the economic and technical performance. The first tool is to graph the downloaded data acquired by the monitoring system. That daily data cannot be graph as detailed by the inverter's provided interface after a day as if the user downloads the information. The second tool is required to find the greatest values of Irradiance, Temperature or Power in a month. When this tool is feed with the files of the month, each file will be paste in a new Excel workbook's sheet, but in the first sheet the user, has a recapitulation per day of the greatest values. With all this ordered information could be prepare a generation profile of the area, and that stats can be used in future investment decision and forecasting.

Finally, the third tool is dedicated to calculated financial indicators such as Payback and IRR. Some scenarios were studied and after applying some stimulus offered by the government that are reflected in the taxes payment, better results were obtained. With this tool is possible run scenarios and evaluate the profitability of new investments.

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Chapter 1 BACKGROUND

Introduction

To create a Mexican electricity market more competitive and modern, on December 24th, 2015 in Mexico, the Energy Transition Act (LTE) is published in the Official Gazette of the Federation. Document explaining the mechanisms needed to meet the country's goal of producing 35% of clean generation electricity, by 2024 and 43% by 2030.

In the last document published by the Secretary of Energy (SENER), in 2017 says that the 28.8% of the total generation are power plants that operate with clean technologies. And that solar technology had an increase of 157.4% between 2015 and 2016.

Developments in solar technology are constant and even though solar cells still do not reach high efficiency levels, good results have been obtained because a solar power generation plant requires little maintenance. The main component of a photovoltaic system, are solar panels, which convert solar radiation into electricity, taking advantage of the photovoltaic effect. The rest of the electrical equipment needed in a photovoltaic system are: inverters, switches and measuring equipment specified in the network code, and some characteristics are mentioned in this document.

This thesis takes as a reference, a solar park installed near Monterrey, in the Development and Innovation Center owned by Schneider Electric. With 50% of the investment coming from government support and the other 50% from Schneider Electric. With 300 W Solartec modules and Schneider Electric's Conext CL25000 inverters, the solar field has a capacity of 270 kW Peak. The purpose of that installation is for knowledge development, for this reason prototypes are tested, and projects are developed related to the operation of a photovoltaic solar system. This solar field has already been the subject of study in a couple thesis from students during their master's Degree.

To analyze the operation, two tools have been developed that facilitate the analysis of the data collected by the monitoring system. The information provided by this equipment is available online, and can be downloaded, but with some limitations. Measurements are made every minute, and before midnight the file contains all the information, the first hour of the next day the information will be summarized, and the file will only contain data of every 15 minutes, after a month only the total of the generation can be obtained. So, one of the tools is used to analyze the data of each day, if it has the file previously downloaded. And the second search in one month, adding each of the files, and displays maximum irradiance, generation or temperature values, according to the user's decision.

Although this project is not destined to the sale of energy, it is an opportunity to review the new regulations and the types of contracts that can hold a generator with a central less than 0.5 MW, to which is known as Distributed Generation (DG). In this way a third tool is developed that facilitates to make an economic projection of this kind of investment, allows in an easy way to realize scenarios in which are contemplated taxes, sale of Certificates of Clean Energy (CEL), replacement of Inverters, loans and interests, etc. After feeding the basic data, obtain numerically and graphically economic indicators such as the internal rate of return (IRR) and Payback.

Objective

The main objective of this thesis is to analyze the operation of a Photovoltaic (PV) System in Mexico, with the aim to find the best alternative to operate a solar field in the research center of Schneider Electric in Apodaca, Nuevo Leon, Mexico. By developing tools that make easier evaluate the economic and technical performance of the mentioned park performance.

Finally, search the equipment required to operate a solar field and according to the new regulations summarized the main characteristics aiming to evaluate the equipment installed in the Schneider Electric's Photovoltaic System.

Justification

The use of solar technology becomes more and more common. One reason is just that the operating costs of a solar power plant are low, it will not require much staff, and maintenance is reduced to keep the panels clean, although this technology is not as efficient as some others, continuous development and the panorama to That the photocells achieve greater efficiencies is promising. Another reason is that, in the face of global warming, measures have been taken at the global level in order to reduce emissions of polluting Green House Gases (GHG) into the atmosphere. The Paris Agreement brings together several countries, including Mexico, with government policies and stimulus to reduce these GHG emissions. Among the measures taken, highlight, the promotion to generate electricity with clean technology. In our country there is, among others, a short-term goal, where 25% of the electricity generation must be clean by 2018.

In the development of this project we study the solar operation of a photovoltaic park. Two Major aspects: The technical and the economic.

For the technical aspect, a review of the development and advances of solar cells and some key points for the installation of a photovoltaic power generation plant will show the considerations that must be made when acquiring new equipment when installing a system. By analyzing the operation of a solar field that is already in operation will be develop digital tools to monitor the performance of the panels, giving the opportunity to analyze the information delivered by the monitoring system in a visual, more clear and orderly way. With all that information, for research purposes, it is possible to make generation forecasts in specific geographical zones, concluding the feasibility of installing there or making the project bigger or looking for another area.

For economic analysis, it is necessary to perform several scenarios to analyze different ways of running a project. The shelf life of the panels is usually guaranteed for 20 years, so the use of an easily configurable tool that delivers results visually and numerically, that can analyze economic issues such as interest rates, loan percentage and capital, total investment and taxes, to name a few, becomes very valuable. By merging the technical and economic part, it is possible to analyze a park before installing it, but also analyze one that is already Running. The economic indicators here contemplated, internal rate of return (IRR) and Payback, help to make economic decisions with a numerical basis.

Mexico is going through a stage of modernization, and the creation of an energy market, where not only electricity is sold, but also associated products such as Certificates of Energy Clean (CEL) is encouraged; also achieve reduced costs in electrical tariffs and good service for Supply the demand for electric power. Some laws have changed, and others have appeared, and by analyzing some of these documents can be summarize important aspects for distributed generation (DG), from interconnection diagrams to specifications of the equipment that producers must be used to interconnect a system to the public network. For Schneider Electric it is important to know which of their products are suitable for this application.

Thesis Scope

The intention of this research is analyzing the current performance of a solar field. Taking in consideration the electricity fares in Mexico, and production data examining the performance of the Schneider Electric generation system.

Summarize the solar field operation characteristics highlighting the definition of this technology, the market and development tendency of a photovoltaic cell. And analyzed the new regulations in Mexico to find the contract schemes with an energy supplier considering the existence of a solar field with a capacity less than 0.5 MW, considering as a study case the photovoltaic installation owned by Schneider and declared as distributed generation.

Thesis organization

- Chapter 2. Regulation for Distributed Generation. In this chapter is presented a review of the Mexican new regulation that implies important aspects for Distributed Generation, as well as, the modalities that can be chosen to sell energy.
- Chapter 3. Solar Technology. To complete this chapter were consulted many papers to find out the development solar technology for generation purposes.
- Chapter 4. Schneider Electric. This part is about the case of the Schneider Electric Solar field. Here can be found technical, economical and ambient specification of the project.
- Chapter 5. Economic Evaluation. To analyze the case threated in this thesis was develop a tool to run many scenarios and based in economic indicator as the IRR and Payback, the project manager can take decisions.
- Chapter 6. Technical Evaluation. The technical evaluation is related to the data measured by the monitoring system installed in the solar field analyzed. Some real graphs and data are presented in this chapter.
- Chapter 7 Conclusion. General comments, challenges and future work of the research are explained in this section.

Chapter 2 REGULATIONS FOR DISTRIBUTED GENERATION

The energy reform brought a profound modification of articles 25, 27 and 28 of the Political Constitution of the United Mexican States. To meet the needs of increasing the rate of economic growth, increase productivity and expand the legal tools that the Mexican state must improve social and economic conditions, generating in this case, a stronger and more competitive electrical market that contributes to the economic growth of the country.

On December 24th, 2015, the Energy Transition Act (LTE) is published in the Official Gazette of the Federation. It establishes guidelines and mechanisms to carry out the execution of an energy reform in the United Mexican States. This aims to make the Mexican electricity industry more competitive and modern, attracting investment for generation projects, especially clean energies.

The Energy Transition Act (LTE) foresees an increase in clean generation to reduce emissions of Green House Gases (GHG), this is to fulfill Mexico's commitment to being part of the "Paris Agreement". Mexico contributes 1.4% of global CO_2 emissions, according to the Mexican Institute for Competitiveness (IMCO), the country's commitment is to reduce its emissions by 25% and will be achieved by generating 35% of the electric energy in a clean way for 2024 and 43% by 2030.

The national electrical industry reports a high number of losses. This is normal for many electrical systems in different countries, but non-technical losses in Mexico account for more than 8%. While technical losses add up to 6%. The fact of not having control over the theft of energy (non-technical losses), provokes high fares to the user and that’s is another reason which promoted the energy reform, cheaper electricity.

Energy reform brings with it new companies in all areas of the electricity market. That competition is expected to force the deficiencies in the current service to be improved. And according to article 35 of the "General Climate Change Act" [1], the Department of Energy (SENER) establishes policies and incentives to promote the use of low-carbon technologies, considering the fuel to be used.

Investments in the electricity sector mostly come from the development Bank, for which precise calculations are necessary since the level of investment is very high and an error causes very high debt. To achieve the creation of projects in the territory, which allow to increase the generation of clean electric energy, the state guarantees openness for the use of transmission and distribution networks for generators. In such a way, it is possible to ensure an environmentally sustainable, reliable and safe electrical supply.

In this chapter are used some acronyms of regulatory institutions in Mexico and the name of some documents will not be translated, however, here are explained in summary these organizations and the relevant documents in the energy reform.

CENACE. Acronym in Spanish from “Centro Nacional de Control de Energía”. It is a decentralized public organization whose purpose is to exercise the operational Control of the national electrical system; The operation of the wholesale electric market and to guarantee impartiality in the access to the national transmission network and to the general distribution networks. The CENACE is the equivalent of the Independent System Operator (ISO), which is the USA would be CAISO, PJM, NYISO and so on.

SENER. Acronym in Spanish from “Secretaría de Energía”. SENER guarantees the competitive, sufficient, high-quality, economically viable and environmentally sustainable supply of energy that requires the development of national life. Equivalent in the USA to the Department of Energy (DOE).

CRE. The Energy Regulatory Commission (CRE) is a unit of the centralized Federal public administration, as a coordinating organization in the energy field. Equivalent in the USA to the Federal Energy Regulatory Commission (FERC).

CEL. For its acronym in Spanish Clean Energy Certificates. These are similar to Renewable Energy Credits (REC), (https://www.epa.gov/greenpower/renewable-energy-certificates-recs).

LIE. For its acronym in Spanish Energy Industry Act

LTE. For its acronym in Spanish Energy Transition Act

Clean Energies

The Energy Industry Act (LIE) in article 3, fraction XII defines clean energies as:

Those energy sources and processes of electricity generation whose emissions or waste, do not override the thresholds established in the regulatory provisions for that purpose are issued. [2]

And add a list where all the technologies recognized as clean energy are included. In the second bullet is mentioned "Solar radiation in all its forms".

Thanks to the energy reform, the development of the market for renewable energies in Mexico will be strengthened. The reform is expected to have a direct impact on the fulfilment of the goals to 2018 and 2024. For this purpose, openness to investment and competition has been offered, clear perspectives on the market expansion trajectories for renewable energy, market mechanisms to encourage investment and a favorable regulatory framework for Distributed Generation (DG).

By establishing policies and measures, it seeks to offer benefits and to minimize the consumption of fossil fuels; These include the creation of clean energy certificates (CEL), the creation of an electric market to facilitate the commercialization of renewable energies, mechanisms for the interconnection of distributed generation, etc.

In the transitional third of the Energy Transition Act (LIE) [2], it indicates as a goal a minimum participation of clean energies in the electricity generation of 25% by 2018, 30% by 2021 and 35% for 2024. Increase by 5% every 3 years from 2015.

Distributed Generation

The distributed generation (DG) is the how Mexico interpreted Distributed Energy Resources (DERs) and is defined as the generation of electrical energy that is interconnected to a distribution circuit that contains a high concentration of load centers and which is subject to the scheme provided for in articles 68, 69 and 70 of the LIE [2]. The same as defined in the first subparagraph of article 17 of the LIE:

Power plants with a capacity less than 0.5 MW which do not require permission to generate electric power. The distributed generation can be located in the facilities of the load centers or outside of these. [3]

The distributed generation is carried out by an owner or possessor of one or more power plants that do not require or have permission to generate electricity in terms of this law. This is known as an exempt generator, term described in the EIA [2]. Although they do not need permits, whenever a power plant is interconnected to the national electrical system, they must conclude contracts with the Regulatory Commission of Energy (CRE) and operate under the instructions of the CENACE (National Center of Energy Control).

Sale of energy and isolated supply

A power plant less than 0.5 MW of installed capacity, recognized as distributed Generation (DG), can be operated in two ways. Exempt generators may only sell their electric power and associated products through a supplier or dedicate their production to the isolated supply.

A Supplier (Utility) is a marketer that requires a contract with CENACE to be a market participant and requires a permission from the CRE because is going to sell to an end user. Two classes of supplier are mentioned in the law qualified and basic services.

Isolated supply, means, to generate electricity for the satisfaction of its own needs, without transmitting such energy by the national transmission network or by the general distribution networks, and no permits are required of the CRE.

On the other hand, we find the sale of energy. For this application there are three modalities in which it is possible to hold a contract with a supplier [4]. NET metering, net Billing and Total sell of energy.

Net Metering

This methodology, considers the electrical energy flows received and delivered, compensating each other during the billing period.

It is considered the exchange of energy flows between the power plant and one or more load centers with the general distribution networks, compensating the energy delivered by the distributed generation power plant to the general distribution networks with the energy received by one or more end users from the general distribution networks in the corresponding period.

The exempt generator can deliver energy to one or more load centers, as well as to deliver their surplus energy to the general distribution networks, and use it later, when there is no generation. After 12 months, if the user has energy in favor, can request that energy to be paid.

Net Billing

Consider electrical energy flows received and delivered. But this methodology is about money, in contrast with net metering that considers energy. The price assigned to the energy is a value that may vary from purchase and sale. The delivery of electricity and the consumption are counted independently.

In the net billing scheme, the interconnection contract must be related to an electric power supply contract since there will be delivery and reception of electrical energy to and from the general distribution networks at the same point of interconnection.

Total Sale of Energy

Occurs in the case where there is no electrical supply contract associated with the same interconnection point of the power plant. In other words, the generating plant and the building that consumes this energy are not in the same geographical location, this being the main difference with net billing.

The electricity delivered, is independent of the calculation of this consideration and will be paid off to the value of the marginal local price.

Clean Energy Certificate

They are titles issued by the CRE that accredit the production of a certain amount of electricity from clean energies, which serve to meet the requirements associated with the consumption of the load centers.

These certificates will be granted by the CRE to the clean generation plants whose capacity is new, after August 11th, 2014 date of publication of LIE. The aforementioned generation plants, will be entitled to receive 1 CEL for each Megawatt-hour(MWh) generated without the use of fossil fuels for a period of 20 years. However, the electrical energy destined for plant uses within the power station will not be accounted for the delivery of CEL to the generator [5].

To reduce emissions from the country's generation, the CEL that CRE will award for each MWh of clean generation in new capacity, will serve to make clean-generation technologies become competitive. The country has set goals in the production of energy and the use of CEL, those goal are described in Fig. 2.1.

All consumption generates obligation. The entities responsible for loading with obligation to acquire CEL are the suppliers, the consumer centers associated with a legacy interconnection contract when the central associated to it is conventional, centers of consumption of isolated supply and the users who do not have a supplier. SENER (Secretary of Energy) stated that the requirement percentage of 2018 is 5% and that of 2019 is 5.8%, which means that every 1,000 MWh of consumption will result in a requirement of 50 CEL in 2018 and 58 CEL in 2019 [6].

Best way to understand them is to look at Renewable Energy Certificates by the EPA https://www.epa.gov/greenpower/renewable-energy-certificates-recs.

In Fig. 2.1 there is a graph made with information published by CRE. The line in blue shows the stablished goals in the country to contributed in the reduction of fossil fuels burning. In 2018, 25% of the Energy Generation should come from clean technology. And by 2050 the expectation is that half of the total energy needed in Mexico is obtained by taking advantages of the renewable resources. As mentioned before, to motivate the use of clean energy, each consumer must compensate the use of energy that was produced by conventional technologies. In 2018, 5% of the total used energy should be justified as clean with CEL. If it was not clean energy, the required certificates will be buy from clean energy producers.

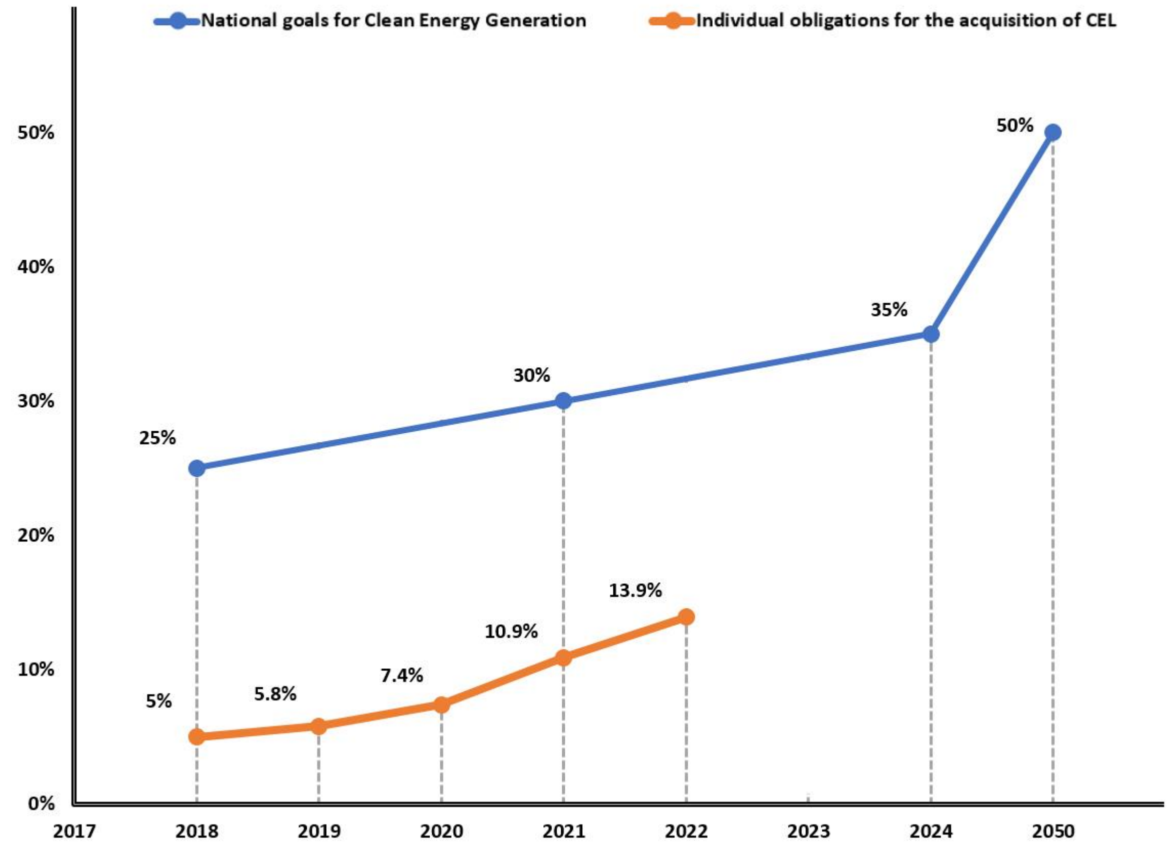


Fig. 2.1 CEL objectives; Source: CRE

Interconnection to general distribution networks

NET Generation classification

Power plants with a capacity less than 0.5 MW are classified according to their net generation and the level of tension to which they are interconnected to the general distribution networks. In the Table 2.1 a classification is shown based on the generation of the power plant.

Table 2.1 Classification of electric power plants based on their net generation [3].

Net generation (kW)		Type
Three-Phase	P ≤ 50	BT
Single-Phase	P ≤ 30	
P ≤ 250		MT1
250 < P < 500		MT2

The capacity for the integration of power plants into the distribution circuits will depend on the effects of these power plants on the criteria of efficiency, quality, reliability, continuity, safety or sustainability of the Electrical National System.

Diagrams for the interconnection of power plants

For generation plants less than 0.5 MW, specific interconnection schemes are presented for each type presented in the Table 2.1, and for every contract.

In the Table 2.2 there are 9 ratings that correspond to the classification of plants with a capacity less than 0.5 MW.

The following diagrams were taken from [3] and at the end of the 9 diagrams there is a list where the tags in the figures are described.

Table 2.2 Interconnection schemes related to the sell and use of energy [3]

Type	Contract	Interconnection Scheme
BT	Net metering	1
	Net billing	4
	Total sale	7
MT1	Net metering	2
	Net billing	5
	Total sale	8
MT2	Net metering	3
	Net billing	6
	Total sale	9

When a power plant chose the net metering scheme, can select one of the following tree specification according to the power plant's capacity. In Fig. 2.2 the solar field is connected in low voltage and the M_B is installed by the supplier. In Fig. 2.3 y Fig. 2.4 the considerations that must be taken are shown, since they are connected to medium voltage, transformers are needed for the measurement and short circuit fuse for protection.

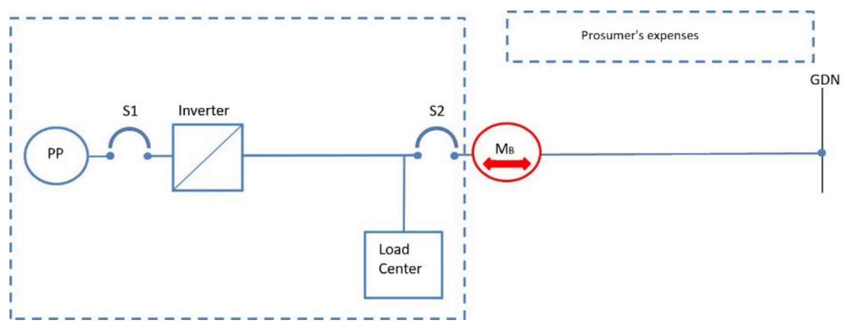


Fig. 2.2 Interconnection Scheme 1 for electric power stations less than or equal to 50 kW in low voltage with load centers [3]

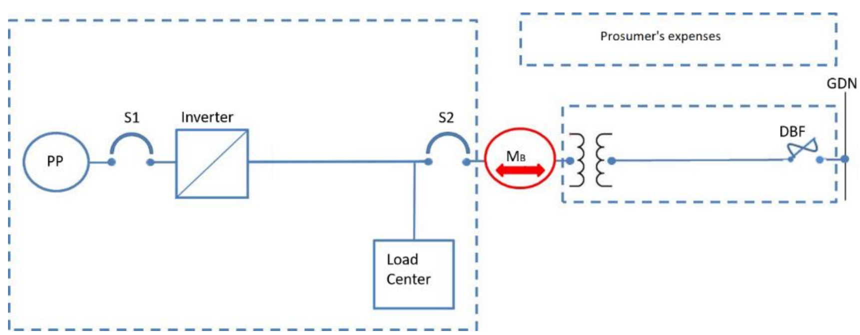


Fig. 2.3 Interconnection Scheme 2 for electric power stations less than or equal to 250 kW in medium voltage with load centers [3]

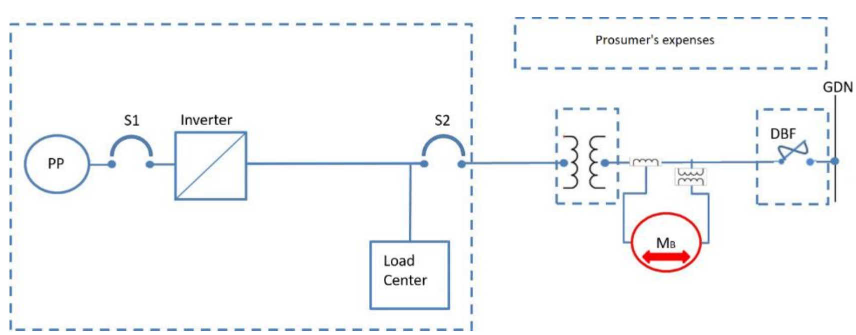


Fig. 2.4 Interconnection Scheme 3 for electric power stations greater than 250 kw and less than 500 kw in medium voltage with load centers [3]

When the contract is for a power plant in Net Billing scheme, any of the following three cases may be presented. In the three diagrams appears M_{pp}, which will be installed by the owner of the plant and this will be an independent meter of the gross generation that could be used for statistical and reporting purposes. The Fig. 2.5 is for interconnection in low voltage while in Fig. 2.6 and Fig. 2.7 for being in medium voltage elements are added in both diagrams.

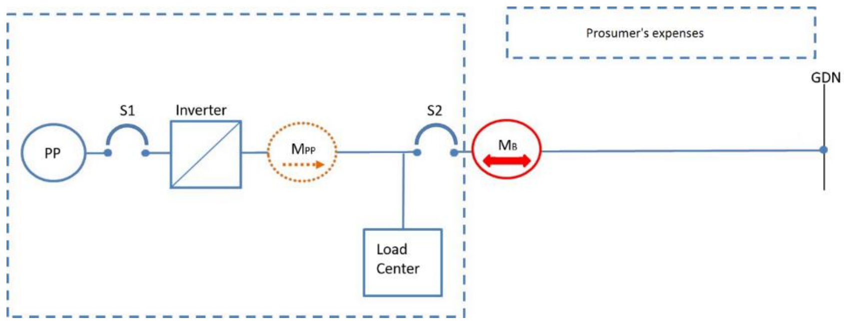


Fig. 2.5 Interconnection Scheme 4 for electric power stations less than or equal to 50 kW in low voltage with load centers [3]

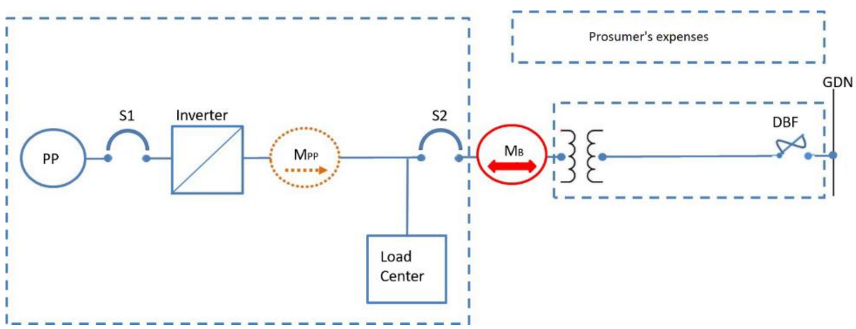


Fig. 2.6 Interconnection Scheme 5 for electric power stations less than or equal to 250 kW in medium voltage with load centers [3]

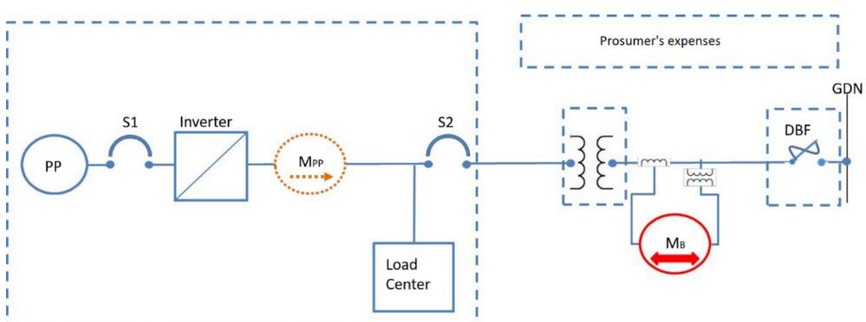


Fig. 2.7 Interconnection Scheme 6 for electric power stations greater than 250 kw and less than 500 kw in medium voltage with load centers [3]

The last mode is that of Total Sale Energy, it is very similar to the previous one only in this case it is possible that the load center is not in the same place as the power plant. All the energy will be delivered in its entirety to the network and therefore the M_B meter is no longer bidirectional. In Fig. 2.8, Fig. 2.9 and Fig. 2.10, the considerations taken by level of tension are repeated as in the previous ones.

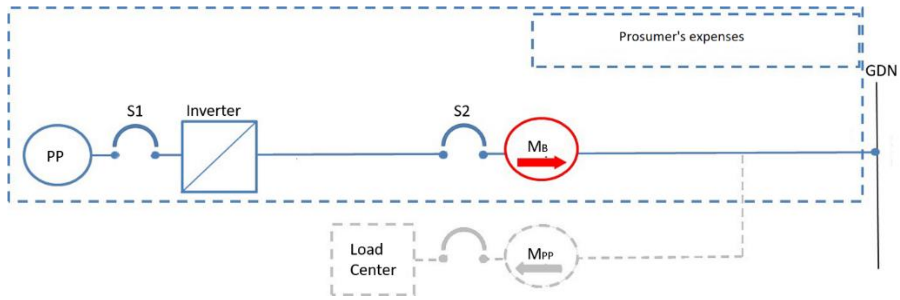


Fig. 2.8 Interconnection Scheme 7 for electric power stations less than or equal to 50 kW in low voltage [3]

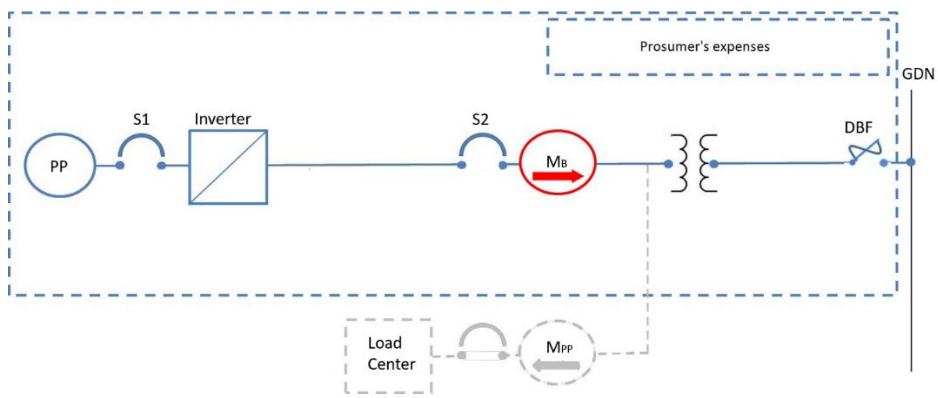


Fig. 2.9 Interconnection Scheme 8 for power stations less than or equal to 250 kW in medium tension with low voltage measurement [3]

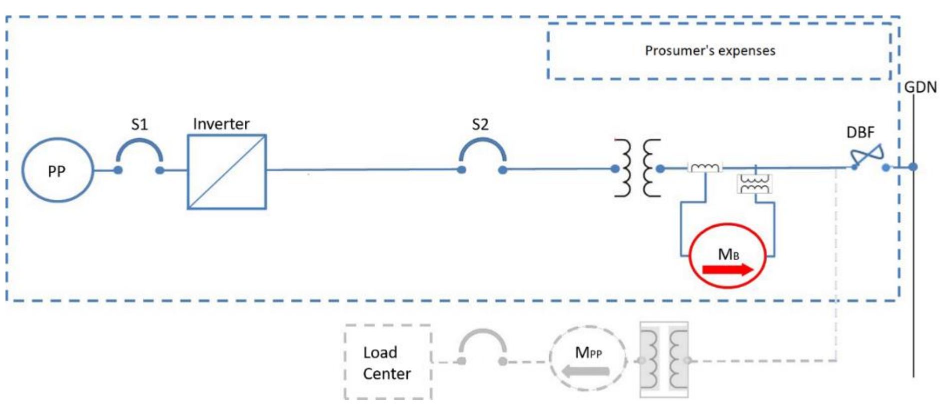


Fig. 2.10 Interconnection Scheme 9 for electric power stations greater than 250 kw and less than 500 kw in medium voltage with measurement in medium tension [3]

Where:
PP: Power plant and/or energy storage equipment
LC: Load Center where Energy will be consumed
M_B: Billing meter for the recording of the electrical energy delivered to the networks General distribution or received from the general supply networks.
M_{PP}: Power station generation meter (optional) for registration of the electric power generated by the power plant
S_1: Power Station Disconnect Switch (DC)
S_2: Particular Network disconnect switch (AC)
DBF: Physical Disconnect Breaker Fuse
IN: Interconnection Node
GDN: General Distribution Networks

Characteristics of the equipment according to the regulations

Next are summarized some of the main characteristics mentioned in [3] for the requirements of the equipment. All data were collected and are presented like the tags used in the previous diagrams and other categorized as power quality.

Switch of the power plant (S_1).

- Be manually operable.
- Have a visible indicator of the "open-closed" position.
- Have the possibility of being mechanically locked in the open position by means of a padlock or safety mechanism.
- Be operable without exposing personnel with energized parts.
- Be clearly identified as the power plant disconnect switch.

Switch to disconnect to the grid (S_2).

- The connection specifications established by the Distributor or the specifications approved by the CRE that replace them.
- Operate with load flow in both directions.
- Be operable without exposing any individual with energized parts.
- Be identified as the disconnect of the grid.

Billing Meter M_B.

- Accuracy of 0.2%
- Measurement of KWh-kW and kVARh inductive and capacitive.
- Bidirectional Flow Measurement with capacity of Storage of the measurement data separately.
- With internal modem for remote communication via telephone line Minimum speed of 1200 baud.
- With interface of Type 2 optical port on the front of the meter, to program, ask and get all the data from the meter.
- Programmable so that every end of month and season perform a demand reset, retaining in memory the time-rate readings (freezing of readings), for access on screen, and proprietary software.
- With non-volatile memory to store, scheduling, configuration and time-rate data.
- With screen showing hourly rates.
- Programmable to provide values of:
  - 4 different time periods, 4 different days, 4 different schedules, 4 seasons and change of daylight saving time.
  - Active and reactive energy, delivered and received, for each of the 4-time periods, of the 4 different days, of the 4 different schedules and of the 4 different stations.
  - Demand shifted in intervals of 15 minutes and subintervals of 5 minutes, for the delivered power, in each of the 4 time periods, of the 4 different days, of the 4 different timetables and of the 4 different stations.
  - Total values per rate and total.
- Device for restoring demand.
- Computer Compatible Portable staff.
- Mass memory to store a minimum of 2 variables every 5 minutes a minimum of thirty-five (35) days.
- Programmable Calendar Clock Based on the frequency of the line or the quartz crystal.
- Battery backup for the clock and mass memory with a minimum lifespan of 5 years and minimum capacity for thirty (30) continuous days or three hundred and sixty five (365) days cumulative.
- Ability to position the meter in test mode, either by software or hardware indicating that you are operating in this mode.
- Screen to display the normal mode, alternate mode and test mode information cyclically.

Protection in the inverter.

- Disconnection device for general distribution networks
- Over-current
- Generator Disconnect Device
- Over-voltage tripping
- Low voltage shooting
- Over-and low-frequency shooting
- Synchronism (Automatic preferably)
- Anti-Island

Energy quality.

- Without causing voltage fluctuation greater than +/-5%.
- No connect the distribution circuit when the circuit is out of service.
- Power Factor in the range of 0.95 (lag or lead).
- Total harmonic Distortion current is 5%.
- The injection of direct current at the interconnection point must be ≤ 0.5% of the nominal current of the generator.
- Disconnect time for V > 120, 0.16 s.
- It must not be reconnected until the voltage at the interconnection point is within the operating limits and the frequency is between 59.3 Hz and 60.5 Hz.
- The power plant interconnect system must include an adjustable time delay (or fixed to 5 min.)
- Disconnect in less than 0.5 s.
- Prevent Island Mode involuntary. No fuses.

Schneider Electric's Products

During the elaboration of this study, the specification of the two following products. The inverter model CL25000 and the meter model ION 8650. Both are key instruments in the installation, due to the switch and protection are more general, Schneider offered a wide range of them for all purposes.

According to the information taking from the datasheet in the brochure of each product, is pretended to check the specification and compared them to the requirements mentioned in the fore section.

Conext CL Three-phase grid-tie string inverter

From the Table 2.3 are some characteristics that can be taken into consideration. The maximum input voltage is 1 kV. The frequency range can be adjusted +/-3 Hz and the regulation said that at least is necessary +/- 1.2 Hz in normal operation, so this is well. According to the regulation the Total Harmonic Distortion (THD) must be under 5%, and this equipment than 3%. While the Power Factor (PF) required is 0.95 leading or lagging, and the output of this inverter can operate from 0.8 to 1 leading or lagging. This kind of inverter can full fill the regulations correctly in the characteristics evaluated.

Table 2.3 Inverter CL25000

Device short name	CL25000 E
Electrical specifications	
Input (DC)	
Full power MPPT voltage range	430 - 800 V
Operating voltage range at	250 - 1000
Max. input voltage, open circuit	1000 V
Number of MPPT / strings per	2 / 4
Max. array short circuit current per	40.0 A
Nominal DC input power	26.5 kW
Max. DC input power per	15.9 kW
Output (AC)	
Rated output power (PF=1)	25.0 kW
Max. apparent power	25.0 kVA
Nominal output voltage	230 / 400 V
AC voltage range	184 - 276 V / 319-478
Frequency	50 / 60 Hz
Frequency range (adjustable)	50 +/- 3 Hz, 60 +/-
Max. output current	37.0 A
Nominal continuous output	36.1 A
Total harmonic distortion	< 3 %
Power factor (adjustable)	0.8 lead to 0.8 lag
AC connection (in the wiring box)	spring cage clamp
Efficiency	
Peak	98.3 %
European	98.0 %

Schneider ION8650

For the meter the regulations required accuracy equal to 0.2% and this meter is 0.1%. This model is able to register active, reactive, and apparent power total or per phase. It is programmable and poses 128 Mb of onboard memory. This information match with the regulations, meaning that evaluating those characteristics from Table 2.4 ION8650it is suitable for this purpose.

Table 2.4 ION8650

Device name	ION8650 A
General	
Use on LV and HV systems	X
Current accuracy	0.1 % reading
Voltage accuracy	0.1 % reading
Power accuracy	0.1 % reading
Samples/cycle	1024
Current, voltage, frequency	X
Active, reactive, apparent power Total & per phase	X
Power factor Total & per phase	X
Current measurement range (autoranging)	0.01 - 20A
Active, reactive, apparent energy	X
Settable accumulation modes	X
Current Present & max. values	X
Active, reactive, apparent power Present & max. values	X
Predicted active, reactive, apparent power	X
Synchronization of the measurement window	X
Demand modes: block (sliding), thermal (exponential)	X
Harmonic distortion Current & voltage	X
Individual harmonics Via front panel	63
Waveform and transient capture	X
Harmonics: magnitude, phase, and interharmonics	50
Detection of voltage sags and swells	X
IEC 61000-4-30 class A /S	A
IEC 61000-4-15 (Flicker)	X
High speed data recording (down to 10 ms)	X
EN50160 compliance reporting	X
Programmable (logic and math functions)	X
Onboard Memory (in Mbytes)	128
Revenue logs	X
Event logs	X
Historical logs	X
Harmonics logs	X

Sag/swell logs	X
Transient logs	X
Time stamping to 1 ms	X
GPS synchronisation (IRIG-B standard)	X
Front panel display	X
Wiring self-test (requires PowerLogic ION Setup)	X
Pulse output (front panel LED)	2
Digital or analogue inputs (1) (max)	11
Digital or analogue outputs(1) (max, including pulse	16
Direct connection voltage	277V(2)
Infrared port	1
RS 485 / RS 232 port	1
RS 485 port	1
Ethernet port (Modbus/TCP/IP protocol) with gateway	1
Internal modem with gateway (ModemGate)	1
HTML web page server (WebMeter)	X
IRIG-B port (unmodulated IRIG B00x time format)	1
Modbus TCP Master / Slave (Ethernet port)	X / X
Modbus RTU Master / Slave (Serial ports)	X / X
DNP 3.0 through serial, modem, and I/R ports	X

Chapter 3 SOLAR TECHNOLOGY

According to the International Energy Outlook 2016 [7], the total world consumption of energy increases 48% from 2012 to 2040. Electrical energy has become a basic need and exists many ways to generate it. This will bring new investees in green generation impulse mainly by the government trying to reach the goal of zero pollution emission, due to the increased awareness about global warming, conventional energy resources use is decreasing [8]. Photovoltaic system is considered as one of the clean method of energy generation. Even though the PV power plants have a high initial cost, they have a longer lifespan of 25 years [9], and the time it takes to repay itself is usually about a decade [10].

Solar PV power is safe and reliable, no noise, no pollution, less constrained, low failure and convenient maintenance [11]. The major demerit is that the power depends entirely on the sun rays [12], and it is no possible to be controlled by humans. Basic unit of a solar PV module is a solar cell. Assemblies of solar cells are used to make solar modules. Multiple of solar modules make solar panel and assembly of solar panel is Photovoltaic system or Photovoltaic module shown in Fig. 3.1 [13].

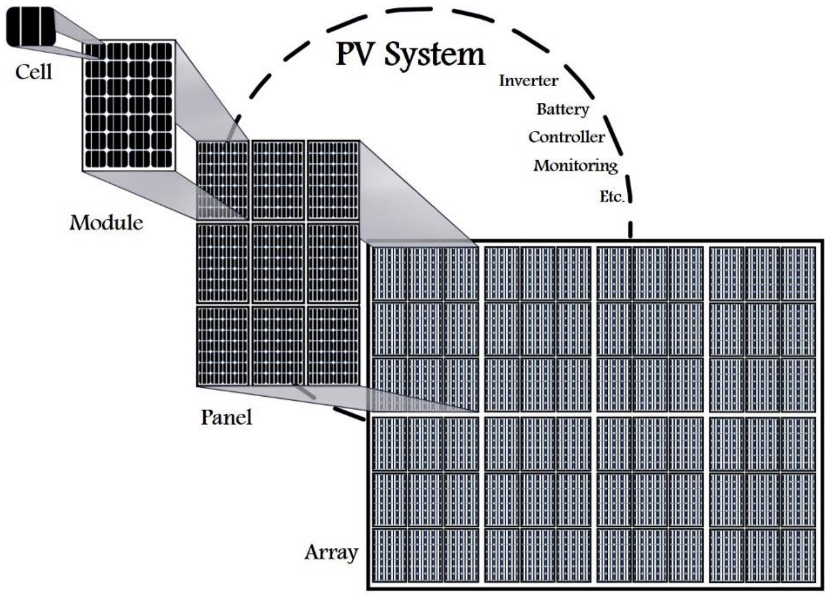


Fig. 3.1 PV system

When a solar cell is working, it produces direct current (DC). Currently the process to use this energy follows the next steps: while sunlight incises the photovoltaic (PV) effect appears and DC is available for harvesting. This energy is directed to an inverter, which changes the naturality of the current, DC is converted to alternating current (AC). It means that when the sun hides the energy flow is stopped, one primary weakness of renewable energy sources is that their operation is not guaranteed based on many things such as weather conditions. PV arrays are the most accessible solar technology, however dark or gloomy days and some obstacles that produce shades on the panel decreases the overall efficiency of the system [14].

A solar cells' performance is dependent on the operating temperature [15], in some world's region on a typical summer day may reach up to 80 C° [10]**.** When installing a solar array, the panels have to be collocated with an optimal orientation and tilt and it is different for every place on the globe [16]**.**

After its invention in 1950s, the solar industry has gained prominence and is growing at a rapid rate across the globe [12]. The major countries such as Germany, Italy, Japan, Spain, the USA and China have proposed many incentive policies to enforce the rapid development of photovoltaic market in the last decade [17]. This technology contributes 1% of the total required electricity of the world [18]**.** In Mexico solar technologies were those that presented the greatest increases with 157.4% [19].

Photovoltaic Cells

The use of photovoltaic (PV) panels is one of the alternative of using of renewable resources, this technology is constantly under development. Even if the actual yield of these panels is relatively low compared to other devices, efforts are being made to improve their performance [20].

Photovoltaic effect

PV effect is a phenomenon that the device when exposed to light generates voltage, first discovered in the cell between the electrodes and electrolyte to the junction by the French experimental physicist Edmund Becquerel in 1839 [11]. PV system's output power depends entirely on the solar irradiance. Solar radiation is the result of fusion of atoms inside the sun. Part of the energy from this fusion process heats the chromosphere and the radiation from the chromosphere becomes the incident solar radiation on earth [21].

Solar radiation outside the earth's atmosphere is called extraterrestrial radiation. Approximately 47% of the incident extraterrestrial solar radiation is in the visible wavelengths. The infrared portion account for another 46% of the incident energy. Finally, the ultraviolet portion accounts for 7% of the extraterrestrial solar radiation. Water vapor and atmospheric dust reduce the amount of direct sunlight. On a clear day, without clouds, approximately 75% of the extraterrestrial direct normal irradiance passes through the atmosphere without being scattered or absorbed [21].

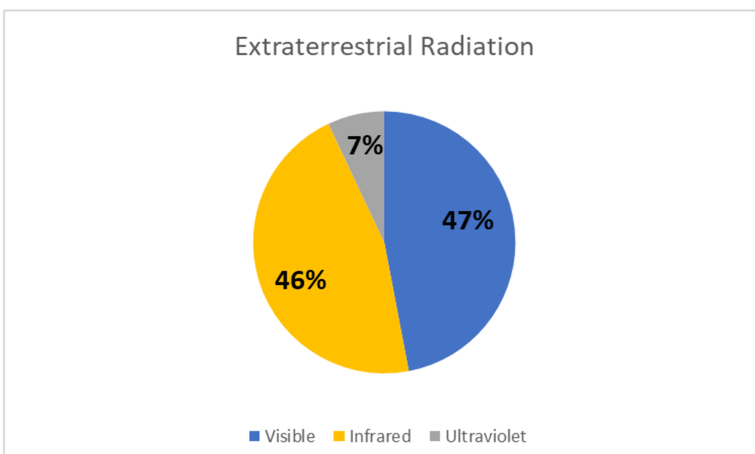


Fig. 3.2 Solar Radiation

The radiation, coming on the earth's surface from the direction of the sun, is called direct normal irradiance (or beam irradiance). Some of the scattered sunlight is scattered back into space and some of it also reaches the surface of the earth. The scattered radiation reaching the earth's surface is called diffuse radiation and it is intensified by dry air mass formations, airborne nanoparticles, and cloud formations at higher atmospheric levels. The total solar radiation on horizontal surface is called global irradiance and is the sum of the incident diffuse radiation plus the direct normal irradiance projected onto the horizontal Surface [21].

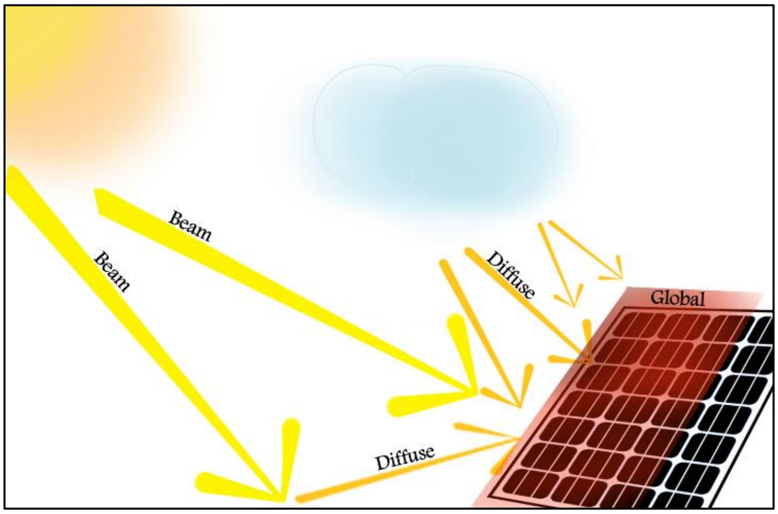


Fig. 3.3 Solar Radiation Components

In the reference [21], are shown three graphs showing the global irradiance measured in November 20, 21 and February 16.

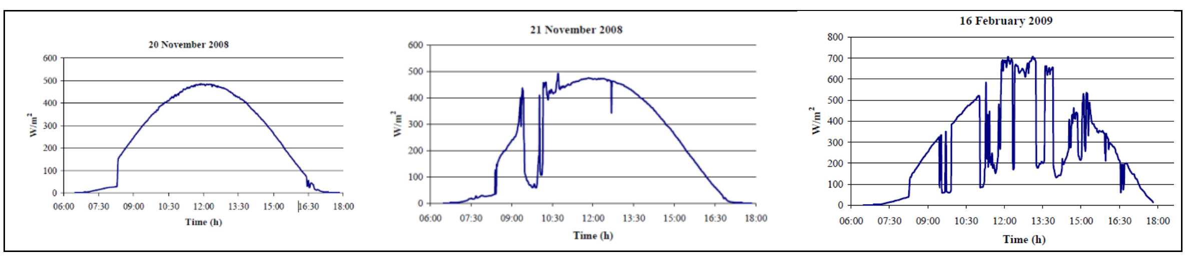


Fig. 3.4 Irradiance measured [21]

Solar cells' development

Free fuel-based PV and wind energy are the only sustainable solutions that can meet the growing energy demands. Due to inherent advantages, PV will take over wind energy and eventually become the dominant electricity generation technology. Without subsidy, PV has the lowest cost of electricity generation on earth [22]. Material selected for development of solar cell should fascinate many conditions like abundancy, ecofriendly, etc. and Silicon sort out most of these issues but problem is that present Silicon based Solar cells have an efficiency of about 28% as they can be used to absorb visible region radiation only [23].

There are three main classes of PV technologies in the solar market. They are crystalline silicon, Thin film and Multi-junction cells (MJC). Crystalline Silicon (c-Si) semiconductors dominate the world PV market, accounting for nearly 90% in 2013. Mono crystalline silicon (mono c-Si) and poly crystalline silicon (poly c-Si) are the different types of c-Si PV technology. Thin film technologies are made with one or more thin layers of PV material deposited onto glass, plastic, metal, or another surface. Cadmium Telluride (CdTe) and Copper Indium Gallium Deselenide (CIGS) are prominent types of thin film technology. Munti-junction cells make of light at different wavelengths more efficiently than crystalline silicon cells through multiple stacked layers of semiconductors [24].

According to the National Renewable Energy Laboratory (NREL), nowadays are many classes of PV technologies in the solar market. In Fig. 3.5, taken form the NREL website is clear that the efficiency has reached 46% under laboratory conditions, talking about the four-junction cells. The ones with the greater efficiency are the ones in purple, under the classification to "Multijunction Cells" (MJC). Another interesting fact from this graph is the section in orange, named "Emerging PV", here brings up one in particular "Quantum dot cells" (QDC), because the ones with the greatest efficiency has taken many years to develop, but the last mentioned has reached 13.4% of efficiency with a steeper slope, meaning fewer years.

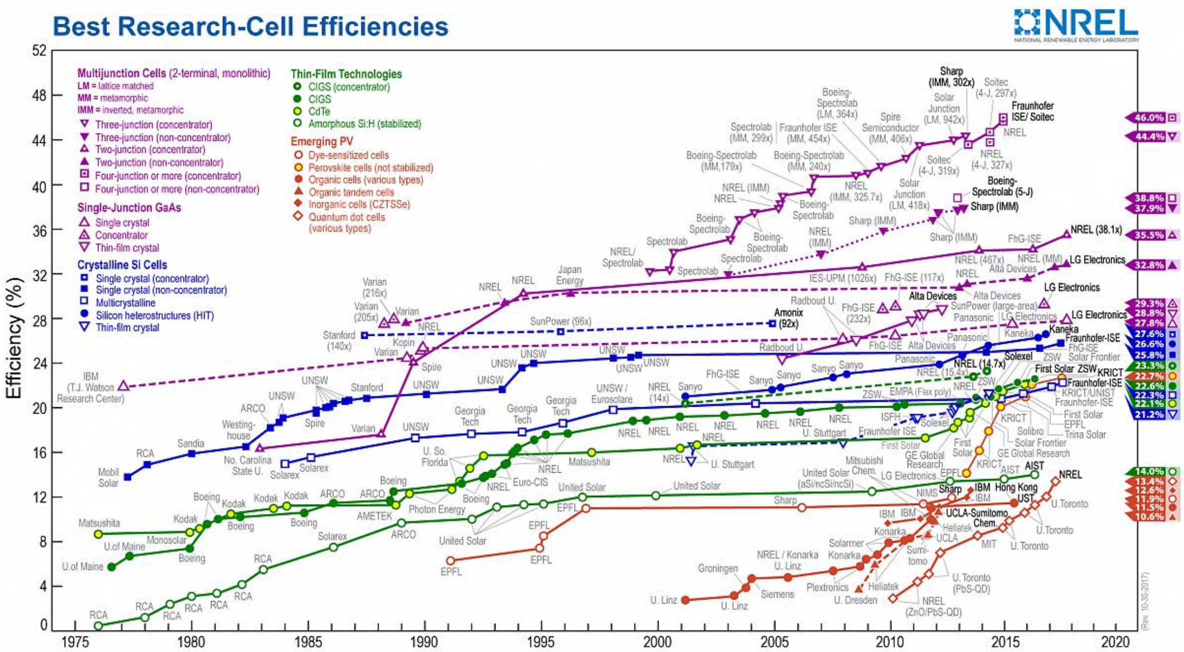


Fig. 3.5 Best Research-Cell Efficiencies

Quantum Dots Cells

Photovoltaic applications are interested on the power delivered by wavelengths corresponding to greater energy values compared to the band-gap of the semiconductor material used to produce the photovoltaic cells, in order to provide the required electron-hole pairs that will be spatially separated by the build-in potential barrier across the p-n junction contact region [21].

Quantum dot (QD)-based solar cells have been the subject of over two decades of research with the hopes of increasing their efficiency to surpass single junction solar cells. To date, no single working device has been developed that surpasses the efficiency of a single junction solar cell [25]**.** But the main advantage found to use Quantum Dot is that along with visible and Infrared region of light they also absorb rays of ultraviolet region which was one of the issue with Silicon based solar cell (along with their poor efficiency) [23].

Absorption of photons by Quantum Dots depends on the wavelength of the light incident and on the material by which Quantum Dot is developed and different materials shows different absorption, in other words, each material absorbs photons of different wavelength by Planck's relationship. For example, Si, Ge, GaAs absorbs light of infrared region where as ZnS absorbs in ultraviolet region [23].

Solar system performance

A solar system is a series of solar modules usually connected in series and parallel circuits to create an additive voltage and a higher current [17] and can be grid connected or independent. The unpredictable natural factors, other pollutants could also cause some malfunction in the photovoltaic system [26], which reduces the output power drastically. The performance of a (PV) array is affected by temperature, solar irradiance, shading, and array configuration [14]**.**

Temperature and irradiance. As the cell's temperature increases, the saturation currents also increase the power decreases by approximately a half percent per each degree (C°). Wind affects the panel's operating temperature by cooling the panel. [10]There is a direct connection between the diodes' saturation currents and the cell's temperature.

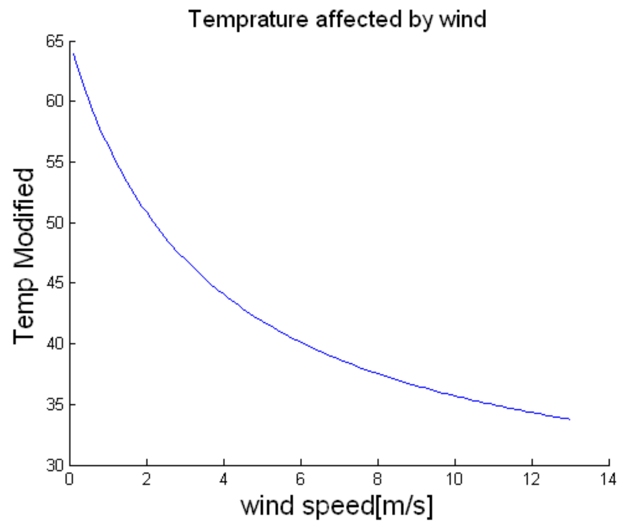


Fig. 3.6 The effect of the wind on the panels' operating temp. [10]

To ensure the desired performance, the PV system needs a Maximum Power Point Tracking (MPPT) algorithm. The maximum power point shows the voltage and current coordinates and makes possible to draw the best performances from the photovoltaic panels taking into account the environmental conditions such as temperature and irradiance [27]. In Fig. 3.7 is shown the optimum operating point according to the temperature to generate the maximum power and in Fig. 3.8 are marked the maximum operating point related to the irradiance.

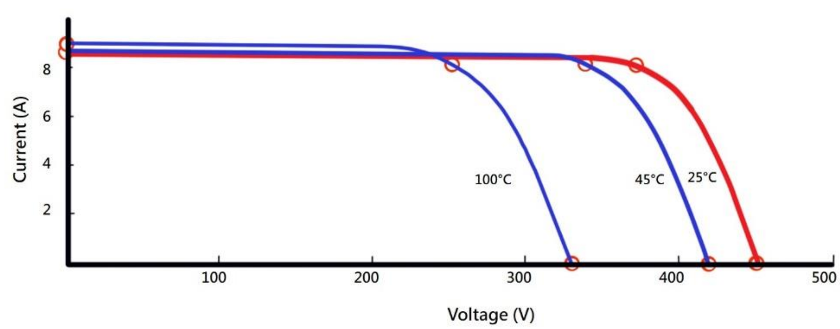


Fig. 3.7 I-V Characteristics [27]

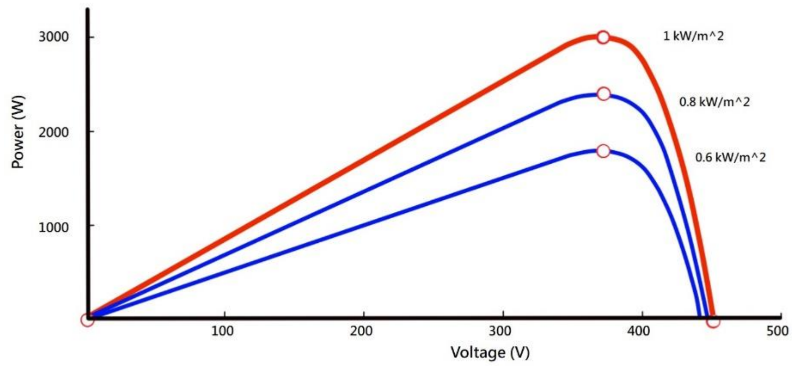


Fig. 3.8 P-V Characteristics [26]

Shading. It can be caused by different reasons, the partial shading is very common in the morning and evening as the prolonged shading of buildings and photovoltaic modules [28], can even damage modules if not properly controlled.

In addition, a single dust storm can reduce the output power by 20% and a reduction of 50% could be experienced if no cleaning is performed on modules for long time that exceeds six months.
The flow of the light incident directly affects the charge carrier generation and thus the current generated by the device.
In fact, cells under shade absorb a large amount of electric power generated by cells receiving high solar irradiation and convert it into heat Non-uniform solar irradiance is the general problem in solar energy. The facts that create non-uniform illumination might be anything in the nature such as clouds, leaves, electric poles, the shadow of buildings, even sand and snow.

Shaded cells cannot produce as much current as unshaded cells. Since all cells are connected in series in a module, the same amount of current must flow through every cell. Unshaded cells will force shaded cells to pass more current than their new short circuit current. The only way that shaded cells can operate at a current higher than their short circuit current is to operate in the region of negative voltage. This causes a net voltage loss in the system. Shaded cells absorb power and begin to act as a load. In other words, shaded cells dissipate power as heat and cause hot spots. Consequently, the current available in a series string is limited by the current of the solar cell with the lowest level of solar irradiance [14].

Array configuration. To eliminate the effects of shading, the PV array configuration technique and the maximum power point tracking (MPPT) techniques are effectively used. The conventional series-parallel (SP) array configuration is much sensitive to partial shading conditions hence alternate configurations like the total-cross-tied (TCT), the bridge-linked (BL) and the honey-comb (HC) array configuration topologies have been derived [12].

The PV arrays should be connected in a methodical manner to reduce the effects of nonlinearity in its output characteristics. Each of these configuration techniques has their own uniqueness. From reference [12], where is explained each one, have been taken the following diagrams in Fig. 3.9 and the explanation.

The SP is the conventional array configuration topology. It consists of PV modules connected in series to get the rated voltage and then they are connected parallel to meet rated current.
In TCT, the modules are first connected in parallel to equal voltages across the ties and then they are connected in series.
In BL, to decrease cost, the number of ties as present in TCT is being reduced and only four modules are cross tied together.
HC is a modified form of TCT and BL. It consists of variable number of cross ties using even number of PV modules (two, four, six, etc.) and is able to provide the requisite power output.

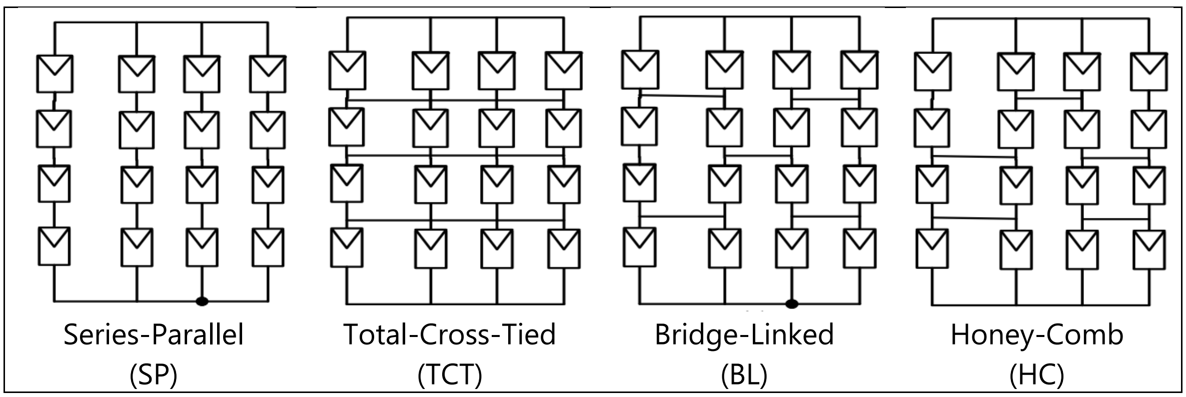


Fig. 3.9 PV Array Configurations [12]

Siting

Output power of an array is directly proportional to power received from the sun. This Will vary throughout the day. The rated maximum output of the module might only be achieved occasionally, depending on the actual site.

System designers calculate the output energy from the peak sun hours, which is a measure of the available solar energy. It is numerically equal to the daily solar radiation in kWh/m2 (it is not the same as the number of hours of sunlight). Peak sun hours vary throughout the year. Peak sun hours are usually averaged and presented as a monthly figure [29]. And this concept can be explain graphically using the
Fig. *3.10*, where the rectangle represents the hours during the which the irradiance will be equal to 1000 W/m2.

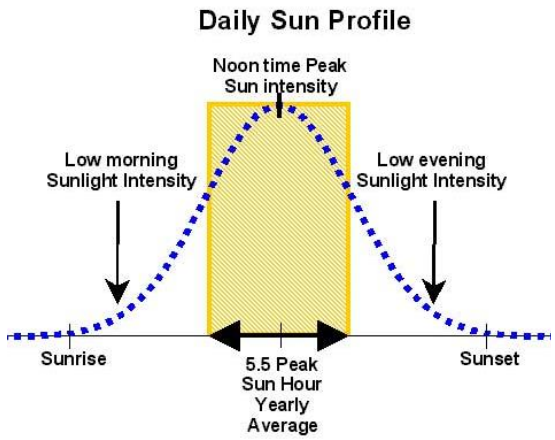


Fig. 3.10 Daily Sun Profile and Sun Hour relation [21]

Orientation. Solar modules produce most power when they are pointed directly at the sun. Ideally, they should be in full sun from 9am to 3pm in mid-winter.

Fig. 3.11 below for latitude 35°S shows the effect of orientation and elevation on module output, expressed as a percentage of the maximum possible output. Note that a wide range of elevation and orientation angles will still provide useful output, and sometimes it depends on the place characteristics [29].

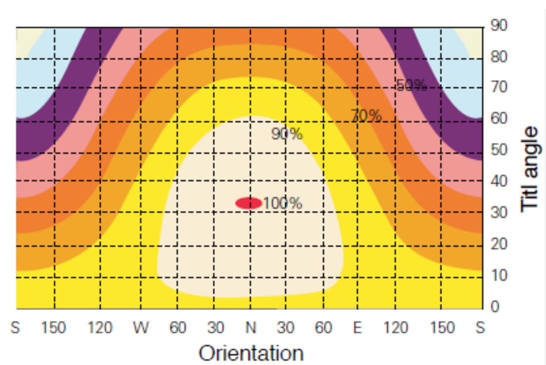


Fig. 3.11 Variation of solar module output with orientation and tilt angle for latitude 35°S [29]

Elevation. For standalone PV systems, where winter operation is crucial, the angle should be the latitude plus 15°. For grid connected systems the angle should be latitude minus 10° to maximize the amount of energy produced annually.

As a rule of thumb, if the main loads are in winter months when solar availability is reduced, tilt angles should be more vertical (approximately equal to latitude plus 15°) to maximize exposure to the low winter sun.

If major loads are cooling and refrigeration the tilt angle should be reduced (approximately latitude minus 10º) to maximize output during summer.

For grid connect systems the summer optimum angle should be used to maximize annual output of the modules [29].

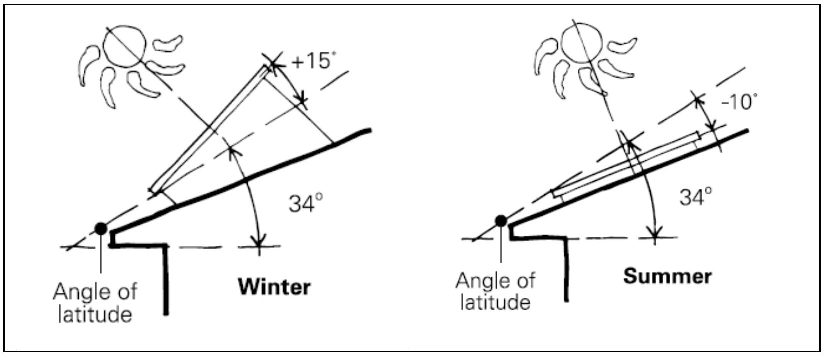


Fig. 3.12 Panel tilt [29]

Grid connected Photovoltaic system

Grid connected PV represents about 75% of the global PV market today [30]. Delivering quality power from the photovoltaic power system involves different stages of operation starting from generation, power conditioning, synchronization and control. It is the most important issue of grid connected solar photovoltaic system (GCPS).

The GCPS faces various issues of power quality like voltage sag, flicker, and harmonics. When are considered the factors influencing the harmonics, indirectly are variation in irradiation, temperature and directly the dead time of inverter, calculation time of the current controller, nonlinear load [8].

PV power generation system has a disadvantage that the PV array loses the output capability when the irradiation is weak, or it is night, which forces the whole system to be removed from the grid. Furthermore, the frequent parallel operation and break-up actions make the control of the system difficult.

A general GCPS system has two control loops. The inner loop is a pulse width modulation (PWM), which modulates output currents of the inverter, to meet the requirements of the waveform and phase.
The outer loop determines the output power of the inverter according to the MPP (Maximum Power Point) of PV panels [31].

Dealing with the above mentioned energy quality issues requires high electronic developments, to not affect the grid stability. Those developments are found in the inverters. Inverter configuration and topology represents the way that how DC power from PV array, in reference [30] are shown three configuration describing the most common ways to connect the inverters. Central string inverters, multi-string inverters and module-integrated PV that can be seen in Fig. 3.13 small or large scale, will be extracted, and how this extracted power will be converted to AC connected to grid or fed to island load [30].

Central inverter is generally used in large-scale 3-phase PV installations, where strings of PV modules are connected in parallel necessitating complex DC cabling. Losses due to module mismatch and shading are usually high in this configuration. To overcome the above disadvantages, string inverter and multistring inverter were developed.
Multi-string inverter accommodates different PV sizes and orientations, where each string is equipped with its own MPPT.
Module-integrated PV inverters achieve highest MPPT efficiency and eliminate the DC cabling. When long lifetime (20 years) is achieved, these plug & play inverters will have a very promising future in Building Integrated PV applications [30]**.**

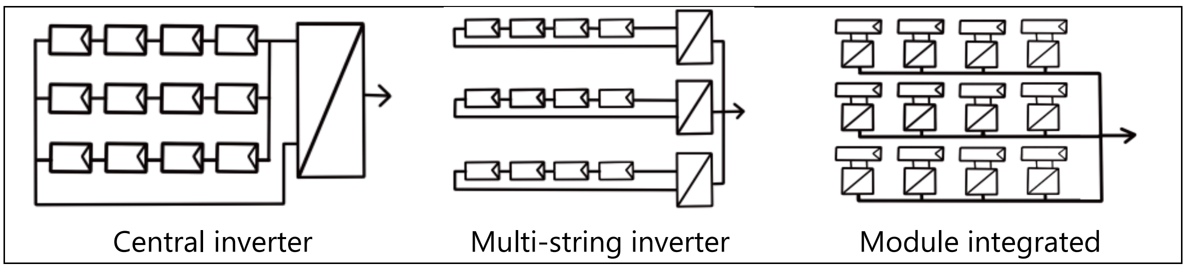


Fig. 3.13 Central string, multi-string and module integrated inverter [30]

Chapter 4 SCHNEIDER ELECTRIC

The company Schneider Electric, in their "Monterrey Development and Innovation Center" (MDIC) built a 270 kW solar field. This park is intended for research purposes and the creation of knowledge about this type of clean generation. It was built with capital arranged in equal parts by CONACyT and Schneider Electric. In Fig. 4.1 can be seen a satellite view of the installation and the geographical position of the solar park. It was taken from Google Maps.

There are currently 9 inverters, each receiving energy from a series 5 arrays of 20 panels each, that deliver a voltage level of 1,000 V. In total the project is designed to deliver 270 kW / h peak.

The solar park was built for scientific purposes; therefore, the inverters can go out of operation because of tests that are executed in the research center.

This electric power plant is classified as Exempt Generator; because the installed capacity is less than 500 kW. Distributed Generation, under the terms of the new Electricity Industry Law, must be produced by an exempt generator, less than 0.5 MW, interconnected to a distribution circuit with protection according to the terms of the market rules.

However, all power plants require permits granted by CRE to deliver electricity to the market. Therefore, the mentioned users require a supplier to represent them, or use energy production for self-consumption.

Fig. 4.1 Satellite view of the Schneider Electric building

The objective of this chapter is to organize the information regarding the installed equipment, the investment and the current operation of the solar field. This way will be explained and summarized available information in the same file, which will allow the researchers to document the operativity and carry out more in-depth analysis of its performance.

Geographical data

Using the coordinates from the Fig. 4.1, the Atmospheric Science Data Center and NASA Surface meteorology and Solar Energy give the parameters for tilted solar panels in different angle. For this area, the obtained data of radiation is Table 4.1. With this information the right tilt depending on the owner's need can be chose. And the calculation related to the energy that will produced a Solar field can be done.

With this information is possible calculated the power that a solar field will produce related to the tilt.

Table 4.1 Average radiation in specific coordinates

Lat 25.76 Lon -100.113	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
SSE HRZ	3.83	4.61	5.73	5.94	6.27	6.19	6.06	5.74	5.05	4.66	4.20	3.64	5.16
K	0.57	0.58	0.61	0.56	0.56	0.54	0.54	0.54	0.52	0.56	0.60	0.57	0.56
Diffuse	1.14	1.37	1.59	2.04	2.25	2.37	2.33	2.18	1.94	1.52	1.13	1.05	1.74
Direct	5.45	5.81	6.62	5.77	5.80	5.51	5.37	5.20	4.79	5.39	6.00	5.45	5.60
Tilt 0	3.72	4.57	5.66	5.82	6.24	6.16	6.03	5.71	4.98	4.62	4.07	3.55	5.10
Tilt 10	4.24	5.04	5.99	5.91	6.15	6.01	5.92	5.71	5.15	5.00	4.61	4.10	5.32
Tilt 25	4.82	5.51	6.22	5.80	5.77	5.55	5.51	5.49	5.19	5.35	5.21	4.74	5.43
Tilt 40	5.14	5.69	6.11	5.40	5.12	4.83	4.84	5.00	4.98	5.41	5.51	5.11	5.26
Tilt 90	4.15	4.13	3.62	2.49	2.00	1.85	1.90	2.19	2.74	3.69	4.33	4.27	3.11
OPT	5.19	5.69	6.22	5.91	6.24	6.16	6.03	5.72	5.20	5.42	5.55	5.20	5.71
OPT ANG	49.0	41.0	28.0	12.0	0.00	0.00	0.00	5.00	20.0	36.0	47.0	52.0	24.0

The temperature of the place can be obtained from the Mexican organization in charge of administrate the water supply, in Mexico it is known as CONAGUA. This organization own many climate stations in the country. And using their software that works with Google Earth is possible download all the historical data each station has saved. The layer with the climate information had been downloaded from this link:
http://smn.cna.gob.mx/es/climatologia/informacion-climatologica

Once in the map, the nearest station was selected. And according to the Fig. 4.2 the highest temperature has been measured in April reaching 50 °C.

SERVICIO METEOROL�GICO NACIONAL

NORMALES CLIMATOL�GICAS

ESTADO DE: NUEVO LEON PERIODO: 1951-2010

ESTACION: 00019004 APODACA LATITUD: 25�47'37" N. LONGITUD: 100�11'50" W. ALTURA: 430.0 MSNM.

ELEMENTOS	ENE	FEB	MAR	ABR	MAY	JUN	JUL	AGO	SEP	OCT	NOV	DIC	ANUAL
TEMPERATURA MAXIMA													
NORMAL	22.9	24.7	29.5	33.1	35.0	36.9	37.2	37.3	34.0	30.0	26.4	23.3	30.9
MAXIMA MENSUAL	31.3	31.4	41.3	40.2	40.5	43.0	41.9	40.9	38.7	34.2	30.7	29.8	
A�O DE MAXIMA	1990	2008	1989	1989	1989	1989	1969	1977	1965	1989	1965	1970	
MAXIMA DIARIA	40.0	42.0	48.0	50.0	47.5	46.0	47.0	45.0	44.0	41.0	41.0	38.0	
FECHA MAXIMA DIARIA	23/1971	28/1989	19/1989	19/1989	06/1971	10/1989	01/1977	18/1969	18/1965	13/1969	27/1965	24/1964	
A�OS CON DATOS	33	34	33	34	33	34	34	34	34	35	34	34	
TEMPERATURA MEDIA													
NORMAL	14.0	15.4	19.5	23.3	25.8	27.8	28.0	28.2	25.7	21.7	17.7	14.5	21.8
A�OS CON DATOS	33	34	33	34	33	34	34	34	34	35	34	34	
TEMPERATURA MINIMA													
NORMAL	5.1	6.1	9.5	13.5	16.7	18.8	18.9	19.0	17.5	13.5	9.0	5.7	12.8
MINIMA MENSUAL	0.9	2.6	5.4	7.7	13.3	12.6	11.8	12.3	9.7	7.1	4.1	1.5	
A�O DE MINIMA	1988	1966	1968	1989	1972	1989	1989	1989	1989	1982	1976	1989	
MINIMA DIARIA	-6.5	-7.5	-5.0	0.0	2.5	7.0	8.0	7.0	3.0	-2.0	-5.0	-8.5	
FECHA MINIMA DIARIA	23/1985	01/1985	03/1980	10/1973	01/1985	10/1983	02/1983	07/1973	28/1989	25/1982	30/1976	24/1983	
A�0S CON DATOS	33	34	33	34	33	34	34	34	34	35	34	34	
PRECIPITACION													
NORMAL	16.4	19.8	15.5	39.9	51.5	63.2	65.9	68.7	150.8	54.1	20.4	22.3	588.5
MAXIMA MENSUAL	69.0	69.5	59.3	175.0	117.5	193.5	405.5	282.5	394.0	258.0	92.5	127.5	
A�O DE MAXIMA	1981	1970	2004	2004	1986	2010	1976	1967	2010	2005	1976	1986	
MAXIMA DIARIA	22.5	58.0	48.0	82.5	71.0	134.0	165.0	102.5	253.0	115.0	53.0	53.5	
FECHA MAXIMA DIARIA	16/2009	22/1966	22/1967	23/2004	11/1988	30/2010	21/2005	11/1975	16/1988	13/2005	01/1986	09/1986	
A�OS CON DATOS	33	34	33	34	33	34	34	34	34	35	34	34	

Fig. 4.2 Meteorological data

Technical data

For low voltage general installations, the 1000V cable is used with the following characteristics:

Solar type cable with certified insulation for solar applications (anti-UV, weatherproof, 90°C) for generation of solar panels for inverters. Cable with THHW-LS2 insulation for alternating current path.

The photovoltaic system counts with nine hundred (900) Solar cells produced by Solartec. And 9 inverters

In Table 4.2 Photovoltaic cell there are the specification taken from the datasheet.

Table 4.2 Photovoltaic cell

Photovoltaic Cell	
Brand	Solartec
Model	S70PC-300
V_{oc}	41.2 VCD
I_{sc}	6.86 Amp
Power	300 watts
Coef % V_{oc}	-0.33 %/°C

In total there are 9 inverters Conext CL 25000 by Schneider. In Table 4.3 there are the specification taken from the Conext CL Brochure.

Table 4.3 Inverter

Inverter	
Brand	Schneider Electric
Model	Conext CL 25000
Full power MPPT Voltage range	500 - 800
Operating Voltage range	250 – 1000
Nominal DC input power	26.5 kW

Each inverter works with 100 cells. Those cells are connected 20 in series generation power equals to 6 kW and the voltage is 824 V and 5 parallels getting at the end 30 kW and the voltage remains the same, 824 V. The total nominal current is 34.3 A.

Chapter 5 ECONOMIC EVALUATION

Taking as a reference the current conditions and the information available, is intended to evaluate if the project is economically viable. In this step a tool was develop, in Excel, that can be applied in the evaluation.

It is divided in three main parts. In the first one, the user is asked to size the solar park. With information took from datasheet, weather conditions of the place and geographical location, an estimated production is calculated. Using a degradation rate, the quantity of energy produced in the first and the following 19 years can be estimated.

The second part is about money. First is required the mount of the investment. And then indicate the loan and capital percentage. In this particular case the whole project was developed with no loan, so in this space is specified 0%. Then the user will write the maintenance and the insurance cost, followed by a rated to simulate the increment in the cost in the coming 20 years.
The next blanks are related to investors interest to evaluate the project and to taxes according to the Mexican laws. Finally, if the user wants to consider the sale of "Clean Energy Certificates" (CEL) can write the estimated cost and again, propose a rate to change the price along the 20 periods.

The third space is about "Others" where the user can consider an extra investment, the mount and the application period are required. For example, the cost of replace the inverters because the solar cells are warrantied per 20 years but the inverter only per 10.

After filling this main page, the user can view the following sheets, and analyze the financial indicators, such as IRR, NPV and Payback. And graphically can be analyze a net cash flow and the payback periods.

Financial Concepts

Net Present Value

The Net Present Value (NPV) is the result of subtracting all future profits from the initial investment, which is equal to subtracting all future profits, the investment that gave rise to them. All this in an instant of time.

It is clear that the investor expects the profits to surpass, or at least equal to, the original investment. The NPV is the gain or loss in terms of the value of the initial money at a rate equal to the MARR. Therefore, if the NPV is positive it means that there will be gains beyond having recovered the money invested and having accepted the investment. If the NPV is negative, it means that the profits are not enough to recover the money invested. If this is the case, you must reject the investment. If the NPV is zero, it means that only the MARR has been recovered and therefore it is also a positive indicator.[32]

Minimum Attractive Rate of Return

To be attractive, a capital project must provide a return that exceeds a minimum level established by the organization. This minimum level is reflected in a firm's Minimum Attractive Rate of Return (MARR). [33]

Many elements contribute to determining the MARR.

- Amount, source, and cost of money available
- Number and purpose of good projects available
- Perceived risk of investment opportunities
- Type of organization

Internal Rate of Return

The Internal Rate of Return (IRR) method is the most widely used rate of return method for performing engineering economic analysis.

It is also called the *investor's method*, the *discounted cash flow* method, and the *profitability index*.

If the IRR for a project is greater than the MARR, then the project is *acceptable*. And it is the interest rate that equates the equivalent worth of an alternative's cash *inflows* (revenue, *R*) to the equivalent worth of cash *outflows* (expenses, *E*).

The use of spreadsheet software can greatly assist in solving for the IRR. Excel uses the *IRR(range, guess)* or *RATE(nper, pmt, pv)* functions. [33]

Straight Line Depreciation

When a corporation purchases equipment, a facility, etc., that is used more than a year, it has to recover the cost over a number of years. This is called depreciating, and the process is depreciation. The annual depreciation from the depreciation formulae or tables is deducted each year from the income in the same manner as regular cost. The remaining cost of the purchase is called the book value.

At any time, if the purchased equipment, property, etc., is sold, the difference between the sale price and the book value is called capital gain or loss and is considered an income or loss and is treated accordingly for tax purposes.

Straight Line Depreciation (SLN) In this method the cost is spread uniformly over a certain number of years N called the life.

The definition of the cost for this purpose is the initial cost P minus the estimated resale value S at the end of the project. [34]

$$SLN = \frac{P - S}{N} \tag{5.1}$$

Cash Flow

The graphic presentation of the costs and benefits over the time is called the cash flow diagram. This is the time profile of all the costs and benefits. It is a presentation of what costs have to be incurred and what benefits are received at all points in time. The following conventions are used in the construction of the cash flow diagram:

- The horizontal axis represents time
- The vertical axis represents costs and benefits
- Costs are shown by downward arrows
- Benefits are shown by upward arrows

The cash flow diagram is the most important and essential element of financial analysis. A proper and accurate cash flow diagram should be constructed and tested before an attempt is made to perform the financial analysis. [33]

Payback

A simple crude method for getting a quick evaluation of the alternatives is to calculate how long it takes to recover the initial investment. The time in any unit that it takes to recover the initial investment is called the payback period. In this method, we first construct the net cash flow diagram and then by simple arithmetic calculation add the benefits and the cost year by year until the total equals the initial investment. [34]

Tool to evaluate economically a project

As mentioned previously, the first step to evaluate the project is to know the quantity of energy that can be delivered by the whole system. The needed information in the first section is shown in the Fig. 5.1.

Technical Data		
Power		270 kW
Solar Resource		5.4 h
Thermal Performance		0.866
Days		365
Theoretical Energy		460,859.22 kWh/y
Real Energy		0.00 kWh/y
Degradation		0.70%
Plant use electricity		100%

Economic Data		
Investment		$259,571 USD
Loan		0%
Capital		100%
Loan Periods		1 Year
Loan interest		10.00%
Maintenance	$	1,350.00 USD
Increment		7.50%
Insurance	$	- USD
Increment		7.50%
Interest		8%
ISR		35%
SLN		1
CEL		18 USD
Increment		7.50%

Others		
Inverters replacement	$	5,000.00 USD
Year?		5

Panel Degradation		
0	460,859.22	kWh
1	457633.2055	kWh
2	454407.1909	kWh
3	451181.1764	kWh
4	447955.1618	kWh
5	444729.1473	kWh
6	441503.1328	kWh
7	438277.1182	kWh
8	435051.1037	kWh
9	431825.0891	kWh
10	428599.0746	kWh
11	425373.0601	kWh
12	422147.0455	kWh
13	418921.031	kWh
14	415695.0164	kWh
15	412469.0019	kWh
16	409242.9874	kWh
17	406016.9728	kWh
18	402790.9583	kWh
19	399564.9437	kWh
20	396338.9292	kWh

Energy Cost		
2015	0.0600	USD/kWh
2016	0.0614	USD/kWh
2017	0.0763	USD/kWh
2018	0.08247117	USD/kWh
2019	0.07882088	USD/kWh
2020	0.07757308	USD/kWh
2021	0.07596397	USD/kWh
2022	0.07663933	USD/kWh
2023	0.08300612	USD/kWh
2024	0.08695102	USD/kWh
2025	0.08929246	USD/kWh
2026	0.08695961	USD/kWh
2027	0.08699907	USD/kWh
2028	0.08775038	USD/kWh
2029	0.08723636	USD/kWh
2030	0.0873286	USD/kWh
2031	0.08743845	USD/kWh
2032	0.08733447	USD/kWh
2033	0.08736717	USD/kWh
2034	0.09231894	USD/kWh
2035	0.09335235	USD/kWh

CEL Price		
2015	18.0000	USD/CEL
2016	19.3500	USD/CEL
2017	20.7000	USD/CEL
2018	22.0500	USD/CEL
2019	23.4000	USD/CEL
2020	24.7500	USD/CEL
2021	26.1000	USD/CEL
2022	27.4500	USD/CEL
2023	28.8000	USD/CEL
2024	30.1500	USD/CEL
2025	31.5000	USD/CEL
2026	32.8500	USD/CEL
2027	34.2000	USD/CEL
2028	35.5500	USD/CEL
2029	36.9000	USD/CEL
2030	38.2500	USD/CEL
2031	39.6000	USD/CEL
2032	40.9500	USD/CEL
2033	42.3000	USD/CEL
2034	43.6500	USD/CEL
2035	45.0000	USD/CEL

Fig. 5.1 Tool to evaluate economically a project

Technical data

In the first table, it says, Technical Data. In this place each row represents theoretical values that can be taken from a datasheet and others from weather data bases.

Power. The kilo Watts peak according to the data sheet. In chapter 4, is reported the power of 300 watts times 900 units is equal to 270 kW peak.

Solar Resource. This data is taken from the NASA's database. The solar resource represents the effective hours when radiation incises on a specific area. To locate the right data is necessary to get the coordinates of the installation. In the Fig. 5.2 is shown the Google Maps' interface, where after typing the name of the building and the bottom of the screen can be seen the coordinates.

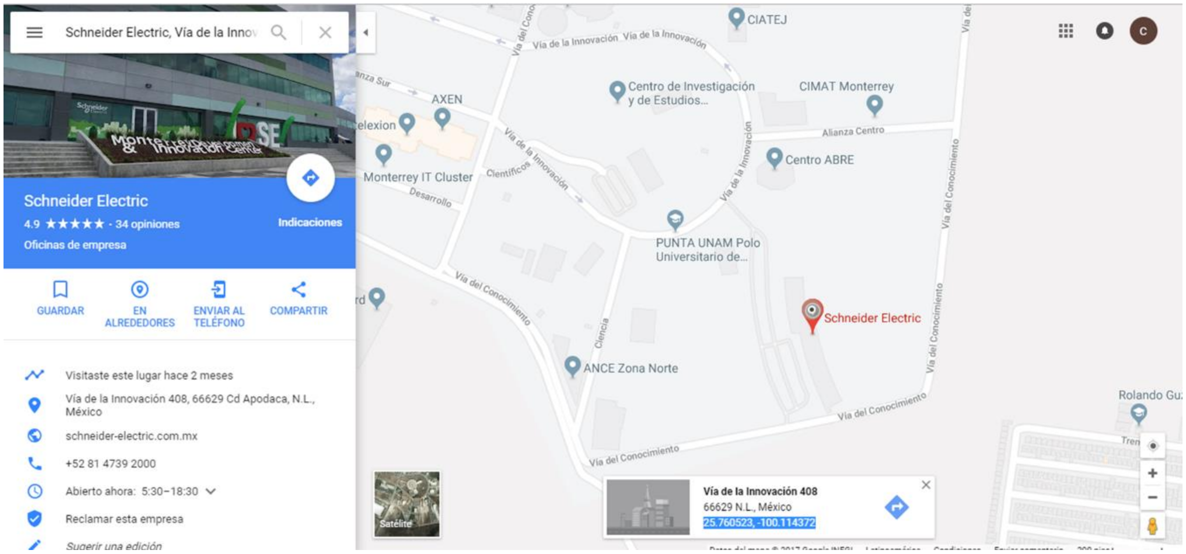


Fig. 5.2 Coordinates of the building

Then the NASA's website, with that data, shows the monthly average radiation incident, ordered by tilt. In the Fig. 5.3 can be seen the average values and in for this case the value is in "tilt 25" and the annual average is 5.4.

ATMOSPHERIC SCIENCE DATA CENTER

NASA Surface meteorology and Solar Energy - Available Tables

Latitude 25.761 / Longitude -100.114 was chosen.

Geometry Information

Elevation: **1082** meters taken from the NASA GEOS-4 model elevation

Northern boundary **26**

Western boundary **-101**

Center Latitude **25.5** Longitude **-100.5**

Eastern boundary **-100**

Southern boundary **25**

Parameters for Tilted Solar Panels:

Monthly Averaged Radiation Incident On An Equator-Pointed Tilted Surface ($kWh/m^2/day$)

Lat 25.761 Lon -100.114	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
SSE HRZ	3.83	4.61	5.73	5.94	6.27	6.19	6.06	5.74	5.05	4.66	4.20	3.64	5.16
K	0.57	0.58	0.61	0.56	0.56	0.54	0.54	0.54	0.52	0.56	0.60	0.57	0.56
Diffuse	1.14	1.37	1.59	2.04	2.25	2.37	2.33	2.18	1.94	1.52	1.13	1.05	1.74
Direct	5.45	5.81	6.62	5.77	5.80	5.51	5.37	5.20	4.79	5.39	6.00	5.45	5.60
Tilt 0	3.72	4.57	5.66	5.82	6.24	6.16	6.03	5.71	4.98	4.62	4.07	3.55	5.10
Tilt 10	4.24	5.04	5.99	5.91	6.15	6.01	5.92	5.71	5.15	5.00	4.61	4.10	5.32
Tilt 25	4.82	5.51	6.22	5.80	5.77	5.55	5.51	5.49	5.19	5.35	5.21	4.74	5.43
Tilt 40	5.14	5.69	6.11	5.40	5.12	4.83	4.84	5.00	4.98	5.41	5.51	5.11	5.26
Tilt 90	4.15	4.13	3.62	2.49	2.00	1.85	1.90	2.19	2.74	3.69	4.33	4.27	3.11
OPT	5.19	5.69	6.22	5.91	6.24	6.16	6.03	5.72	5.20	5.42	5.55	5.20	5.71
OPT ANG	49.0	41.0	28.0	12.0	0.00	0.00	0.00	5.00	20.0	36.0	47.0	52.0	24.0

NOTE: *Diffuse radiation, direct normal radiation and tilted surface radiation are not calculated when the clearness index (K) is below 0.3 or above 0.8.*

Parameter Definition

Fig. 5.3 Monthly average radiation incident

Thermal performance. It represents the losses associated to the temperature affect in the panel. It is calculated using a series of formulas. The following methodology was studied from the thesis in reference [35].

$$Tp = 1 - \Delta P \tag{5.2}$$

$$\Delta P = -\frac{\partial y}{\partial x} * \frac{\Delta T}{100} \tag{5.3}$$

$$T_{cell} = T_{amb} + C_1 * G \tag{5.4}$$

$$C_1 = \frac{T_{NOCT} - 20°C}{800\, W/m^2} \tag{5.5}$$

In (5.5) is missing the value of T_{NOCT}. It is provided by the manufacturer, so in the datasheet this value is equal to 45°. The value of $C_1 = 0.03125$. The (5.4) needs the ambient temperature. This value is got with Google Earth Pro combined with a system given by CONAGUA (National Water Commission), it is Mexican organization responsible for bringing water to the cities. The Fig. 5.4 shows the nearest temperature monitoring system from the geographical location of the field.

Then in the Fig. 5.5 is the screen loaded when downloading the historical data. And the monthly maximum average temperature is 30.1° C. and G is the maximum irradiance in site. With this information $T_{cell} = 57.625°\, C$. Next the *(5.3)* is completed with two data from the datasheet. $\frac{\partial y}{\partial x}$ is the temperature losses coefficient and ΔT is the subtraction cell temperature minus T_{STC} (given in the datasheet). $\Delta P = 0.866$. Finally, *(5.2)* $Tp = 0.866$.

The previous factors, when multiplying, give the Theoretical Energy in the chart.

Real Energy. If the user has the real information of the produced energy can be write in the blank “Real Energy” and in the calculations “Theoretical Energy” will be ignored.

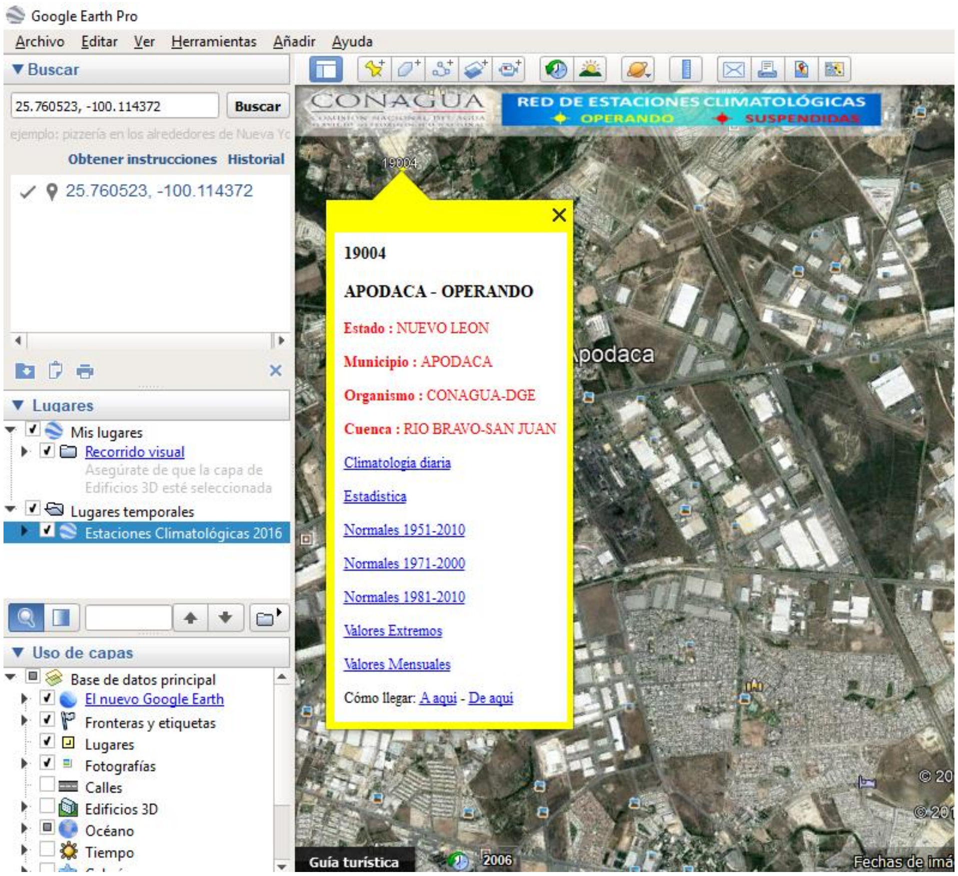
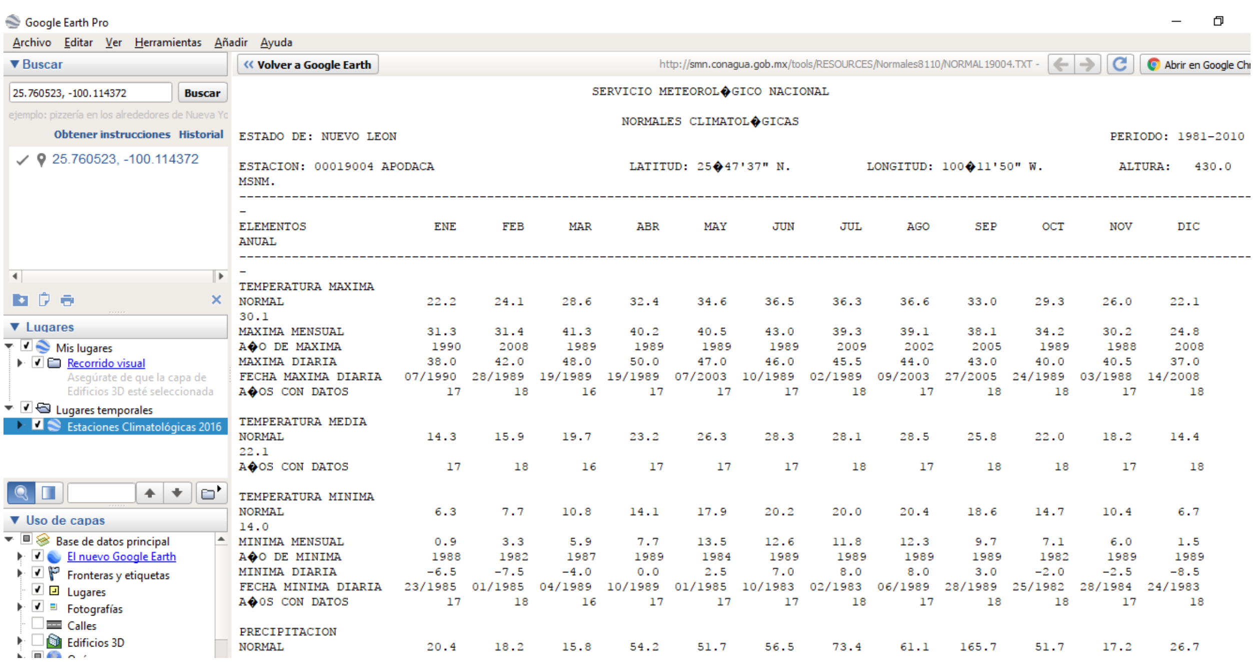


Fig. 5.4 CONAGUA Database in Google Earth



SERVICIO METEOROL�GICO NACIONAL

NORMALES CLIMATOL�GICAS

ESTADO DE: NUEVO LEON — PERIODO: 1981-2010

ESTACION: 00019004 APODACA — LATITUD: 25�47'37" N. — LONGITUD: 100�11'50" W. — ALTURA: 430.0 MSNM.

ELEMENTOS	ENE	FEB	MAR	ABR	MAY	JUN	JUL	AGO	SEP	OCT	NOV	DIC	ANUAL
TEMPERATURA MAXIMA													
NORMAL	22.2	24.1	28.6	32.4	34.6	36.5	36.3	36.6	33.0	29.3	26.0	22.1	30.1
MAXIMA MENSUAL	31.3	31.4	41.3	40.2	40.5	43.0	39.3	39.1	38.1	34.2	30.2	24.8	
A�O DE MAXIMA	1990	2008	1989	1989	1989	1989	2009	2002	2005	1989	1988	2008	
MAXIMA DIARIA	38.0	42.0	48.0	50.0	47.0	46.0	45.5	44.0	43.0	40.0	40.5	37.0	
FECHA MAXIMA DIARIA	07/1990	28/1989	19/1989	19/1989	07/2003	10/1989	02/1989	09/2003	27/2005	24/1989	03/1988	14/2008	
A�OS CON DATOS	17	18	16	17	17	17	18	17	18	18	17	18	
TEMPERATURA MEDIA													
NORMAL	14.3	15.9	19.7	23.2	26.3	28.3	28.1	28.5	25.8	22.0	18.2	14.4	22.1
A�OS CON DATOS	17	18	16	17	17	17	18	17	18	18	17	18	
TEMPERATURA MINIMA													
NORMAL	6.3	7.7	10.8	14.1	17.9	20.2	20.0	20.4	18.6	14.7	10.4	6.7	14.0
MINIMA MENSUAL	0.9	3.3	5.9	7.7	13.5	12.6	11.8	12.3	9.7	7.1	6.0	1.5	
A�O DE MINIMA	1988	1982	1987	1989	1984	1989	1989	1989	1989	1982	1989	1989	
MINIMA DIARIA	-6.5	-7.5	-4.0	0.0	2.5	7.0	8.0	8.0	3.0	-2.0	-2.5	-8.5	
FECHA MINIMA DIARIA	23/1985	01/1985	04/1989	10/1989	01/1985	10/1983	02/1983	06/1989	28/1989	25/1982	28/1984	24/1983	
A�OS CON DATOS	17	18	16	17	17	17	18	17	18	18	17	18	
PRECIPITACION													
NORMAL	20.4	18.2	15.8	54.2	51.7	56.5	73.4	61.1	165.7	51.7	17.2	26.7	

Fig. 5.5 Temperature Historical Data

Degradation. It was taken from data sheet and represents the diminution in the energy produced. With this percentage can be realize the assumption of how much energy will be produced in the following periods.

Plant use electricity. A clean energy plant can earn CEL (Certificates Clean Energy). The energy used in the electric power plant does not produce CEL. By writing 100% it means no CEL in the simulation. When this percentage is 0% means that all the produced energy produces CEL.

Economic Data

Investment. It is the total amount of money spent in the project. This quantity must be in American dollars. The sum of the loan and the capital. And in the next cells, the user should indicate the percentage of each.

Loan & Capital. It is a space where is necessary to write what percentage of the Investment was a Loan and how much came from the owner's capital. Obviously, both should sum 100%, in case it is not fulfilled, an alarm is displayed.

Maintenance & Insurance. is how much will be spent per year under these concepts. It is supposed that this bill will be increasing each year, that is the reason of the next cell, where the user can suggest an increment rate to make a projection.

Interest of the project. This percentage is defined by the investors in order to make the project attractive. It is known as MARR (Minimum Acceptable Rate of Return) and represents the discount rate at the time to calculate the net present value. By moving all the cash flow to the same time, the project will go on if the value is greater or equal to zero, otherwise will be discarded.

ISR. It is a tax according to the Mexican laws. In a published document LISR, the article 9 says that over the net revenue, will be paid 30% of taxes.

SLN "Straight Line Depreciation". It is the kind of depreciation applied in México, according to the laws, a solar field can be depreciated in one year.

The price of **CELS** and a rate to increment that price each year.

Others

Others. Sometimes it is necessary to include the cost generated by the inverters replacement. Write the amount and the year when it is going to be consider.

Energy Cost

Here the user needs to realize a projection of the energy prices along the 20 periods. By pasting the data in the column, the cash flow is being generated.

In this case, the price was taken from a published projection by SENER (Energy Secretary). The prices were calculated per hour, so the average was taken. In the Table 5.1 is shown the values taken from the document after applied the average function in Excel. The prices are in American dollars, and that is main reason the whole evaluation is done using this currency. Those prices represent the energy cost in this case was supposed that the energy cost is only the 80% of the final price; so, the price was incremented trying to get a more realistic final fare.

Fig. 5.6 is a graph with the marginal prices in Monterrey, Mexico waited from 2016 to 2033. The straight line in the graph, represents the trendline and its equation. Where the value of "x" is the period. By substituting the period number is possible to obtained mathematically, the last two values, necessary for this evaluation and missing in the projection used.

Table 5.1 Average prices from the SENER's projection

	Year	**USD $ MWh**	**USD $ kWh**
1	2016	29.23	0.02923
2	2017	36.32	0.03632
3	2018	39.27	0.03927
4	2019	37.53	0.03753
5	2020	36.94	0.03694
6	2021	36.17	0.03617
7	2022	36.49	0.03649
8	2023	39.53	0.03953
9	2024	41.41	0.04141
10	2025	42.52	0.04252
11	2026	41.41	0.04141
12	2027	41.43	0.04143
13	2028	41.79	0.04179
14	2029	41.54	0.04154
15	2030	41.59	0.04159
16	2031	41.64	0.04164
17	2032	41.59	0.04159
18	2033	41.60	0.0416
19	2034	43.96	0.04396
20	2035	44.45	0.04445

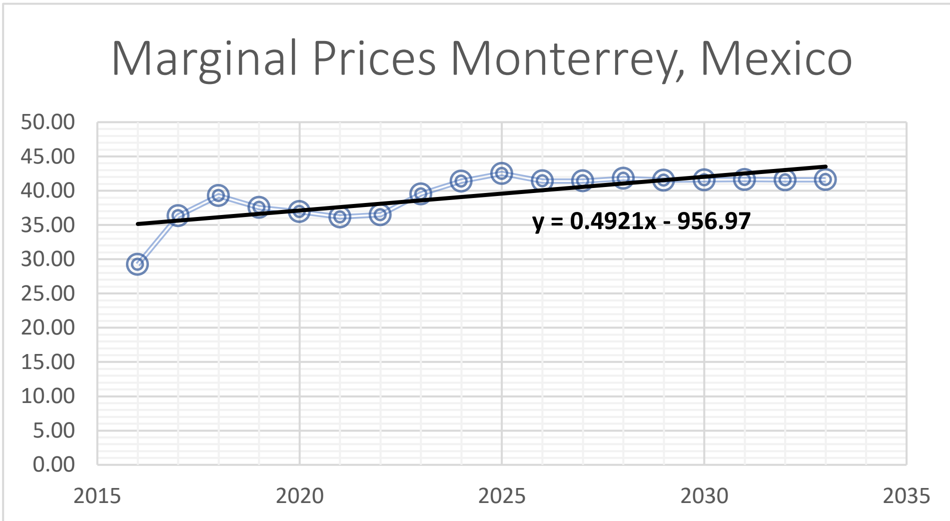


Fig. 5.6 Energy Marginal Prices vs year

Discount in total balance

This option represents a way to consider the investment if it is made for a company with big incomes.

According to the law, a company must pay the 30% of the total revenue during a specific period. The revenue is the rest of the total income minus some expenses that can be discounted to the total income. The law also says that the any solar project can be depreciated at 100%, meaning 1 period. So, the company will not pay taxes for installing an electrical energy plant.

The total cost of the project can be adding in the section of expenses when the company calculates the taxes to be paid. By doing this the net revenue will be the same minus the project's investment. Then the 30% of the cost will be an amount that the company will save in the taxes.

In the Table 5.2 there is a simplified example of the before mentioned. Supposing an income of $300,000,000.00 USD, in the case of A, the expenses in total were $500,000.00 USD and did not payed for a solar field. The net revenue is the subtraction of both, resulting $299,500,000.00 USD. The 30% of that value is equal to $89,850,000.00. The company will pay that quantity to the government. But in the case B, the expenses were $600,000.00, consequently the net revenue will be $100,000.00 USD less than the first scenario, resulting $89,820,000.00. The 30% is equal to $89,820,000.00 USD.

Can be easily detect that the difference in the taxes payment is equal to $30,000.00, corresponding to the 30% of $100,000.00. The company invested in the solar field, to get some benefits. But will also produce some energy with clean technologies and the government will support this.

So as a global view, the firm will save the 30% of the total amount expended in the construction of the Photovoltaic system. And it is a benefit that helps to reduce the payback period making more attractive the investment in projects of this nature. And it can be seen in the fourth scenario simulated in the section of result in this chapter.

Table 5.2 Tax savings

Concept	A	B
Income	$ 300,000,000.00	$ 300,000,000.00
Expenses	$ 500,000.00	$ 500,000.00
Solar field	$ -	$ 100,000.00
Net Revenue	$ 299,500,000.00	$ 299,400,000.00
Taxes	$ 89,850,000.00	$ 89,820,000.00

To apply this consideration in the evaluation, was added in the cash Flow an option where the user can check or uncheck to consider the 30% as a benefit if the company want to add it in the total annual balance.

In Fig. 5.7 and Fig. 5.8 is an aleatory example, just to show the differences in the financial indicators and graphically in the cash flow diagram. In the first the flows seem smaller because the investment is greater than in the second figure due to the discount produced by the already explained consideration.

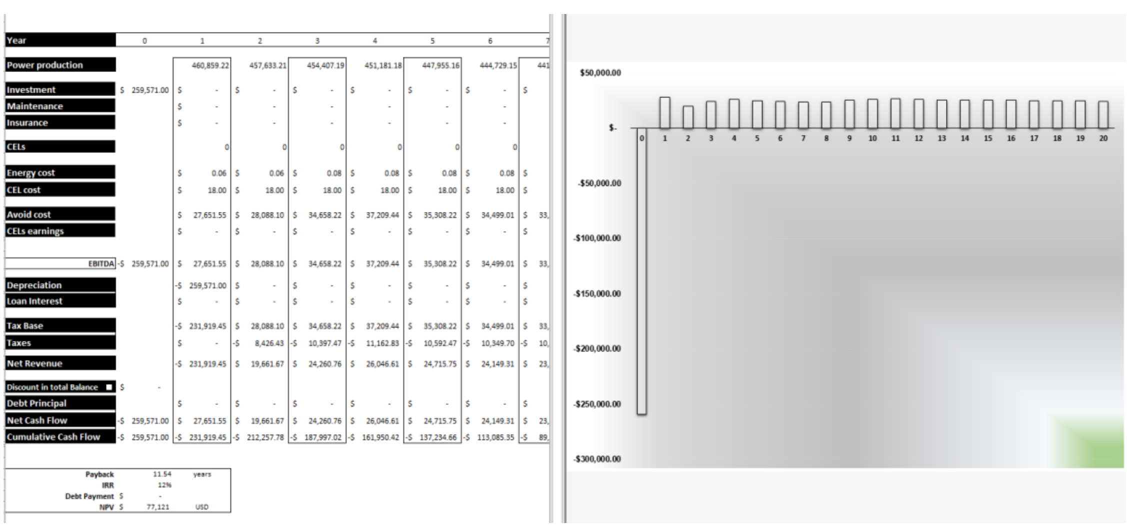


Fig. 5.7 Discount in total balance, unchecked

Year	0	1	2	3	4	5	6	7
Power production		460,859.22	457,633.21	454,407.19	451,181.18	447,955.16	444,729.15	441
Investment	$ 259,571.00	$ -	$ -	$ -	$ -	$ -	$ -	$
Maintenance		$ -	-	-	-	-	-	
Insurance		$ -	-	-	-	-	-	
CELs		0	0	0	0	0	0	
Energy cost		$ 0.06	$ 0.06	$ 0.08	$ 0.08	$ 0.08	$ 0.08	$
CEL cost		$ 18.00	$ 18.00	$ 18.00	$ 18.00	$ 18.00	$ 18.00	$
Avoid cost		$ 27,651.55	$ 28,088.10	$ 34,658.22	$ 37,209.44	$ 35,308.22	$ 34,499.01	$ 33,
CELs earnings		$ -	$ -	$ -	$ -	$ -	$ -	$
EBITDA	-$ 259,571.00	$ 27,651.55	$ 28,088.10	$ 34,658.22	$ 37,209.44	$ 35,308.22	$ 34,499.01	$ 33,
Depreciation		-$ 259,571.00	$ -	$ -	$ -	$ -	$ -	$
Loan Interest		$ -	$ -	$ -	$ -	$ -	$ -	$
Tax Base		-$ 231,919.45	$ 28,088.10	$ 34,658.22	$ 37,209.44	$ 35,308.22	$ 34,499.01	$ 33,
Taxes		$ -	-$ 8,426.43	-$ 10,397.47	-$ 11,162.83	-$ 10,592.47	-$ 10,349.70	-$ 10,
Net Revenue		-$ 231,919.45	$ 19,661.67	$ 24,260.76	$ 26,046.61	$ 24,715.75	$ 24,149.31	$ 23,
Discount in total Balance ☑	$ 77,871.30							
Debt Principal		$ -	$ -	$ -	$ -	$ -	$ -	$
Net Cash Flow	-$ 181,699.70	$ 27,651.55	$ 19,661.67	$ 24,260.76	$ 26,046.61	$ 24,715.75	$ 24,149.31	$ 23,
Cumulative Cash Flow	-$ 181,699.70	-$ 154,048.15	-$ 134,386.48	-$ 110,125.72	-$ 84,079.12	-$ 59,363.36	-$ 35,214.05	-$ 11,

Payback	8.50	years
IRR	12%	
Debt Payment	$ -	
NPV	$ 77,121	USD

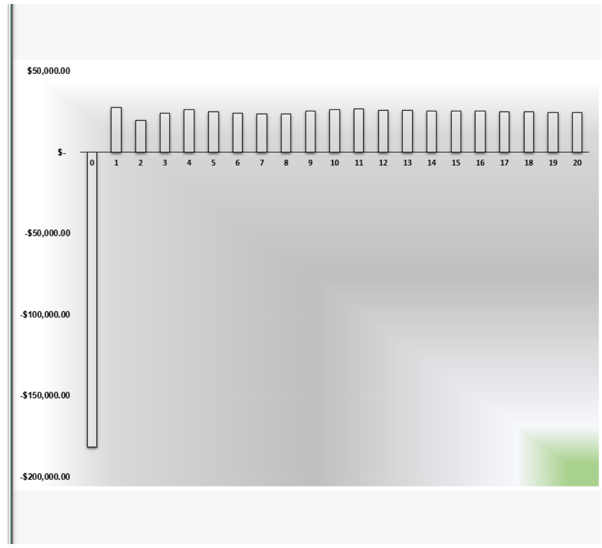


Fig. 5.8 Discount in total balance, checked

Results

With this tool can easily run many scenarios, with the intention of evaluate the solar field used in this thesis as a study case. In chapter 4, were mentioned the characteristics of this project and in the current chapter was shown how to use the tool, to evaluate the performance of a Photovoltaic System. The implementation of this method gave as output interesting results and give a clear image of the project's significant parameters for the purposes of financial analysis.

As shown before in the example, the technical data remains the same in most cases, and it was calculated as explain during this chapter, using information from datasheet like the power of the solar panel, from NASA's database the solar resource, from meteorological station installed in the surrounding area was gotten the average temperature in the place, and the use of formulas to get the thermal performance. The theoretical energy is 460,859.22 kWh/y. And also, the amount of investment is the same for every case, and it was given by Schneider.

The total amount of money is considered as 100% of capital, because to develop this solar field, half of the money were paid by the government and the other half by the company. Consequently, no considering loan periods nor loan interest.

The Interest rate is the same in all the following, is was decided in reference to the inflation in the country. An acceptable rate of return should be greater than the inflation value to be attractive. This value in Mexico is around 7%, the rate selected was 8%.

The energy cost also remains the same for all the cases. This consideration depends on the evaluator choice, and in this case the energy cost was taken from a public organization's publication SENER. It was decided to take the marginal price as energy price, but the final fare includes other considerations like distribution, for example. So, the price in that column is the result of add an extra 20% of the value.

After all those parameters were mentioned, it is important to highlight that all the estimations and considerations that result in the final indicators of the project's profitability, are fully parameterized as a result of research and were approved by the company which owns the solar field. In other words, the inputs needed lead to a specific result, any change of the initial parameters means different results.

Case number 1

The following consideration in the Table 5.3**,** were considered to analyze this case. In Fig. 5.9 is the main page where all the values were feed to obtain the following result. Fig. 5.10 and Fig. 5.11 show graphically two indicators, IRR and Payback period. Both were generated automatically generated by the tool presented in this chapter.

Table 5.3 Summarized considerations. Case 1

Concept	Consideration
Energy	Theoretical
Loan	0%
Capital	100%
Maintenance	0
Insurance	0
CEL; Price; Increment	No;0;0

Comments.

This is a simulation that can be proposed before installing the solar field. With the energy theoretical that can be supposed it will produce. And not paying a maintenance nor insurance bill and not selling CEL is the current operation of the system. Results are summarized in Table 5.4. The payback period is almost 12 years, 10 years is common value but 12 is not too bad. The IRR is 12%, with is indicator is possible say the project is profitable. And Net Present Value is positive.

This scenario is good considering that the missing concept as maintenance and insurance is an accepted risk by owners in this project.

Table 5.4 Summarized results. Case 1

Indicator	Value
Payback	11.54 Years
IRR	12%
NPV	$77,121.00 USD

Technical Data		
Power	270	kW
Solar Resource	5.4	h
Thermal Performance	0.866	
Days	365	
Theoretical Energy	460,859.22	kWh/y
Real Energy	0.00	kWh/y
Degradation	0.70%	
Plant Use Energy	0%	

Economic Data			
Investment		$259,571	USD
Loan		0%	
Capital		100%	
Loan Periods		1	Year
Loan interest		0.00%	
Maintenance	$	-	USD
Increment		0.00%	
Insurance	$	-	USD
Increment		0.00%	
Interest		8%	
ISR		30%	
SLN		1	year
CEL		0	USD
Increment		0.00%	

Others			
Inverters replacement	$	-	USD
Year?		10	

Panel Degradation		
0	460,859.22	kWh
1	457633.2055	kWh
2	454407.1909	kWh
3	451181.1764	kWh
4	447955.1618	kWh
5	444729.1473	kWh
6	441503.1328	kWh
7	438277.1182	kWh
8	435051.1037	kWh
9	431825.0891	kWh
10	428599.0746	kWh
11	425373.0601	kWh
12	422147.0455	kWh
13	418921.031	kWh
14	415695.0164	kWh
15	412469.0019	kWh
16	409242.9874	kWh
17	406016.9728	kWh
18	402790.9583	kWh
19	399564.9437	kWh
20	396338.9292	kWh

Energy Cost		
2015	0.0600	USD/kWh
2016	0.0614	USD/kWh
2017	0.0763	USD/kWh
2018	0.08247117	USD/kWh
2019	0.07882088	USD/kWh
2020	0.07757308	USD/kWh
2021	0.07596397	USD/kWh
2022	0.07663933	USD/kWh
2023	0.08300612	USD/kWh
2024	0.08695102	USD/kWh
2025	0.08929246	USD/kWh
2026	0.08695961	USD/kWh
2027	0.08699907	USD/kWh
2028	0.08775038	USD/kWh
2029	0.08723636	USD/kWh
2030	0.0873286	USD/kWh
2031	0.08743845	USD/kWh
2032	0.08733447	USD/kWh
2033	0.08736717	USD/kWh
2034	0.09231894	USD/kWh
2035	0.09335235	USD/kWh

CEL Price		
2015	0.0000	USD/CEL
2016	0.0000	USD/CEL
2017	0.0000	USD/CEL
2018	0.0000	USD/CEL
2019	0.0000	USD/CEL
2020	0.0000	USD/CEL
2021	0.0000	USD/CEL
2022	0.0000	USD/CEL
2023	0.0000	USD/CEL
2024	0.0000	USD/CEL
2025	0.0000	USD/CEL
2026	0.0000	USD/CEL
2027	0.0000	USD/CEL
2028	0.0000	USD/CEL
2029	0.0000	USD/CEL
2030	0.0000	USD/CEL
2031	0.0000	USD/CEL
2032	0.0000	USD/CEL
2033	0.0000	USD/CEL
2034	0.0000	USD/CEL
2035	0.0000	USD/CEL

Fig. 5.9 Case 1 Data input

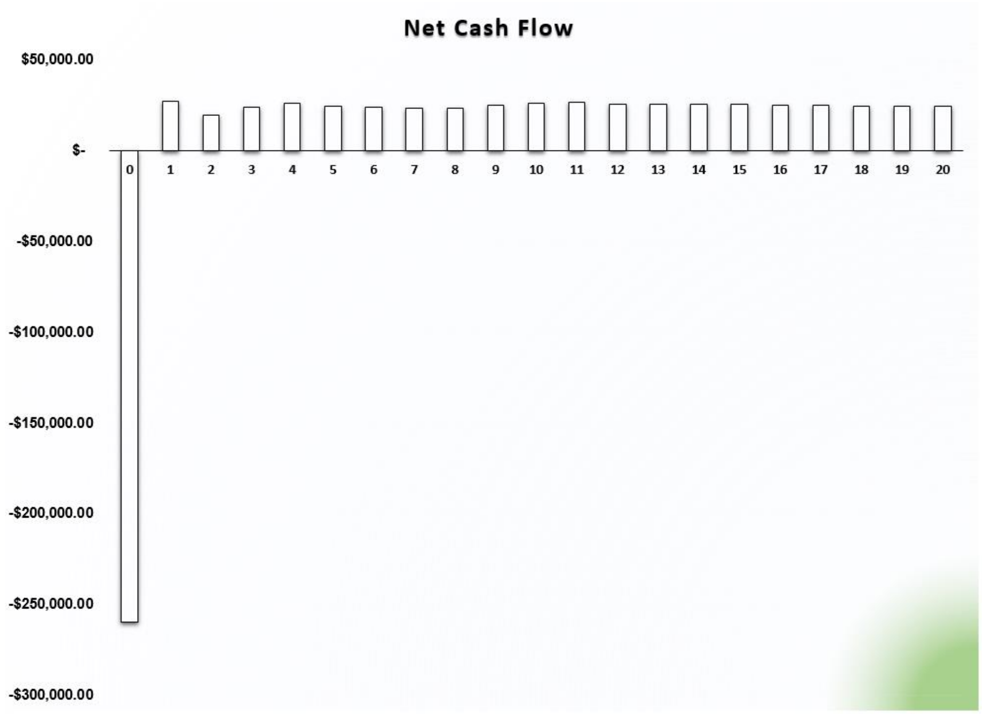


Fig. 5.10 Case 1 Net cash flow

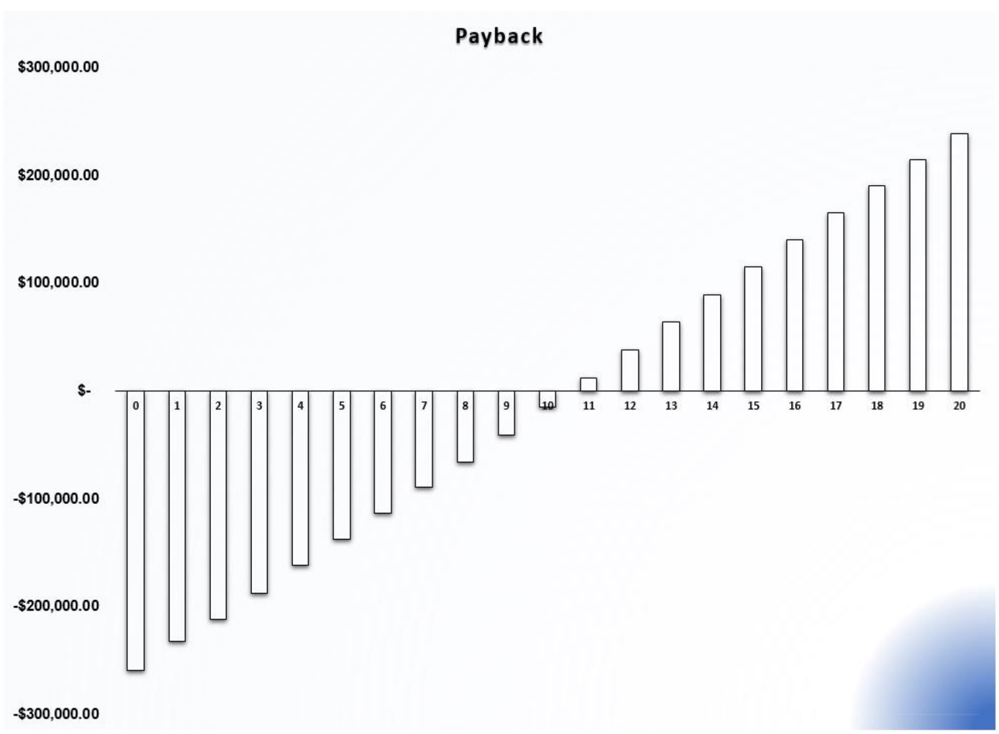


Fig. 5.11 Case 1 Payback

Case number 2

The real energy is being measured during the time the solar field is being working. Table 5.5 shows the reported values. Some sections were hidden for space reason, but the kWh related to the solar production were averaged. And then the average of the three values were taken as real energy in this case, to be able to make the projection, and assume that the degradation of the panel is as the datasheet says.

Anyway, this value is almost the half of the energy calculated. And the main reason is that this field was created only for technical research purposes. The measurement has been made, but some studies realized in the field needs to cover some panels or disconnected a whole line to analyze the performance of a single inverter. Examples like the already mentioned has affect to that measured, and in this case, is going to be analyzed if as an energy business, is profitable or not.

Table 5.5 Average energy produce

	ene-15	dic-15	ene-16	dic-16	ene-17	dic-17	
Total Energy	129,019	130,931	136,781	137,448	144,931	123,949	
Average per Y		261,813		256,963		271,059	263,278

The following consideration in the Table 5.6**,** were considered to analyze this case. In Fig. 5.12 is the main page where all the values were feed to obtain the following result. Fig. 5.13 and Fig. 5.14 show graphically two indicators, IRR and Payback period. Both were generated automatically generated by the tool presented in this chapter.

Table 5.6 Summarized considerations. Case 2

Concept	Consideration
Energy	Real
Loan	0%
Capital	100%
Maintenance	0
Insurance	0
CEL; Price; Increment	No;0;0

Comments.

In contrast to the first case, here is used the real measured energy. As mentioned in the beginning of this case, the energy is almost half of the calculated. The found reasons to explain this are that the inverters were prototype and frequently disconnected to fix settings or analyzed the performance isolated. Also, there was another research that implied to cover some panels in a string and take measures.

In Table 5.7 are summarized the values of the financial indicators. And the payback period is near of the end of the project, 20 years, the IRR is low, and the Net Present Value is negative. For the company is doesn´t represents a problem because they use the field for research purposes and some products are test in there and some developments are based in it. At the end of the day that represents greater earnings and knowledge.

Table 5.7 Summarized results. Case 2

Indicator	Value
Payback	19.20 Years
IRR	4%
NPV	-$67,227 USD

Technical Data		
Power	270	kW
Solar Resource	5.4	h
Thermal Performance	0.866	
Days	365	
Theoretical Energy	460,859.22	kWh/y
Real Energy	263,278.00	kWh/y
Degradation	0.70%	
Plant Use Energy	0%	

Economic Data			
Investment		$259,571	USD
Loan		0%	
Capital		100%	
Loan Periods		1	Year
Loan interest		0.00%	
Maintenance	$	-	USD
Increment		0.00%	
Insurance	$	-	USD
Increment		0.00%	
Interest		8%	
ISR		30%	
SLN		1	year
CEL		0	USD
Increment		0.00%	

Others			
Inverters replacement	$	-	USD
Year?		10	

Panel Degradation		
0	263,278.00	kWh
1	261435.054	kWh
2	259592.108	kWh
3	257749.162	kWh
4	255906.216	kWh
5	254063.27	kWh
6	252220.324	kWh
7	250377.378	kWh
8	248534.432	kWh
9	246691.486	kWh
10	244848.54	kWh
11	243005.594	kWh
12	241162.648	kWh
13	239319.702	kWh
14	237476.756	kWh
15	235633.81	kWh
16	233790.864	kWh
17	231947.918	kWh
18	230104.972	kWh
19	228262.026	kWh
20	226419.08	kWh

Energy Cost		
2015	0.0600	USD/kWh
2016	0.0614	USD/kWh
2017	0.0763	USD/kWh
2018	0.08247117	USD/kWh
2019	0.07882088	USD/kWh
2020	0.07757308	USD/kWh
2021	0.07596397	USD/kWh
2022	0.07663933	USD/kWh
2023	0.08300612	USD/kWh
2024	0.08695102	USD/kWh
2025	0.08929246	USD/kWh
2026	0.08695961	USD/kWh
2027	0.08699907	USD/kWh
2028	0.08775038	USD/kWh
2029	0.08723636	USD/kWh
2030	0.0873286	USD/kWh
2031	0.08743845	USD/kWh
2032	0.08733447	USD/kWh
2033	0.08736717	USD/kWh
2034	0.09231894	USD/kWh
2035	0.09335235	USD/kWh

CEL Price		
2015	0.0000	USD/CEL
2016	0.0000	USD/CEL
2017	0.0000	USD/CEL
2018	0.0000	USD/CEL
2019	0.0000	USD/CEL
2020	0.0000	USD/CEL
2021	0.0000	USD/CEL
2022	0.0000	USD/CEL
2023	0.0000	USD/CEL
2024	0.0000	USD/CEL
2025	0.0000	USD/CEL
2026	0.0000	USD/CEL
2027	0.0000	USD/CEL
2028	0.0000	USD/CEL
2029	0.0000	USD/CEL
2030	0.0000	USD/CEL
2031	0.0000	USD/CEL
2032	0.0000	USD/CEL
2033	0.0000	USD/CEL
2034	0.0000	USD/CEL
2035	0.0000	USD/CEL

Fig. 5.12 Case 2 Data input

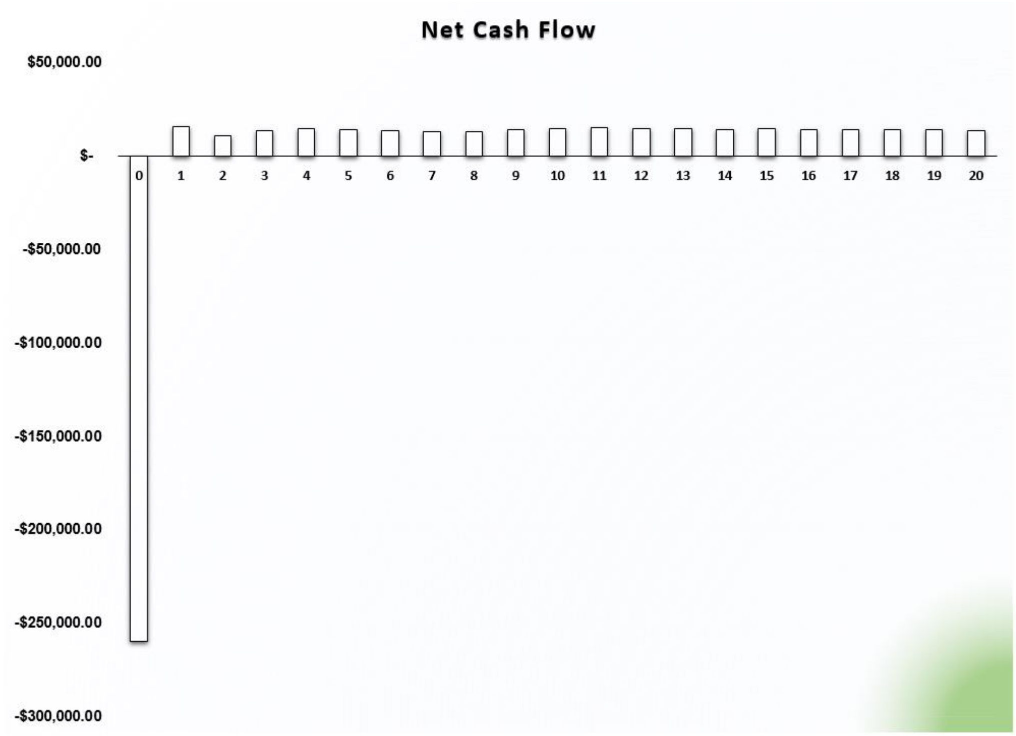


Fig. 5.13 Case 2 Net cash flow

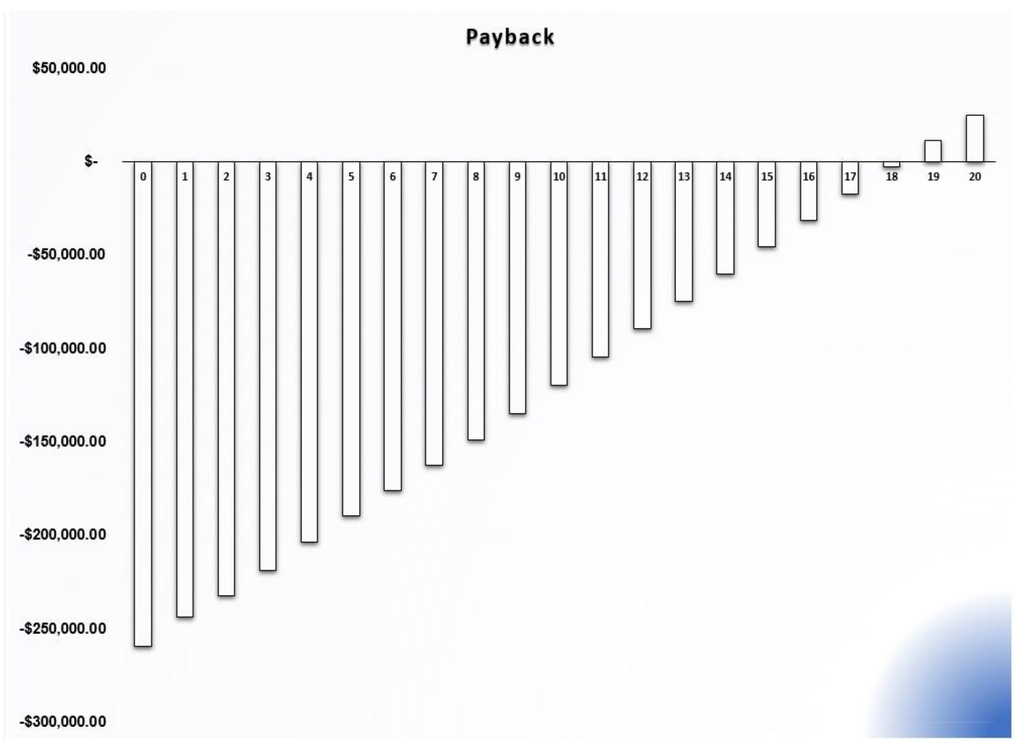


Fig. 5.14 Case 2 Payback

Case number 3

The following consideration in the Table 5.8**,** were considered to analyze this case. In Fig. 5.15 is the main page where all the values were feed to obtain the following result. Fig. 5.16 and Fig. 5.17 show graphically two indicators, IRR and Payback period. Both were generated automatically generated by the tool presented in this chapter.

Table 5.8 Summarized considerations. Case 3

Concept	Consideration
Energy	Theoretical
Loan	0%
Capital	100%
Maintenance	$1,350.00
Insurance	$25,960.00
CEL; Price; Increment	Yes; $18;0

Comments.

Using again the theoretical value of energy but including the most recommend services like Maintenance and Insurance and considering the sale of CEL at $ 18.00 USD with an increment rate.

The Table 5.9 summarized the indicators value and is clear that good values were obtained. First of all, the sale of CEL is an extra income. Even that every year has to be aid for both services (Maintenance and Insurance) the IRR is equal to 14% and the Payback period is 10 years with a positive Net Present Value at the end of the project.

Concluding that if the price of CEL keeps a near value of the supposed here, is a good alternative to motivate the investment in clean energy generation. Not only economics benefits but environmental that helps everyone.

Table 5.9 Summarized results. Case 3

Indicator	Value
Payback	9.98 Years
IRR	14%
NPV	$130,531.00 USD

Technical Data		
Power	270	kW
Solar Resource	5.4	h
Thermal Performance	0.866	
Days	365	
Theoretical Energy	460,859.22	kWh/y
Real Energy	0.00	kWh/y
Degradation	0.70%	
Plant Use Energy	0%	

Economic Data		
Investment	$259,571	USD
Loan	0%	
Capital	100%	
Loan Periods	1	Year
Loan interest	0.00%	
Maintenance	$ 1,350.00	USD
Increment	7.50%	
Insurance	$ 26,000.00	USD
Increment	7.50%	
Interest	8%	
ISR	30%	
SLN	1	year
CEL	18	USD
Increment	0.00%	

Others		
Inverters replacement	$ -	USD
Year?	10	

Panel Degradation		
0	460,859.22	kWh
1	457633.2055	kWh
2	454407.1909	kWh
3	451181.1764	kWh
4	447955.1618	kWh
5	444729.1473	kWh
6	441503.1328	kWh
7	438277.1182	kWh
8	435051.1037	kWh
9	431825.0891	kWh
10	428599.0746	kWh
11	425373.0601	kWh
12	422147.0455	kWh
13	418921.031	kWh
14	415695.0164	kWh
15	412469.0019	kWh
16	409242.9874	kWh
17	406016.9728	kWh
18	402790.9583	kWh
19	399564.9437	kWh
20	396338.9292	kWh

Energy Cost		
2015	0.0600	USD/kWh
2016	0.0614	USD/kWh
2017	0.0763	USD/kWh
2018	0.08247117	USD/kWh
2019	0.07882088	USD/kWh
2020	0.07757308	USD/kWh
2021	0.07596397	USD/kWh
2022	0.07663933	USD/kWh
2023	0.08300612	USD/kWh
2024	0.08695102	USD/kWh
2025	0.08929246	USD/kWh
2026	0.08695961	USD/kWh
2027	0.08699907	USD/kWh
2028	0.08775038	USD/kWh
2029	0.08723636	USD/kWh
2030	0.0873286	USD/kWh
2031	0.08743845	USD/kWh
2032	0.08733447	USD/kWh
2033	0.08736717	USD/kWh
2034	0.09231894	USD/kWh
2035	0.09335235	USD/kWh

CEL Price		
2015	18.0000	USD/CEL
2016	18.0000	USD/CEL
2017	18.0000	USD/CEL
2018	18.0000	USD/CEL
2019	18.0000	USD/CEL
2020	18.0000	USD/CEL
2021	18.0000	USD/CEL
2022	18.0000	USD/CEL
2023	18.0000	USD/CEL
2024	18.0000	USD/CEL
2025	18.0000	USD/CEL
2026	18.0000	USD/CEL
2027	18.0000	USD/CEL
2028	18.0000	USD/CEL
2029	18.0000	USD/CEL
2030	18.0000	USD/CEL
2031	18.0000	USD/CEL
2032	18.0000	USD/CEL
2033	18.0000	USD/CEL
2034	18.0000	USD/CEL
2035	18.0000	USD/CEL

Fig. 5.15 Case 3 Data input

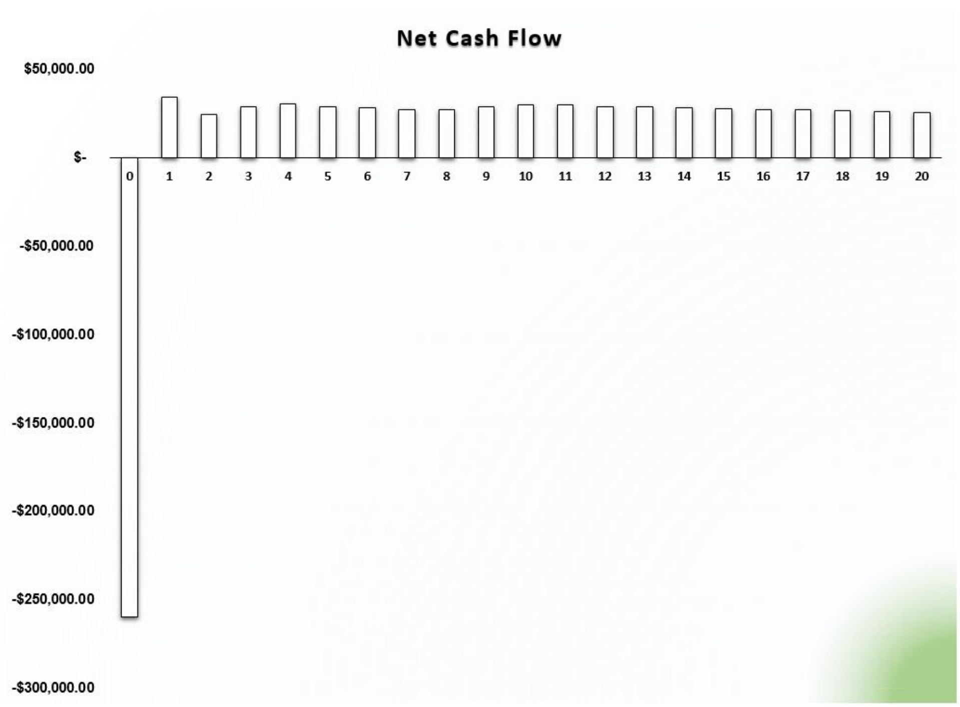


Fig. 5.16 Case 3 Net cash flow

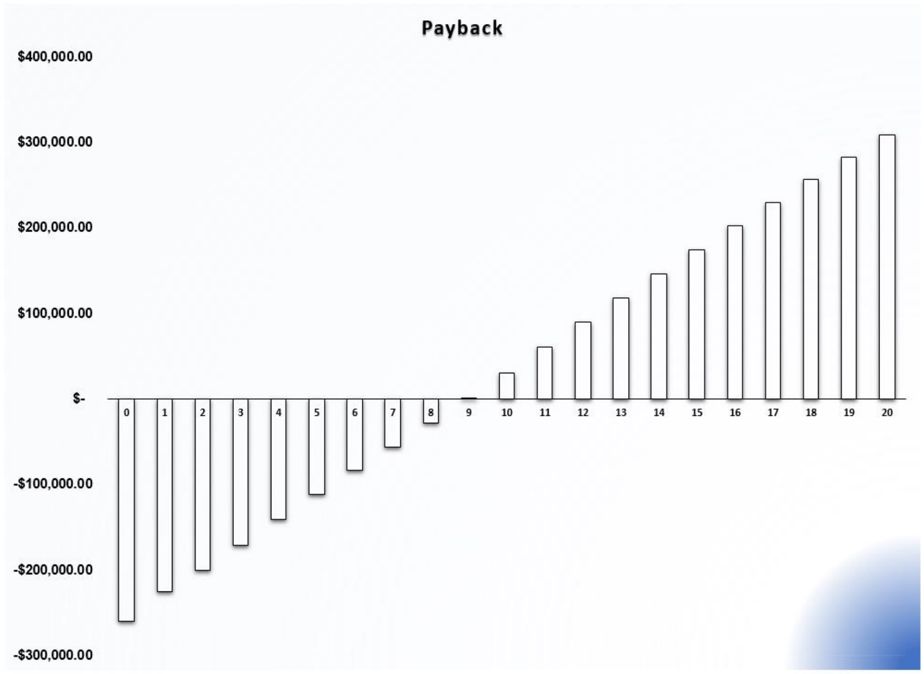


Fig. 5.17 Case 3 Payback

Case number 4

The following consideration in the Table 5.10**,** were considered to analyze this case. In Fig. 5.18 is the main page where all the values were feed to obtain the following result. Fig. 5.19 and Fig. 5.20 show graphically two indicators, IRR and Payback period. Both were generated automatically generated by the tool presented in this chapter.

Table 5.10 Summarized considerations. Case 4

Concept	Consideration
Energy	Theoretical
Loan	0%
Capital	100%
Maintenance	$1,350.00
Insurance	$25,960.00
CEL; Price; Increment	Yes; $18;0
Others; period	$20,0;10
Discount in total balance	yes

Comments.

The last case reported in this work is almost equal as the third. The difference is that the "Discount in total balance" was checked. Assuming that the firm is solvent enough, and that the cost of the entire project is less that the annual income.

The theoretical value of energy, maintenance and insurance paid, sale of CEL. The Table 5.11 summarize the results. The payback period is extremely short. The IRR is good and the Net Present Value ins acceptable.

With this exercise is demonstrate how legal stimulus giving by the government, can impulse the development of similar projects, helping to reduce some of the problems bring by the fossil fuels technologies.

Table 5.11 Summarized results. Case 4

Indicator	Value
Payback	7.21 Years
IRR	14%
NPV	$128,215.00 USD

Technical Data		
Power	270	kW
Solar Resource	5.4	h
Thermal Performance	0.866	
Days	365	
Theoretical Energy	460,859.22	kWh/y
Real Energy	0.00	kWh/y
Degradation	0.70%	
Plant Use Energy	0%	

Economic Data		
Investment	$259,571	USD
Loan	0%	
Capital	100%	
Loan Periods	1	Year
Loan interest	0.00%	
Maintenance	$ 1,350.00	USD
Increment	7.50%	
Insurance	$ 26,000.00	USD
Increment	7.50%	
Interest	8%	
ISR	30%	
SLN	1	year
CEL	18	USD
Increment	0.00%	

Others		
Inverters replacement	$ 5,000.00	USD
Year?	10	

Panel Degradation		
0	460,859.22	kWh
1	457633.2055	kWh
2	454407.1909	kWh
3	451181.1764	kWh
4	447955.1618	kWh
5	444729.1473	kWh
6	441503.1328	kWh
7	438277.1182	kWh
8	435051.1037	kWh
9	431825.0891	kWh
10	428599.0746	kWh
11	425373.0601	kWh
12	422147.0455	kWh
13	418921.031	kWh
14	415695.0164	kWh
15	412469.0019	kWh
16	409242.9874	kWh
17	406016.9728	kWh
18	402790.9583	kWh
19	399564.9437	kWh
20	396338.9292	kWh

Energy Cost		
2015	0.0600	USD/kWh
2016	0.0614	USD/kWh
2017	0.0763	USD/kWh
2018	0.08247117	USD/kWh
2019	0.07882088	USD/kWh
2020	0.07757308	USD/kWh
2021	0.07596397	USD/kWh
2022	0.07663933	USD/kWh
2023	0.08300612	USD/kWh
2024	0.08695102	USD/kWh
2025	0.08929246	USD/kWh
2026	0.08695961	USD/kWh
2027	0.08699907	USD/kWh
2028	0.08775038	USD/kWh
2029	0.08723636	USD/kWh
2030	0.0873286	USD/kWh
2031	0.08743845	USD/kWh
2032	0.08733447	USD/kWh
2033	0.08736717	USD/kWh
2034	0.09231894	USD/kWh
2035	0.09335235	USD/kWh

CEL Price		
2015	18.0000	USD/CEL
2016	18.0000	USD/CEL
2017	18.0000	USD/CEL
2018	18.0000	USD/CEL
2019	18.0000	USD/CEL
2020	18.0000	USD/CEL
2021	18.0000	USD/CEL
2022	18.0000	USD/CEL
2023	18.0000	USD/CEL
2024	18.0000	USD/CEL
2025	18.0000	USD/CEL
2026	18.0000	USD/CEL
2027	18.0000	USD/CEL
2028	18.0000	USD/CEL
2029	18.0000	USD/CEL
2030	18.0000	USD/CEL
2031	18.0000	USD/CEL
2032	18.0000	USD/CEL
2033	18.0000	USD/CEL
2034	18.0000	USD/CEL
2035	18.0000	USD/CEL

Fig. 5.18 Case 4 Data input

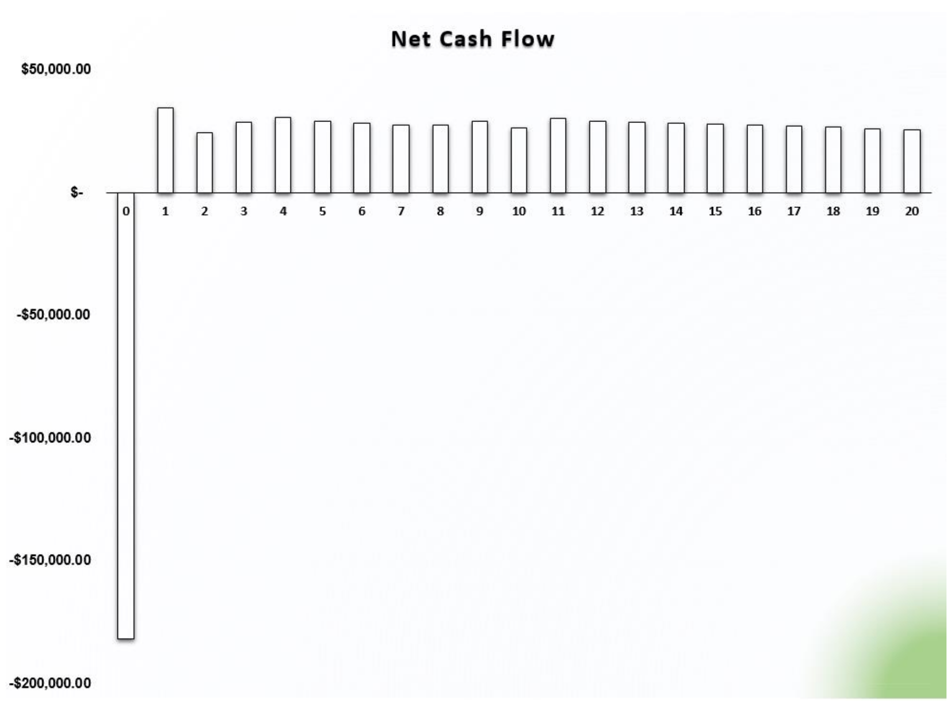


Fig. 5.19 Case 4 Net cash flow

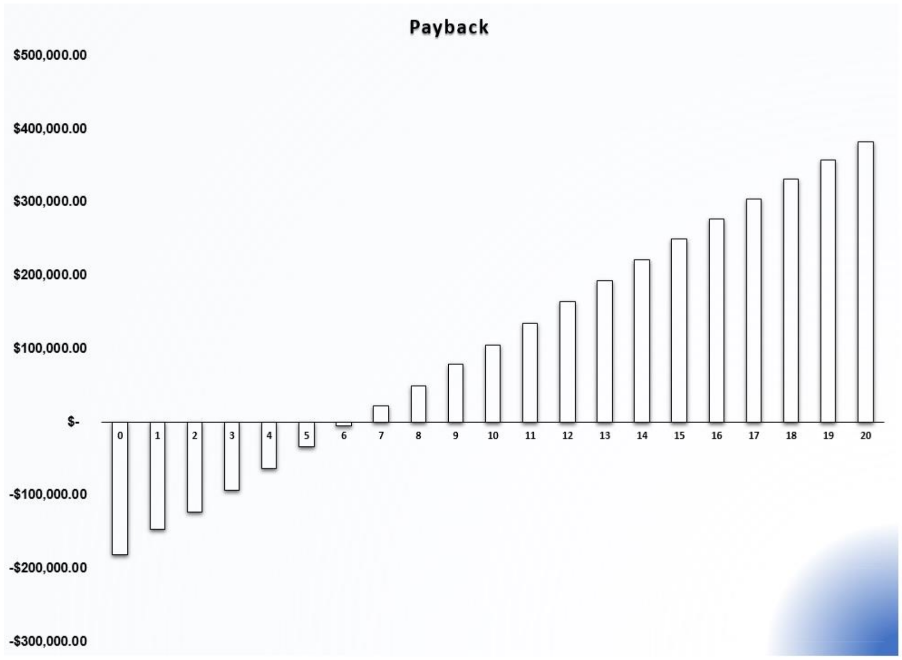


Fig. 5.20 Case 4 Payback

Chapter 6 Technical Evaluation

In this chapter are presented two tools developed to process the information downloaded from the monitoring system in the study case of this project. The first tool was made in Matlab and offers to the user the facility to graph the production reporter daily. The inverter software can also graph, the difference in here is that if the user downloaded the information could see the performance of any day since the system was install, and this tool can also overlap two days that can be consecutives or the same day in different year or random days. The user can also view the energy graph per hour and the total energy produced, or a graph of power versus time.

In contrast the second tool was developed in Visual Basic, and this one is used when analyzing a month, not a day. The information downloaded by the user is a comma separated values file (.csv) that can be easily processed by Excel. This program merge in the same book all the days per pages of a main Excel's book. In the first page the user will find a summary, because each day is analyzed according to the user's selections and the maximum values per day are presented together to be compared.

Detailed information is necessary when a solar field is built for research, like the one in this project. That is why those tools deal with measurements made per minute, but if the information was got each fifteen the programs recognized it and proceed the same way.

Daily Operation Data

The equipment used for monitoring the park's performance is named "SMARTBOX" made by Schneider. This equipment measure power, wind speed, irradiance and temperature. The report containing data per minute can be download if the file is saved before midnight, after that the offered information is data taken each fifteen minute. The last-mentioned file is available per 30 days before been discard automatically. In other words, having a "per minute" file, there are almost 1400 measurements that can be downloaded before 23:59 hours. The next day is possible download other lighter version with data taken each fifteen minutes, resulting a file with 96 measurements.

The solar production must be analyzed but not precisely every day. Is very useful to have previous information and available to check over and compare in order to understand the performance of this technology. That is the main reason a MATLAB application was developed to allow the user to manage the data files with the extension .csv, calculating the energy per day and generating graphs to see the solar resource graphically.

When graphing the data coming from a fifteen minutes file, the result is a points connection draw. Generating an unattractive graph and a behavior far from reality. Through a cubic splines interpolation, is pretended to a rounded shape between each point; this will give a better figure and near the representation to a more natural behavior without affecting the energy calculations when changing the shape.

Current software

A Graphic User Interface was developed in MATLAB to be used by the researchers in charge of the solar field project. This software is able to manage a big number of files, making it easier to find a specific day available in the folder. Once a day has been chosen the user can analyze the whole day, get information about the produced energy and the hour of the day when the production was greater.

All the downloaded files must be saved in the same folder to use the software. It is recommended to put the folder in an easy access route, because all the next downloaded files from the SmartBox must be in there. As an example, in the Fig. 6.1 a folder with data from august is shown.

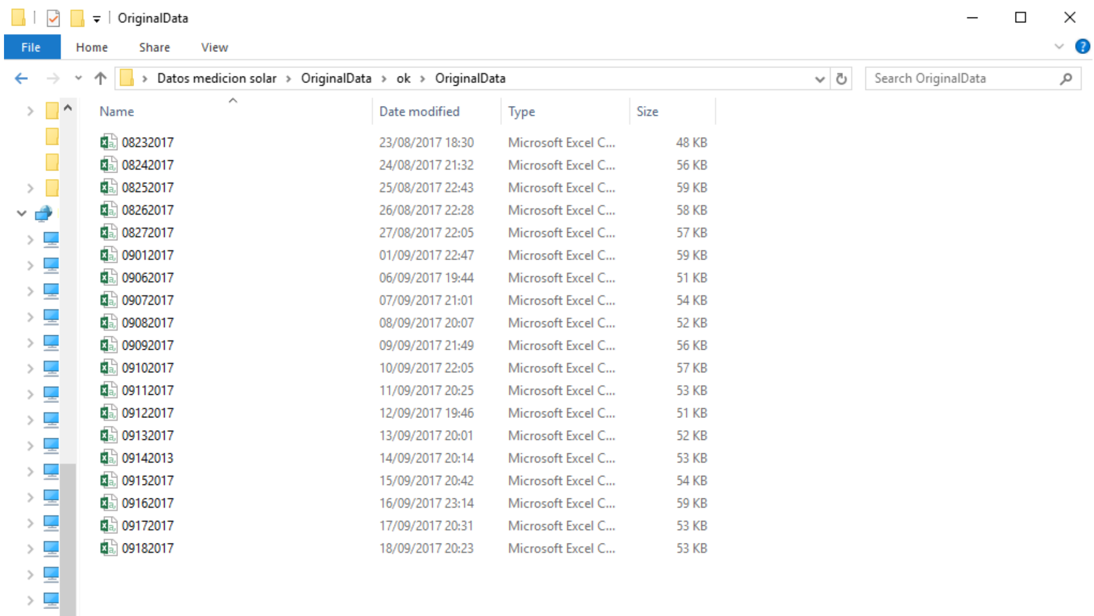


Fig. 6.1 Available data

Click on the icon to start the program. If the user has the complete version of MATLAB installed in the computer, the application will run without a problem. Otherwise will be necessary having a MATLAB Runtime. It can be downloaded freely from internet. The executable icon is shown in Fig. 6.2, by clicking the program will run.

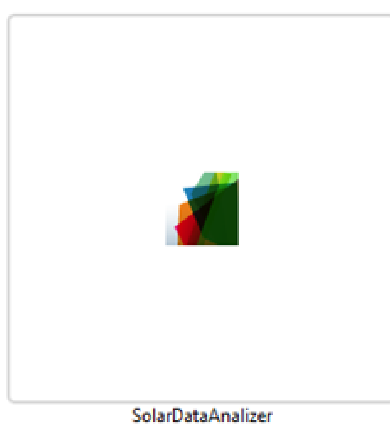


Fig. 6.2 Application icon

Once the application has been started, the graphic interface shown in Fig. 6.3 is loaded on the screen. First, it is necessary to indicate where all the files are. By doing this the software will search in this route when a date is request. This configuration is made clicking on "Choose the folder with the information" button.

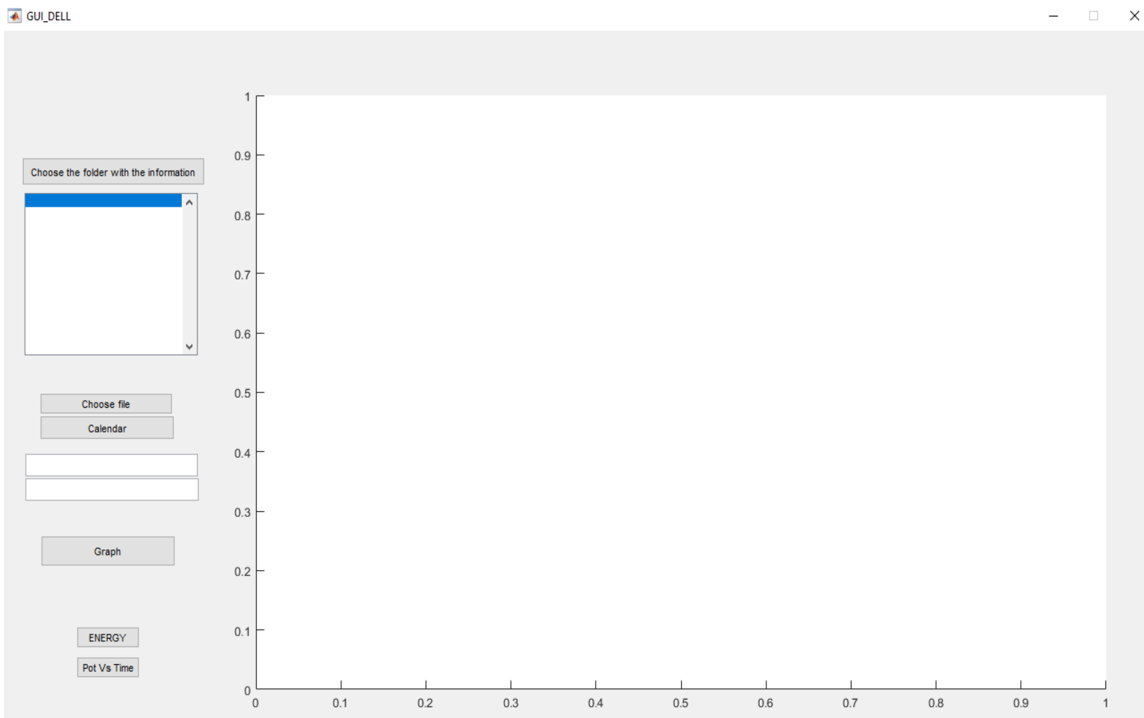


Fig. 6.3 Graphic User Interface

After the folder is chosen, the algorithm makes sure all the files were saved correctly. So, an initial routine oversees verifying each single file in the folder. They will be open, read and the file´s name will be the date wrote in the first column plus a root which indicate to the routine that the current file was already renamed and not losing time again. It is a good practice when new files are added. In Fig. 6.4 can be seen the files found in the selected route with the name changed.

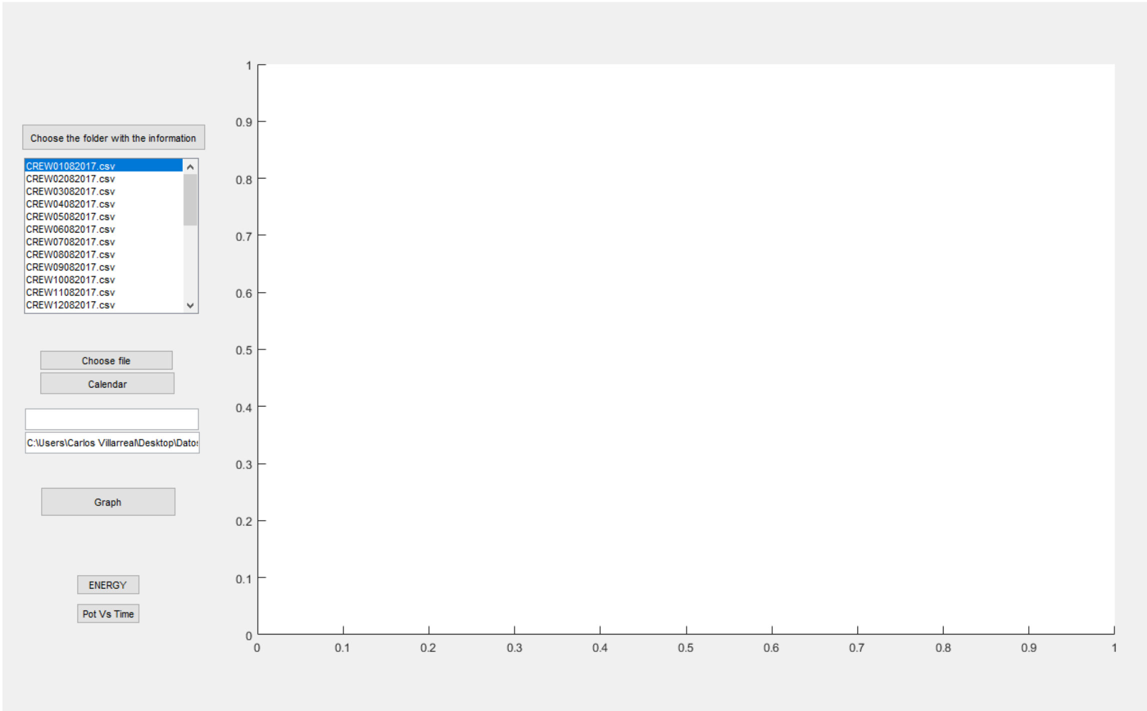


Fig. 6.4 Found files

To see a graph of the specific day, exist three ways to realize the task.

1. Chose the file directly from the list. It can be done if the user knows the name or if it is at the top, eventually this list will be long because each file represents a day.
2. Click on "Calendar" button. This will open a pop up calendar where the user can select a date. The routine will search and if the file exists, a graph will be display in the designated area.
3. "Choose file" button. This option can be used when the file is new, but this option can be used to graph two days in the same space to compare.

In the Fig. 6.5 a graph was generated from August 26, 2017. Can be seen in the lower right corner appears an indicator if the data was taken per minute or per fifteen minutes. The graph is little esthetic and not natural because the points were united by straight lines. Furthermore, in the Fig. 6.6 is shown the same day, but with information of fifteen minutes and 1 minute. Evidently, the fifteen minutes graph has lees information than the one minute graph, but is more probable having the fifteen minutes file.

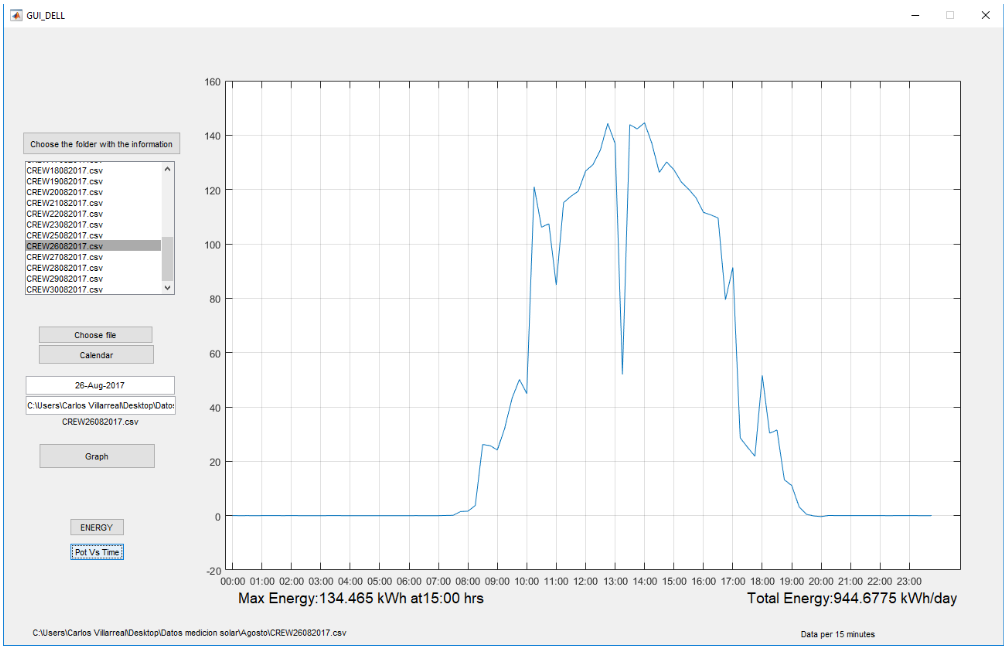


Fig. 6.5 August 26 graph

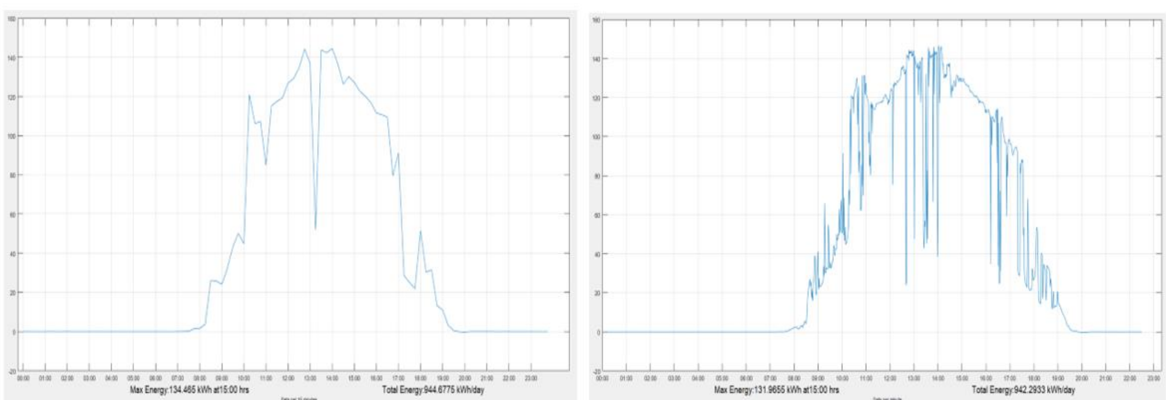


Fig. 6.6 Comparison graph. 15 minutes files (left). 1 minute file (rigth)

Cubic Splines Application with MATLAB

To give a plus to the program which graphs the information generated by the solar field, is wanted that the graphic produced with information taken each fifteen minutes looks rounded lines instead of straight ones. By doing this the graphic look better, the energy calculations are nearer from the one minute result and represent a more natural behavior.

The applied method is called "Cubic Splines". This interpolation method gets new points mathematically between two real values. That is made by getting the coefficients of a third-grade equation for each pair of real values. As mentioned before a file with fifteen minutes information has 96 real values, with this tool will be graph 1440 values as in the graphic draw from a one minute file.

The first step was to develop a new shorter software where the method is tested. The development algorithm to test the method follow the next logic sequence.

1. To show to the user all the available files with the fifteen minutes information and requires a file to be chosen, from the existent ones. In the Fig. 6.7 is shown that when the program is executed, asks for the file.

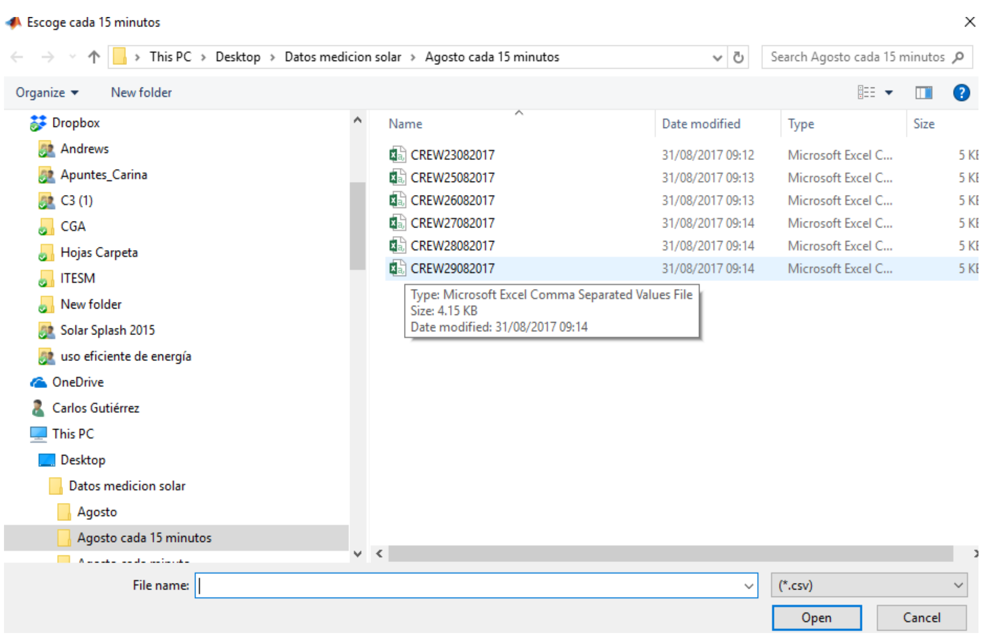


Fig. 6.7 Available 15 minutes data

2. The calculation of the area under the curve is made with function "*Trapz*", from the original information. With this function, MATLAB makes trapezoid and calculate the area of each element. It gives an acceptable value and this step is done to be compare with the following calculation´s results applying cubic spines. In the Fig. 6.8 is possible to see the MATLAB Command Window with the first result.

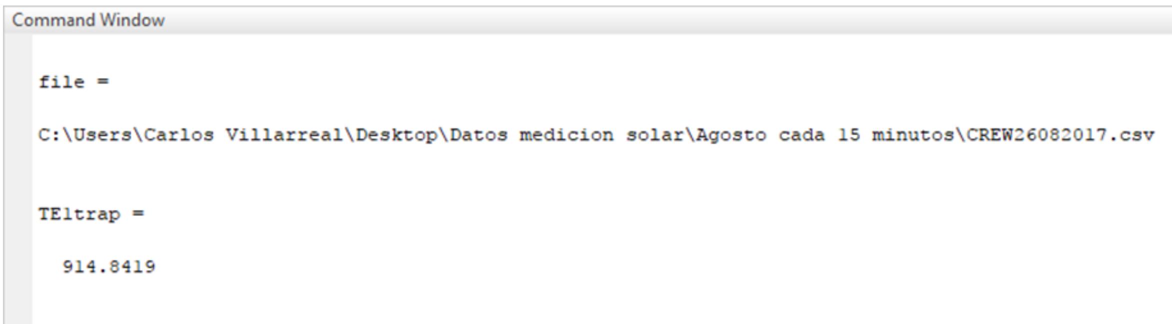


Fig. 6.8 Energy from the original data

3. Applied the cubic splines method, with the function *"Spines"* in MATLAB. The information composed by 96 measurement points (24 hours, 4 measurements per hour), through a cubic interpolation, draw a graph using 1440 points (24 hours, 60 per minute). New data is obtained, new graph is drawn, and the energy is calculated again with same function "*Trapz".* In the Fig. 6.9 is shown the TE2trap that means: Total Energy 2 *Trapz.*

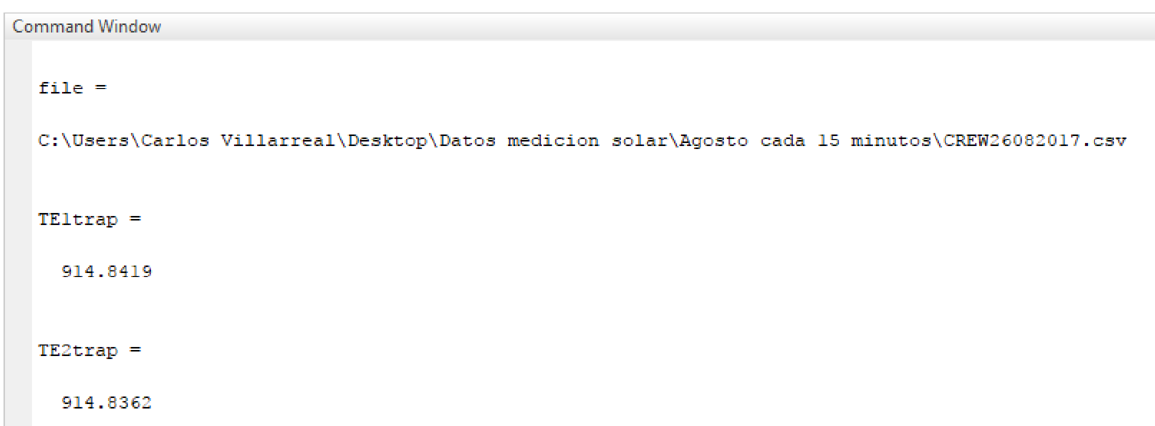


Fig. 6.9 Second calculation

4. With the function *"Spines"* is possible to obtain the coefficients for each variable of each pair of real values. MATLAB gives a matrix with 4 columns: a, b, c and d. The Fig. 6.10 is a screenshot with those coefficients.

```
Command Window

cof =

   1.0e+03 *

   -0.0023    0.0023   -0.0006    0.0000
   -0.0023    0.0006    0.0001   -0.0000
    0.0030   -0.0011   -0.0000         0
   -0.0019    0.0011   -0.0000   -0.0000
   -0.0002   -0.0003    0.0002         0
    0.0007   -0.0005   -0.0000    0.0000
    0.0010    0.0000   -0.0001         0
   -0.0026    0.0008    0.0001   -0.0000
    0.0022   -0.0011    0.0000    0.0000
   -0.0007    0.0005   -0.0001   -0.0000
   -0.0001    0.0000    0.0000   -0.0000
    0.0005   -0.0001   -0.0000   -0.0000
   -0.0006    0.0003    0.0000   -0.0000
   -0.0004   -0.0001    0.0001         0
    0.0008   -0.0004   -0.0000    0.0000
    0.0001    0.0002   -0.0001   -0.0000
   -0.0005    0.0003    0.0000   -0.0000
   -0.0001   -0.0001    0.0000   -0.0000
    0.0007   -0.0002   -0.0000   -0.0000
   -0.0008    0.0004    0.0000   -0.0000
    0.0005   -0.0002    0.0000   -0.0000
```

Fig. 6.10 Energy from the original data

5. According with the specification of the function in MATLAB, the equation follow the next form: f(x)=a(x - x1)3+b(x - x1)2+c(x - x1)+d. By integrating and evaluating with each row of the matrix is possible to obtain the area under the curve for each small section created between two real points. All added is the total energy. In Fig. 6.11 is shown the code where the equation is evaluated 95 times.

```
%Calcular los coeficientes = [a,b,c,d]
pp = spline(x,y);
cof=pp.coefs

%Evaluar la derivada de f(x)=a(x - x1)3+b(x - x1)2+c(x - x1)+d

acum=0;
for i=1:95

  acum= (cof(i,4)*(x(i+1)-x(i)) + (cof(i,3)*((x(i+1)-x(i))^2))/2 +...
  (cof(i,2)*((x(i+1)-x(i))^3))/3 + (cof(i,1)*((x(i+1)-x(i))^4)/4)) + acum;

end
TE2coef=acum
```

Fig. 6.11 Evaluate 95 times

6. Now the user must choose from the option, the same day but the information per minute. Thus, both graph can be compare with the aim to see the differences and validate that the method is giving coherent information.
7. Finally, is shown a window divided in three. The first place is taken by graphic generated with one minute information. The second with fifteen minutes information and the third the new result of the interpolation applying cubic spines method. Another window will show the three graphs overlapped.

In Fig. 6.12 are shown the three graphs overlapped. With a solid line appears the graph with one minute information. The fifteen minutes information are marked with points. The new result is represented with a dotted line, showing the result of the interpolation.

In Fig. 6.13 are the same graphs separately. In the first site was collocated the one minute information result. In the second place the graph with fifteen minutes information. And at the bottom is the one draw with the cubic spines interpolation. Furthermore, in the header of each graph was wrote the result of the energy calculation.

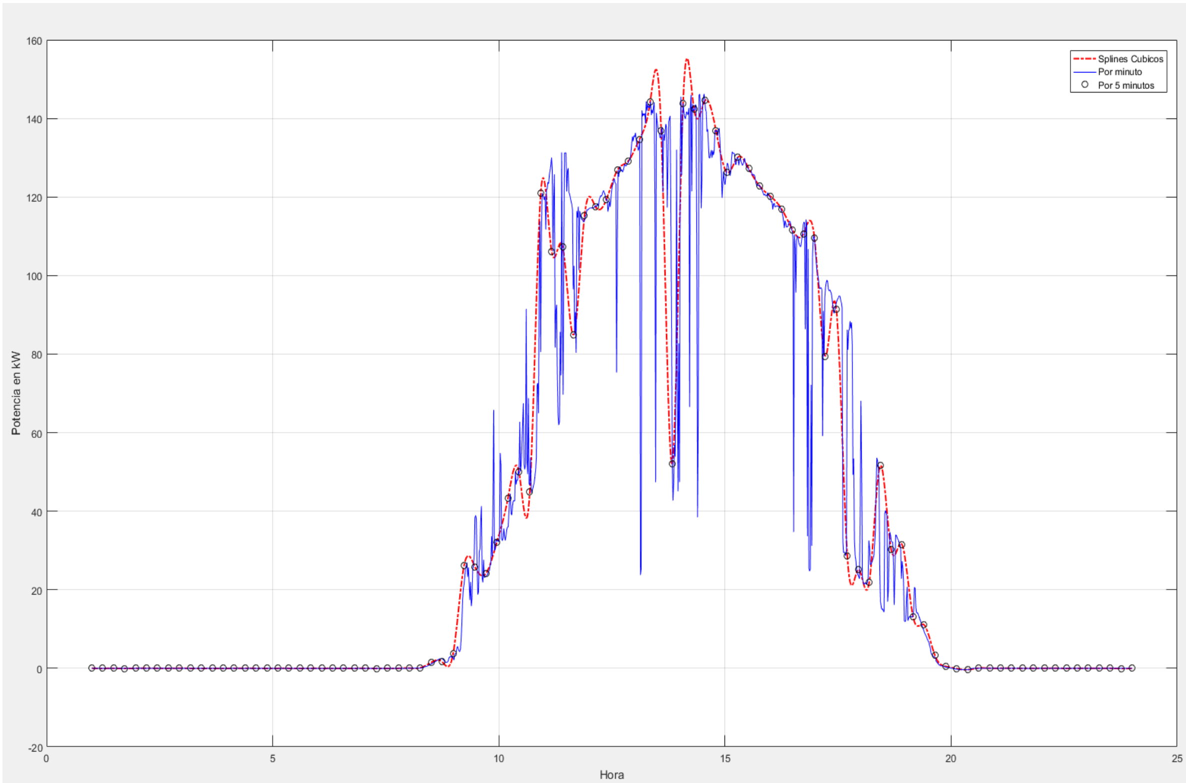


Fig. 6.12 Overlapped Graphs

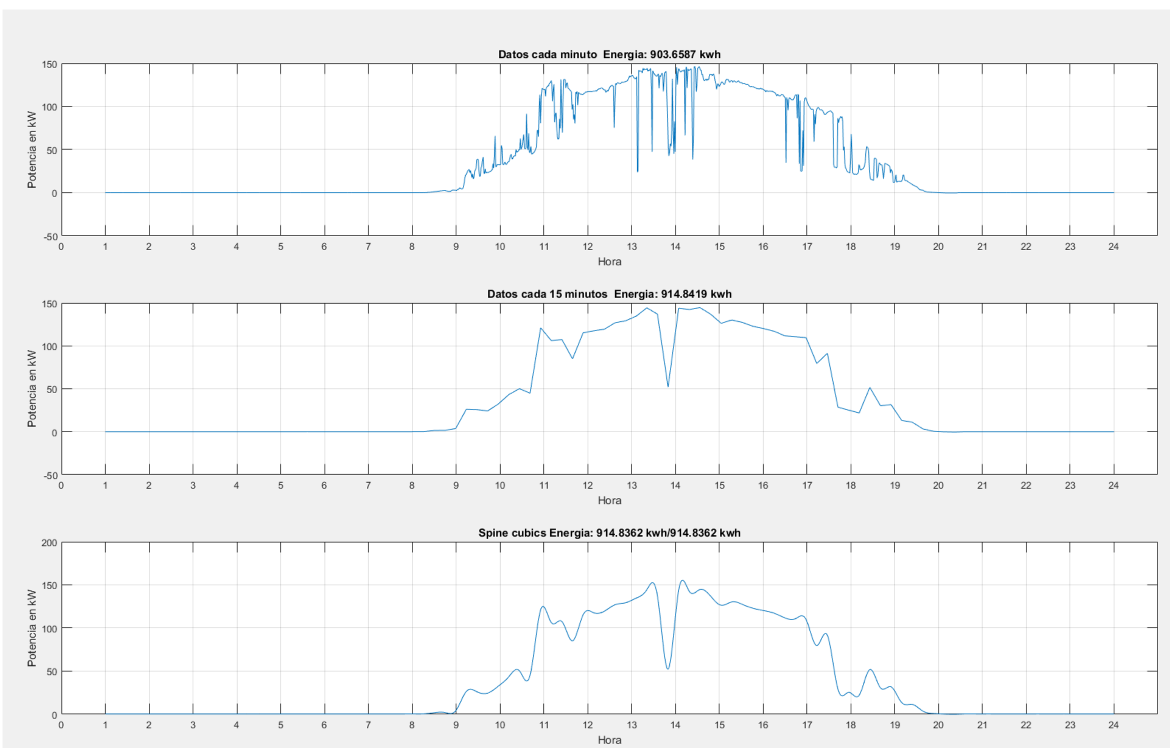


Fig. 6.13 Separated graphs

Brief example

With the information presented in a graphical interface, is easier because as it was explained in Chapter 3, the irradiance is a key element to produce clean energy in a Solar PV System. The Generation follows the irradiance behavior and when we see disturbs in the presented graph, can be developed a viability of operate a solar park in the place. Because diffuse irradiance can be produced by dust, by air polluted and by skipped maintenance of the modules.

When overlapping daily information, like shown in Fig. 6.14 two consecutive days were graphed. And when the behavior is similar in near hours, can be a building or structure in the surroundings that projects a shadow in a specific season. These factors could be omitted in the first design but can be considered in the following project steps.

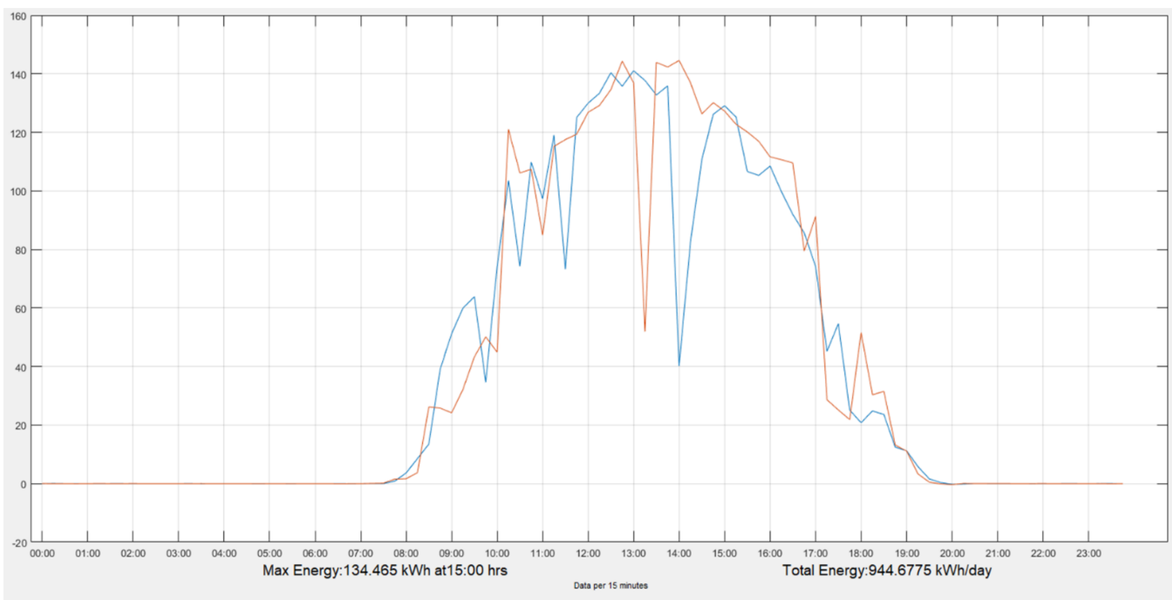


Fig. 6.14 August 25th and 26th 2017

Finally, many diffuse irradiances can be produced only by dirtiness of the solar module. When they accumulate dust in the surface and it remains in there, decrease the effectiveness of the system. And by a deep analyze of the generation behavior can be noticed a wrong performance and the maintenance should be scheduled according to the season.

Monthly Operation Data

The Excel files downloaded from the monitoring sistem, have the information reletead to the performance of the solar field per day. A second tool was develop to merge all those files in one. The main benefit when running this program is, that the algoritm find the maximun value in each file opened. The user can define which is the most valuable data (irradiance, generation or temperature), finally in the first page there is a summnary per day with greatest value found.

The Fig. 6.15 shows the main screen of the program. First by clicking on "Slect Folder", the user will indicate the path where the downloaded data is saved.

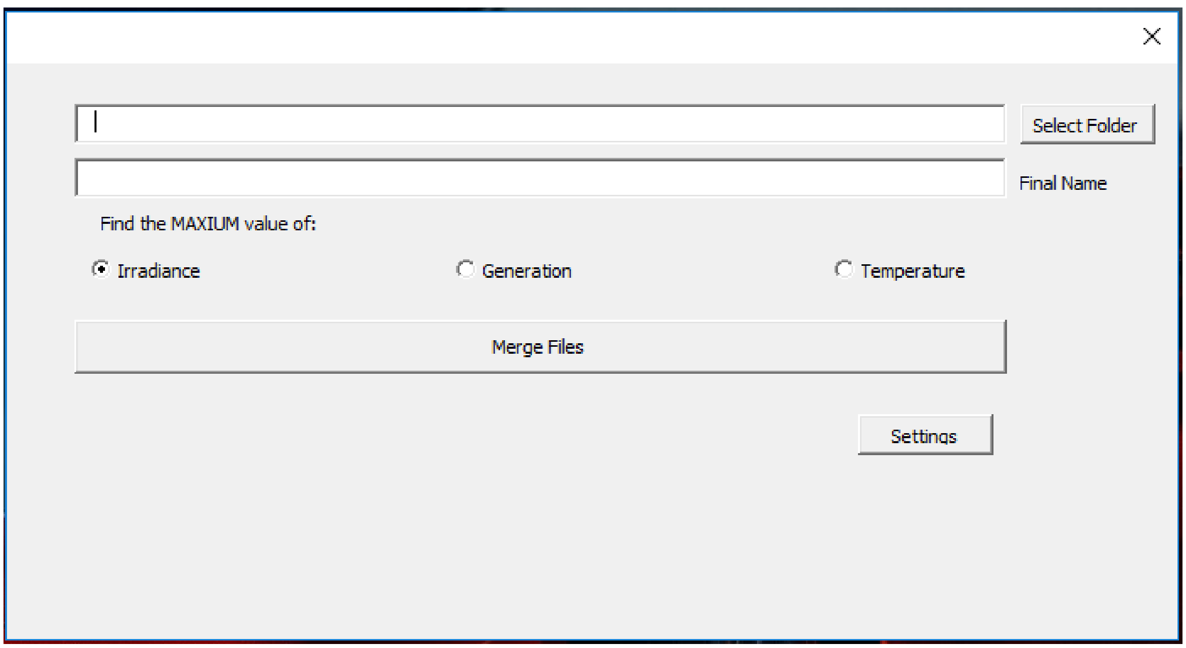


Fig. 6.15 Main Screen

Then, from the windows file explorer as seen in Fig. 6.16, choose the folder. Every file in this path will be opened and merged in the same file, the user will only need open one file to examine the monthly solar performance of the field with the downloaded and merged information files.

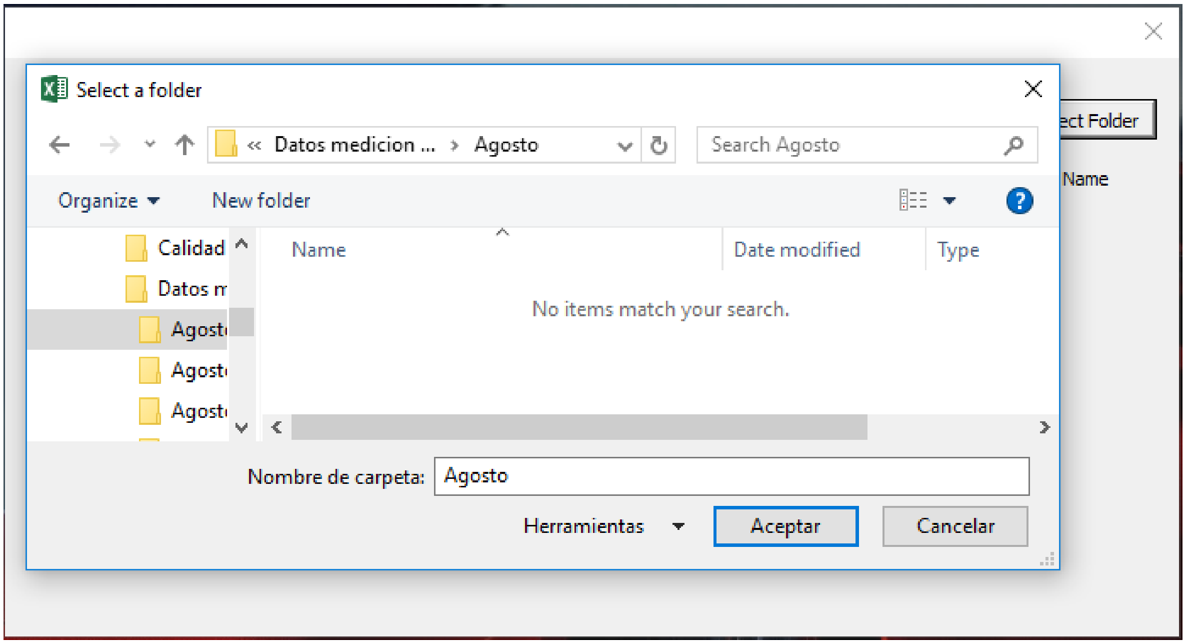


Fig. 6.16 Choosing of the data files

In the next space, is required a name to the file to be save. And the new file will be place in the same folder afore selected. Three radio buttons can be seen under the title "Find the MAXIMUN value of:", click on the one that represents the information searched. In other words, the user indicates to the program where to find a maximum value, having in mind that the maximum generation was not produced, with the maximum temperature, and neither precisely with the maximum irradiance, in most of the cases. In the Fig. 6.17 is shown all the spaces filled, finally when the user clicks on "Merge Files" button, every file in the folder will be analyzed.

When the routine finished, all the program closes itself automatically. So, the user needs to open the selected folder that contains the files, and there will be the new created merged file. The example was run doing merging all the files corresponding to august 2017. The Fig. 6.18shows the folder used to this example. At the top can be seen the new file with the name that was wrote in the previous figure.

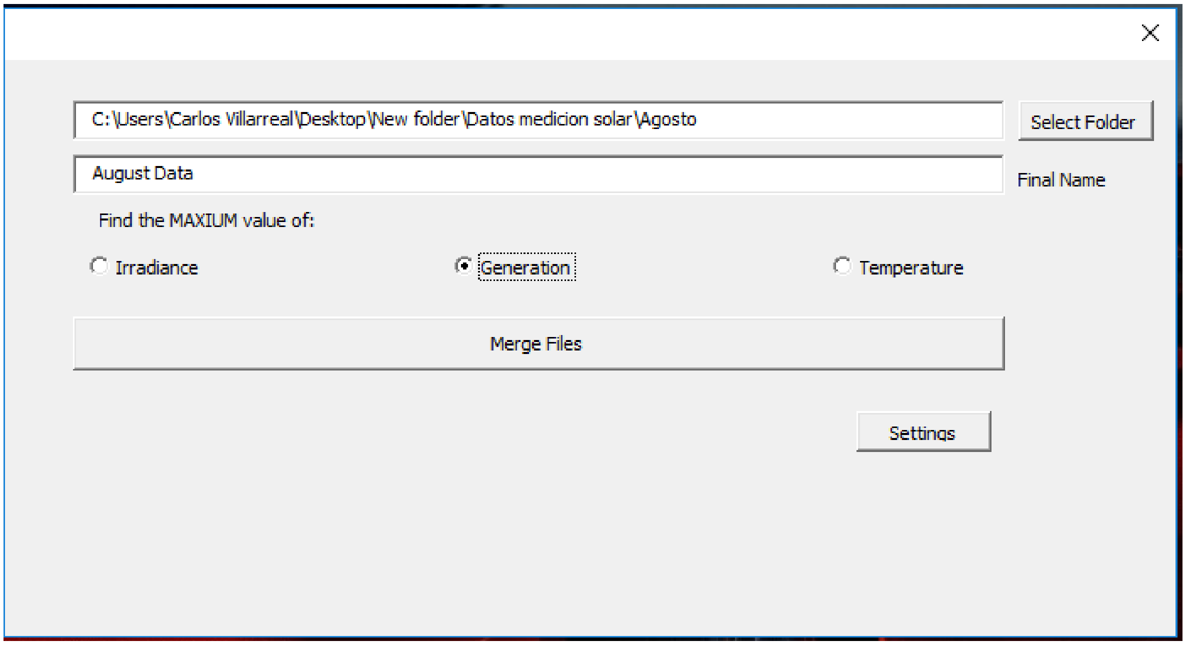
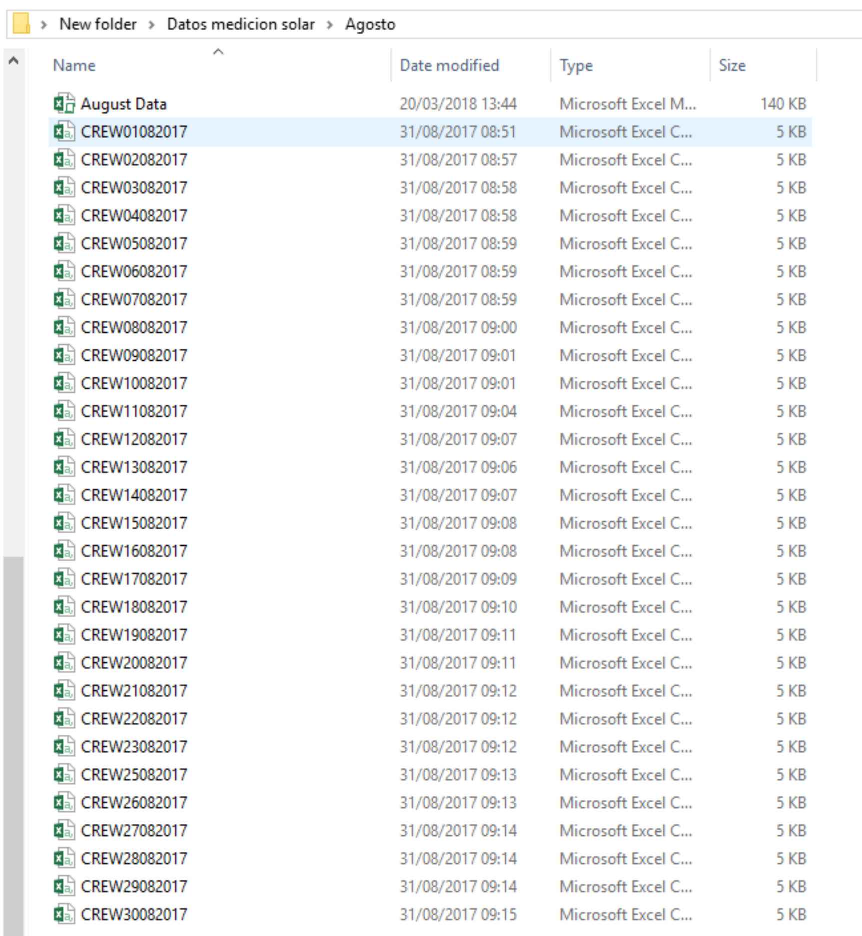


Fig. 6.17 Ready to merge


New folder > Datos medicion solar > Agosto

Name	Date modified	Type	Size
August Data	20/03/2018 13:44	Microsoft Excel M...	140 KB
CREW01082017	31/08/2017 08:51	Microsoft Excel C...	5 KB
CREW02082017	31/08/2017 08:57	Microsoft Excel C...	5 KB
CREW03082017	31/08/2017 08:58	Microsoft Excel C...	5 KB
CREW04082017	31/08/2017 08:58	Microsoft Excel C...	5 KB
CREW05082017	31/08/2017 08:59	Microsoft Excel C...	5 KB
CREW06082017	31/08/2017 08:59	Microsoft Excel C...	5 KB
CREW07082017	31/08/2017 08:59	Microsoft Excel C...	5 KB
CREW08082017	31/08/2017 09:00	Microsoft Excel C...	5 KB
CREW09082017	31/08/2017 09:01	Microsoft Excel C...	5 KB
CREW10082017	31/08/2017 09:01	Microsoft Excel C...	5 KB
CREW11082017	31/08/2017 09:04	Microsoft Excel C...	5 KB
CREW12082017	31/08/2017 09:07	Microsoft Excel C...	5 KB
CREW13082017	31/08/2017 09:06	Microsoft Excel C...	5 KB
CREW14082017	31/08/2017 09:07	Microsoft Excel C...	5 KB
CREW15082017	31/08/2017 09:08	Microsoft Excel C...	5 KB
CREW16082017	31/08/2017 09:08	Microsoft Excel C...	5 KB
CREW17082017	31/08/2017 09:09	Microsoft Excel C...	5 KB
CREW18082017	31/08/2017 09:10	Microsoft Excel C...	5 KB
CREW19082017	31/08/2017 09:11	Microsoft Excel C...	5 KB
CREW20082017	31/08/2017 09:11	Microsoft Excel C...	5 KB
CREW21082017	31/08/2017 09:12	Microsoft Excel C...	5 KB
CREW22082017	31/08/2017 09:12	Microsoft Excel C...	5 KB
CREW23082017	31/08/2017 09:12	Microsoft Excel C...	5 KB
CREW25082017	31/08/2017 09:13	Microsoft Excel C...	5 KB
CREW26082017	31/08/2017 09:13	Microsoft Excel C...	5 KB
CREW27082017	31/08/2017 09:14	Microsoft Excel C...	5 KB
CREW28082017	31/08/2017 09:14	Microsoft Excel C...	5 KB
CREW29082017	31/08/2017 09:14	Microsoft Excel C...	5 KB
CREW30082017	31/08/2017 09:15	Microsoft Excel C...	5 KB

Fig. 6.18 New file at the top

The new file is an Excel's book. With a number of sheets equal to the number of files in the folder. The first worksheet was named "MAIN". In the column "Day" was wrote date of the measurement. In the next column the hour, indicating the time when, in this case (because that was the selection in the user's interface), the generation was greater. And the follow columns indicate, with the selection (Generation) what other data displayed in the same moment. As can be seen in the Fig. 6.19, the column header "Generation" is bold, that is because indicates the selection made by the user.

	B	C	D	E	F	G	H	I	J	K
1	Day	Hour	**Generation**	Irradiance	Temperature	Wind Speed				
2	01-ago	14:54	134.02	867	35.5	3				
3	02-ago	13:54	136.64	884	35.9	2				
4	03-ago	13:54	146.88	981	33.7	3				
5	04-ago	12:39	83.99	523	29.5	1				
6	05-ago	13:39	143.63	940	32.6	4				
7	06-ago	14:09	131.9	851	35	1				
8	07-ago	12:09	133.29	913	33.7	3				
9	08-ago	12:54	148.11	997	30.9	2				
10	09-ago	14:09	145.57	923	33.5	3				
11	10-ago	12:54	147.32	287	31.4	5				
12	11-ago	14:09	147.33	930	32.3	4				
13	12-ago	13:54	134.23	846	33.1	4				
14	13-ago	13:39	133.65	845	33.1	3				
15	14-ago	13:54	129.34	817	33.4	4				
16	15-ago	12:09	136.9	863	28.8	2				
17	16-ago	14:09	130.63	815	34.7	1				
18	17-ago	13:09	131.22	834	33.4	2				
19	18-ago	13:09	133.48	842	33.8	2				
20	19-ago	13:39	142.06	912	33.5	2				
21	20-ago	13:09	147.2	947	32.2	2				
22	21-ago	14:39	143.96	887	33.9	2				
23	22-ago	13:09	134.53	867	33.5	1				
24	23-ago	13:54	140.51	946	35.4	2				
25	25-ago	13:09	141.03	854	32.6	6				
26	26-ago	14:09	144.54	891	34.3	6				
27	27-ago	13:54	141.07	831	33.7	7				
28	28-ago	11:39	148.1	942	29.8	10				
29	29-ago	13:09	141.9	832	32.3	7				
30	30-ago	12:39	137.19	857	32.6	1				
31										
32										
33										
34										
35										

MAIN | 01.08 | 02.08 | 03.08 | 04.08 | 05.08 | 06.08 | 07.08 | 08.08 | 09.08 | 10.0 ...

Fig. 6.19 Exploring the new file

In the Fig. 6.20 is shown the names of each worksheet in the book. The tag correspond to the day and month of the measurement, and the sheets have the original information, allowing faster access to the data providing and be able employ it in research calculations.

	A	B	C	D	E	F	G
1							
2	Date and time	PV generatic	POA irradian	Ambient ten	Wind speed (m/s)		
3	30/08/2017 00:09	0.01	0	28.2	1		
4	30/08/2017 00:24	-0.01	0	28.6	1		
5	30/08/2017 00:39	-0.02	0	29	1		
6	30/08/2017 00:54	0.01	0	29.1	1		
7	30/08/2017 01:09	-0.01	0	28.6	0		
8	30/08/2017 01:24	0	0	28.7	1		
9	30/08/2017 01:39	0	0	28.7	1		
10	30/08/2017 01:54	0	0	28.5	1		
11	30/08/2017 02:09	-0.01	0	28	1		
12	30/08/2017 02:24	0	0	27.6	0		
13	30/08/2017 02:39	-0.01	0	27.4	2		
14	30/08/2017 02:54	-0.02	0	24.5	3		
15	30/08/2017 03:09	-0.03	0	24.7	2		
16	30/08/2017 03:24	0	0	25	1		
17	30/08/2017 03:39	-0.01	0	25.2	1		
18	30/08/2017 03:54	-0.02	0	25.2	1		
19	30/08/2017 04:09	-0.02	0	25.3	1		
20	30/08/2017 04:24	-0.02	0	25.1	1		
21	30/08/2017 04:39	-0.02	0	25.2	1		
22	30/08/2017 04:54	-0.01	0	25.2	1		
23	30/08/2017 05:09	-0.04	0	25	0		
24	30/08/2017 05:24	-0.02	0	24.8	0		
25	30/08/2017 05:39	-0.02	0	24.5	0		
26	30/08/2017 05:54	-0.04	0	24.5	1		
27	30/08/2017 06:09	-0.01	0	24.7	2		
28	30/08/2017 06:24	-0.02	0	24.7	1		
29	30/08/2017 06:39	-0.01	0	24.3	1		
30	30/08/2017 06:54	-0.01	0	24.5	1		
31	30/08/2017 07:09	-0.01	0	24.9	2		
32	30/08/2017 07:24	0.03	5	24.8	2		
33	30/08/2017 07:39	0.39	17	23.3	3		
34	30/08/2017 07:54	1.59	73	23.7	1		
35	30/08/2017 08:09	3.5	129	24.8	1		

... 21.08 22.08 23.08 25.08 26.08 27.08 28.08 29.08 **30.08**

Fig. 6.20 Pages named with the containing day

Brief Example

By using this application were run an example using just few of the available days in the information. The exercise was repeated tree times to get the information finding the maximum value of generation, temperature and irradiance. In Fig. 6.21 were place the first age of the generated Excel's book.

When the search was made using the PV Generation as the search criteria, analyzing august 23, the greatest value was 142 kW and the conditions which produced that power was Irradiance 961 w/m^2 and Temperature 35.3° C. Now when the maximum Temperature was asked, it results at almost 18 hours, 37.4° C but the irradiance was reduced around one third of the needed to produce the maximum PV Generation. Finally, in the data resulted by searching the maximum Irradiance, the result was 968 w/m^2. The PV Generation was not the greatest but comparing to the maximum PV Generation conditions, the Temperature is a little bit hotter and the difference in kW is less than 10. The difference in time is one minute, by comparing more data, better conclusion can be reach.

By doing this exercise is explained the important of this development, and that way how it can be applied during this research. A tool to analyze solar data with research purposes is needed to understand the relationship between Temperature, Irradiance and Generation.

D1 Generation

Day	Hour	Generation	Irradiance	Temperature	Wind Speed
23-ago	13:54	142.11	961	35.3	1
25-ago	13:56	145.66	901	33.1	5
26-ago	14:01	146.21	891	34.1	5
27-ago	12:16	146.87	710	31.7	3
28-ago	13:12	148.23	1002	30.2	7
29-ago	14:36	144.68	854	33.4	7

F1 Temperature

Day	Hour	Generation	Irradiance	Temperature	Wind Speed
23-ago	17:48	57.2	356	37.4	1
25-ago	16:34	95.51	555	35.5	2
26-ago	16:28	114.26	577	37.1	3
27-ago	16:33	99.14	544	35.1	5
28-ago	17:51	14.98	94	33.7	5
29-ago	16:48	90.2	503	34.9	4

E1 Irradiance

Day	Hour	Generation	Irradiance	Temperature	Wind Speed
23-ago	13:55	133.02	968	35.7	0
25-ago	13:56	145.66	901	33.1	5
26-ago	12:58	144.11	922	33.8	5
27-ago	12:17	146.01	888	32.2	3
28-ago	12:41	89.64	1279	29.7	6
29-ago	14:31	131.91	909	33.4	3

Fig. 6.21 Results comparison

Chapter 7 Conclusions

With the modifications that were made to the Mexican laws concerning the energy market, it is intended to establish a solid electricity market in the country. But it also seeks to meet the goals of generating clean electricity to reduce emissions of Green House Gases (GHG). It is expected that half of the total energy consumed in the country comes from renewable sources by 2050.

For distributed Generation (DG), a power plant which produces less than 500 kW is catalogued as exempt generator, there are clauses to regulate the installation and the operation. The produced energy can be destined for self-consumption or for sale.

This work takes as a study case a solar park owned by Schneider Electric, at the "Monterrey Development and Innovation Center" (MDIC). For this particular case is concluded that the most viable option, taking into consideration the current status of the system, is Net Metering. The whole installation produces less of the total energy consumed by the building, surplus energy to inject to the network is not common and in case that occurs the bidirectional meter will be able to count it. Net Billing is ruled out because the energy would take a monetary value, related to the node to which it is injected. The building will need to buy energy in the same node, and the supplier pay less than what he charges. In other words, for the building is more valuable to consume its own energy, which is reflected as a saving, greater than the income could be. And clearly, is still necessary to buy the missing energy from the supplier. Total Sale of Energy would be considered if the power plant and the building were not on adjacent areas. At last the isolated supply is also ruled out because through the supplier is possible CEL's selling, generating an extra income that helps the profitability of the project and if it is the case the surplus energy can go to the network.

Also, was review the technical aspect and resulted that data management is a complicated task when the park has been operating for some years. Two tools were developed with the aim to facilitate the monitoring of the system's performance and being able to analyze it graphically. The measurement equipment allows to download the files where the measurements are recorded. The first tool is capable of processing each one of those files and showing a profile of the generation of that day. Also Calculate how much energy produced and at what time the maximum generation was obtained. It can even overlap graphics to compare the behavior between stations or from one day to another, as needed.

There were certain graphs showing oscillations and sudden changes in the shape of the curve. After reviewing the literature, it was concluded that this behavior is related to the diffuse radiation that affects the panels. Which is affected by factors such as the amount of dust, moisture in the air, the amount of clouds and even wind speed. With this type of information is possible to analyze the typical behavior of irradiation in a particular area, thus making decisions on the viability of more projects in the surroundings. However, the duration of the project and the information collected is not sufficient to do it yet.

The second tool is also a support to analyze the park's performance, but it is used to extract monthly data. When you feed the program with the set of files generated in one month (or a specific period), each one will be analyzed, the maximum values of that day will be searched, and the summary will show the found value accompanied by the other values that were presented in that moment (generation, irradiation, temperature).

With one more tool, a 20-year projection of an economic analysis is carried out. In Chapter 5 the versatility of this tool was shown. It was made to analyze the profitability of photovoltaic systems. Scenarios were performed to analyze the current study case performance. The extra positive flow that adds the sale of CEL helps to make the investment more profitable. But there is also a fiscal stimulus that allows depreciation of the project in the first year, so, no taxes that period. Also, if it is possible to report the PV system as an expense, it helps to avoid a percentage of the total taxes that the company would have to pay. In this way it is concluded that both benefits analyzed really cause improvements in economic indicators and that through the use of this template, create proposals that encourage investments of this type makes easier.

With properly applied government stimulus, with information on the environmental conditions of specific places and following the trend of increasing the efficiency of solar panels that currently report up to 46%, it is possible to invest in solar parks that work interconnected to the network. Since the surplus energy can be delivered to the supplier and if you can also receive CEL, the period of Payback can reach 6 years with attractive IRR.

Future jobs.

Make the application developed in MATLAB, which is used to graph daily information, be able to recognize the files of several investors. Since each one accommodates the data in different columns. So, if the algorithm searches for information and not just the specified columns, the current development may be adjustable to any measurement equipment.

Obtain more data, in order to analyze the local conditions of solar incidence in the area. Check the degradation of the panels and that the analyze the patterns in the generation when they are dirty, can serve as indicators to program an optimal maintenance.

Analyze what kind of extra stimulus, the government can offer to encourage the installation of solar panels, without affecting any of the parties involved in the future. To do this, is possible to use the tool developed in Excel, because it involves spaces to vary the tax rate and the years to depreciate the value of the system.

Develop a methodology to get the price of energy over the 20 following periods. Since this value should change and, at least in Mexico, one factors that can affect the energy price, is the social aspect.

Appendix A

Cash flow data obtained in case 1 of the chapter 5.

Year	0	1	2	3
Investment	$ 259,571.00	$ -	$ -	$ -
Power production		460,859	457,633	454,407
CELs		460	457	454
Maintenance		$ -	$ -	$ -
Insurance		$ -	$ -	$ -
Energy cost		$ 0.06	$ 0.06	$ 0.08
CEL cost		$ -	$ -	$ -
Avoid cost		$ 27,651.55	$ 28,088.10	$ 34,658.22
CELs earnings		$ -	$ -	$ -
EBITDA	-$ 259,571.00	$ 27,651.55	$ 28,088.10	$ 34,658.22
Depreciation		-$ 259,571.00	$ -	$ -
Loan Interest		$ -	$ -	$ -
Tax Base		-$ 231,919.45	$ 28,088.10	$ 34,658.22
Taxes		$ -	-$ 8,426.43	-$ 10,397.47
Net Revenue		-$ 231,919.45	$ 19,661.67	$ 24,260.76
Discount in total Balance	$ -			
Debt Principal		$ -	$ -	$ -
Net Cash Flow	-$ 259,571.00	$ 27,651.55	$ 19,661.67	$ 24,260.76
Cumulative Cash Flow	-$ 259,571.00	-$ 231,919.45	-$ 212,257.78	-$ 187,997.02

Payback	11.54	years
IRR	12%	
Debt Payment	$ -	
NPV	$ 77,121	USD

4	5	6	7	8	9
$ -	$ -	$ -	$ -	$ -	$ -
451,181	447,955	444,729	441,503	438,277	435,051
451	447	444	441	438	435
$ -	$ -	$ -	$ -	$ -	$ -
$ -	$ -	$ -	$ -	$ -	$ -
$ 0.08	$ 0.08	$ 0.08	$ 0.08	$ 0.08	$ 0.08
$ -	$ -	$ -	$ -	$ -	$ -
$ 37,209.44	$ 35,308.22	$ 34,499.01	$ 33,538.33	$ 33,589.27	$ 36,111.90
$ -	$ -	$ -	$ -	$ -	$ -
$ 37,209.44	$ 35,308.22	$ 34,499.01	$ 33,538.33	$ 33,589.27	$ 36,111.90
$ -	$ -	$ -	$ -	$ -	$ -
$ -	$ -	$ -	$ -	$ -	$ -
$ 37,209.44	$ 35,308.22	$ 34,499.01	$ 33,538.33	$ 33,589.27	$ 36,111.90
-$ 11,162.83	-$ 10,592.47	-$ 10,349.70	-$ 10,061.50	-$ 10,076.78	-$ 10,833.57
$ 26,046.61	$ 24,715.75	$ 24,149.31	$ 23,476.83	$ 23,512.49	$ 25,278.33
$ -	$ -	$ -	$ -	$ -	$ -
$ 26,046.61	$ 24,715.75	$ 24,149.31	$ 23,476.83	$ 23,512.49	$ 25,278.33
-$ 161,950.42	-$ 137,234.66	-$ 113,085.35	-$ 89,608.52	-$ 66,096.04	-$ 40,817.70

10	11	12	13	14	15
$ -	$ -	$ -	$ -	$ -	$ -
431,825	428,599	425,373	422,147	418,921	415,695
431	428	425	422	418	415
$ -	$ -	$ -	$ -	$ -	$ -
$ -	$ -	$ -	$ -	$ -	$ -
$ 0.09	$ 0.09	$ 0.09	$ 0.09	$ 0.09	$ 0.09
$ -	$ -	$ -	$ -	$ -	$ -
$ 37,547.63	$ 38,270.66	$ 36,990.28	$ 36,726.40	$ 36,445.74	$ 36,477.40
$ -	$ -	$ -	$ -	$ -	$ -
$ 37,547.63	$ 38,270.66	$ 36,990.28	$ 36,726.40	$ 36,445.74	$ 36,477.40
$ -	$ -	$ -	$ -	$ -	$ -
$ -	$ -	$ -	$ -	$ -	$ -
$ 37,547.63	$ 38,270.66	$ 36,990.28	$ 36,726.40	$ 36,445.74	$ 36,477.40
-$ 11,264.29	-$ 11,481.20	-$ 11,097.08	-$ 11,017.92	-$ 10,933.72	-$ 10,943.22
$ 26,283.34	$ 26,789.47	$ 25,893.19	$ 25,708.48	$ 25,512.02	$ 25,534.18
$ -	$ -	$ -	$ -	$ -	$ -
$ 26,283.34	$ 26,789.47	$ 25,893.19	$ 25,708.48	$ 25,512.02	$ 25,534.18
-$ 14,534.36	$ 12,255.11	$ 38,148.30	$ 63,856.78	$ 89,368.80	$ 114,902.98

16	17	18	19	20
$ -	$ -	$ -	$ -	$ -
412,469	409,243	406,017	402,791	399,565
412	409	406	402	399
$ -	$ -	$ -	$ -	$ -
$ -	$ -	$ -	$ -	$ -
$ 0.09	$ 0.09	$ 0.09	$ 0.09	$ 0.09
$ -	$ -	$ -	$ -	$ -
$ 35,982.29	$ 35,738.62	$ 35,501.49	$ 35,177.53	$ 34,908.86
$ -	$ -	$ -	$ -	$ -
$ 35,982.29	$ 35,738.62	$ 35,501.49	$ 35,177.53	$ 34,908.86
$ -	$ -	$ -	$ -	$ -
$ -	$ -	$ -	$ -	$ -
$ 35,982.29	$ 35,738.62	$ 35,501.49	$ 35,177.53	$ 34,908.86
-$ 10,794.69	-$ 10,721.59	-$ 10,650.45	-$ 10,553.26	-$ 10,472.66
$ 25,187.60	$ 25,017.03	$ 24,851.05	$ 24,624.27	$ 24,436.20
$ -	$ -	$ -	$ -	$ -
$ 25,187.60	$ 25,017.03	$ 24,851.05	$ 24,624.27	$ 24,436.20
$ 140,090.58	$ 165,107.62	$ 189,958.66	$ 214,582.93	$ 239,019.14

Appendix B

Cash flow data obtained in case 2 of the chapter 5.

Year	0	1	2	3
Investment	$ 259,571.00	$ -	$ -	$ -
Power production		263,278	261,435	259,592
CELs		263	261	259
Maintenance		$ -	$ -	$ -
Insurance		$ -	$ -	$ -
Energy cost		$ 0.06	$ 0.06	$ 0.08
CEL cost		$ -	$ -	$ -
Avoid cost		$ 15,796.68	$ 16,046.07	$ 19,799.43
CELs earnings		$ -	$ -	$ -
EBITDA	-$ 259,571.00	$ 15,796.68	$ 16,046.07	$ 19,799.43
Depreciation		-$ 259,571.00	$ -	$ -
Loan Interest		$ -	$ -	$ -
Tax Base		-$ 243,774.32	$ 16,046.07	$ 19,799.43
Taxes		$ -	-$ 4,813.82	-$ 5,939.83
Net Revenue		-$ 243,774.32	$ 11,232.25	$ 13,859.60
Discount in total Balance	$ -			
Debt Principal		$ -	$ -	$ -
Net Cash Flow	-$ 259,571.00	$ 15,796.68	$ 11,232.25	$ 13,859.60
Cumulative Cash Flow	-$ 259,571.00	-$ 243,774.32	-$ 232,542.07	-$ 218,682.48

Payback	19.20	years
IRR	4%	
Debt Payment	$ -	
NPV	$ (67,227)	USD

4	5	6	7	8	9
$ -	$ -	$ -	$ -	$ -	$ -
257,749	255,906	254,063	252,220	250,377	248,534
257	255	254	252	250	248
$ -	$ -	$ -	$ -	$ -	$ -
$ -	$ -	$ -	$ -	$ -	$ -
$ 0.08	$ 0.08	$ 0.08	$ 0.08	$ 0.08	$ 0.08
$ -	$ -	$ -	$ -	$ -	$ -
$ 21,256.87	$ 20,170.75	$ 19,708.47	$ 19,159.66	$ 19,188.76	$ 20,629.88
$ -	$ -	$ -	$ -	$ -	$ -
$ 21,256.87	$ 20,170.75	$ 19,708.47	$ 19,159.66	$ 19,188.76	$ 20,629.88
$ -	$ -	$ -	$ -	$ -	$ -
$ -	$ -	$ -	$ -	$ -	$ -
$ 21,256.87	$ 20,170.75	$ 19,708.47	$ 19,159.66	$ 19,188.76	$ 20,629.88
-$ 6,377.06	-$ 6,051.23	-$ 5,912.54	-$ 5,747.90	-$ 5,756.63	-$ 6,188.96
$ 14,879.81	$ 14,119.53	$ 13,795.93	$ 13,411.76	$ 13,432.13	$ 14,440.92
$ -	$ -	$ -	$ -	$ -	$ -
$ 14,879.81	$ 14,119.53	$ 13,795.93	$ 13,411.76	$ 13,432.13	$ 14,440.92
-$ 203,802.66	-$ 189,683.14	-$ 175,887.21	-$ 162,475.45	-$ 149,043.32	-$ 134,602.40

10	11	12	13	14	15
$ -	$ -	$ -	$ -	$ -	$ -
246,691	244,849	243,006	241,163	239,320	237,477
246	244	243	241	239	237
$ -	$ -	$ -	$ -	$ -	$ -
$ -	$ -	$ -	$ -	$ -	$ -
$ 0.09	$ 0.09	$ 0.09	$ 0.09	$ 0.09	$ 0.09
$ -	$ -	$ -	$ -	$ -	$ -
$ 21,450.08	$ 21,863.13	$ 21,131.67	$ 20,980.93	$ 20,820.59	$ 20,838.68
$ -	$ -	$ -	$ -	$ -	$ -
$ 21,450.08	$ 21,863.13	$ 21,131.67	$ 20,980.93	$ 20,820.59	$ 20,838.68
$ -	$ -	$ -	$ -	$ -	$ -
$ -	$ -	$ -	$ -	$ -	$ -
$ 21,450.08	$ 21,863.13	$ 21,131.67	$ 20,980.93	$ 20,820.59	$ 20,838.68
-$ 6,435.02	-$ 6,558.94	-$ 6,339.50	-$ 6,294.28	-$ 6,246.18	-$ 6,251.60
$ 15,015.05	$ 15,304.19	$ 14,792.17	$ 14,686.65	$ 14,574.41	$ 14,587.07
$ -	$ -	$ -	$ -	$ -	$ -
$ 15,015.05	$ 15,304.19	$ 14,792.17	$ 14,686.65	$ 14,574.41	$ 14,587.07
-$ 119,587.35	-$ 104,283.16	-$ 89,490.99	-$ 74,804.34	-$ 60,229.92	-$ 45,642.85

16	17	18	19	20
$ -	$ -	$ -	$ -	$ -
235,634	233,791	231,948	230,105	228,262
235	233	231	230	228
$ -	$ -	$ -	$ -	$ -
$ -	$ -	$ -	$ -	$ -
$ 0.09	$ 0.09	$ 0.09	$ 0.09	$ 0.09
$ -	$ -	$ -	$ -	$ -
$ 20,555.83	$ 20,416.63	$ 20,281.17	$ 20,096.10	$ 19,942.61
$ -	$ -	$ -	$ -	$ -
$ 20,555.83	$ 20,416.63	$ 20,281.17	$ 20,096.10	$ 19,942.61
$ -	$ -	$ -	$ -	$ -
$ -	$ -	$ -	$ -	$ -
$ 20,555.83	$ 20,416.63	$ 20,281.17	$ 20,096.10	$ 19,942.61
-$ 6,166.75	-$ 6,124.99	-$ 6,084.35	-$ 6,028.83	-$ 5,982.78
$ 14,389.08	$ 14,291.64	$ 14,196.82	$ 14,067.27	$ 13,959.83
$ -	$ -	$ -	$ -	$ -
$ 14,389.08	$ 14,291.64	$ 14,196.82	$ 14,067.27	$ 13,959.83
-$ 31,253.77	-$ 16,962.13	-$ 2,765.31	$ 11,301.96	$ 25,261.78

Appendix C

Cash flow data obtained in case 3 of the chapter 5.

Year	0	1	2	3
Investment	$ 259,571.00	$ -	$ -	$ -
Power production		460,859	457,633	454,407
CELs		460	457	454
Maintenance		$ 1,350.00	$ 1,451.25	$ 1,560.09
Insurance		$ 26,000.00	$ 27,950.00	$ 30,046.25
Energy cost		$ 0.06	$ 0.06	$ 0.08
CEL cost		$ 18.00	$ 18.00	$ 18.00
Avoid cost		$ 27,651.55	$ 28,088.10	$ 34,658.22
CELs earnings		$ 8,280.00	$ 8,226.00	$ 8,172.00
EBITDA	-$ 259,571.00	$ 34,581.55	$ 34,862.85	$ 41,270.13
Depreciation		-$ 259,571.00	$ -	$ -
Loan Interest		$ -	$ -	$ -
Tax Base		-$ 224,989.45	$ 34,862.85	$ 41,270.13
Taxes		$ -	-$ 10,458.85	-$ 12,381.04
Net Revenue		-$ 224,989.45	$ 24,403.99	$ 28,889.09
Discount in total Balance	$ -			
Debt Principal		$ -	$ -	$ -
Net Cash Flow	-$ 259,571.00	$ 34,581.55	$ 24,403.99	$ 28,889.09
Cumulative Cash Flow	-$ 259,571.00	-$ 224,989.45	-$ 200,585.45	-$ 171,696.36

Payback	9.98	years
IRR	14%	
Debt Payment	$ -	
NPV	$ 130,531	USD

4	5	6	7	8	9
$ -	$ -	$ -	$ -	$ -	$ -
451,181	447,955	444,729	441,503	438,277	435,051
451	447	444	441	438	435
$ 1,677.10	$ 1,802.88	$ 1,938.10	$ 2,083.46	$ 2,239.72	$ 2,407.70
$ 32,299.72	$ 34,722.20	$ 37,326.36	$ 40,125.84	$ 43,135.28	$ 46,370.42
$ 0.08	$ 0.08	$ 0.08	$ 0.08	$ 0.08	$ 0.08
$ 18.00	$ 18.00	$ 18.00	$ 18.00	$ 18.00	$ 18.00
$ 37,209.44	$ 35,308.22	$ 34,499.01	$ 33,538.33	$ 33,589.27	$ 36,111.90
$ 8,118.00	$ 8,046.00	$ 7,992.00	$ 7,938.00	$ 7,884.00	$ 7,830.00
$ 43,650.34	$ 41,551.34	$ 40,552.91	$ 39,392.87	$ 39,233.55	$ 41,534.21
$ -	$ -	$ -	$ -	$ -	$ -
$ -	$ -	$ -	$ -	$ -	$ -
$ 43,650.34	$ 41,551.34	$ 40,552.91	$ 39,392.87	$ 39,233.55	$ 41,534.21
-$ 13,095.10	-$ 12,465.40	-$ 12,165.87	-$ 11,817.86	-$ 11,770.07	-$ 12,460.26
$ 30,555.24	$ 29,085.94	$ 28,387.04	$ 27,575.01	$ 27,463.49	$ 29,073.95
$ -	$ -	$ -	$ -	$ -	$ -
$ 30,555.24	$ 29,085.94	$ 28,387.04	$ 27,575.01	$ 27,463.49	$ 29,073.95
-$ 141,141.13	-$ 112,055.19	-$ 83,668.15	-$ 56,093.14	-$ 28,629.66	$ 444.29

10	11	12	13	14	15
$ -	$ -	$ -	$ -	$ -	$ -
431,825	428,599	425,373	422,147	418,921	415,695
431	428	425	422	418	415
$ 2,588.27	$ 2,782.39	$ 2,991.07	$ 3,215.40	$ 3,456.56	$ 3,715.80
$ 49,848.21	$ 53,586.82	$ 57,605.83	$ 61,926.27	$ 66,570.74	$ 71,563.55
$ 0.09	$ 0.09	$ 0.09	$ 0.09	$ 0.09	$ 0.09
$ 18.00	$ 18.00	$ 18.00	$ 18.00	$ 18.00	$ 18.00
$ 37,547.63	$ 38,270.66	$ 36,990.28	$ 36,726.40	$ 36,445.74	$ 36,477.40
$ 7,758.00	$ 7,704.00	$ 7,650.00	$ 7,596.00	$ 7,524.00	$ 7,470.00
$ 42,717.36	$ 43,192.27	$ 41,649.20	$ 41,107.00	$ 40,513.18	$ 40,231.60
$ -	$ -	$ -	$ -	$ -	$ -
$ -	$ -	$ -	$ -	$ -	$ -
$ 42,717.36	$ 43,192.27	$ 41,649.20	$ 41,107.00	$ 40,513.18	$ 40,231.60
-$ 12,815.21	-$ 12,957.68	-$ 12,494.76	-$ 12,332.10	-$ 12,153.96	-$ 12,069.48
$ 29,902.15	$ 30,234.59	$ 29,154.44	$ 28,774.90	$ 28,359.23	$ 28,162.12
$ -	$ -	$ -	$ -	$ -	$ -
$ 29,902.15	$ 30,234.59	$ 29,154.44	$ 28,774.90	$ 28,359.23	$ 28,162.12
$ 30,346.44	$ 60,581.03	$ 89,735.48	$ 118,510.38	$ 146,869.60	$ 175,031.72

16	17	18	19	20
$ -	$ -	$ -	$ -	$ -
412,469	409,243	406,017	402,791	399,565
412	409	406	402	399
$ 3,994.48	$ 4,294.07	$ 4,616.13	$ 4,962.34	$ 5,334.51
$ 76,930.81	$ 82,700.62	$ 88,903.17	$ 95,570.91	$ 102,738.72
$ 0.09	$ 0.09	$ 0.09	$ 0.09	$ 0.09
$ 18.00	$ 18.00	$ 18.00	$ 18.00	$ 18.00
$ 35,982.29	$ 35,738.62	$ 35,501.49	$ 35,177.53	$ 34,908.86
$ 7,416.00	$ 7,362.00	$ 7,308.00	$ 7,236.00	$ 7,182.00
$ 39,403.81	$ 38,806.55	$ 38,193.37	$ 37,451.20	$ 36,756.35
$ -	$ -	$ -	$ -	$ -
$ -	$ -	$ -	$ -	$ -
$ 39,403.81	$ 38,806.55	$ 38,193.37	$ 37,451.20	$ 36,756.35
-$ 11,821.14	-$ 11,641.96	-$ 11,458.01	-$ 11,235.36	-$ 11,026.90
$ 27,582.67	$ 27,164.58	$ 26,735.36	$ 26,215.84	$ 25,729.44
$ -	$ -	$ -	$ -	$ -
$ 27,582.67	$ 27,164.58	$ 26,735.36	$ 26,215.84	$ 25,729.44
$ 202,614.39	$ 229,778.97	$ 256,514.33	$ 282,730.17	$ 308,459.61

Appendix D

Cash flow data obtained in case 3 of the chapter 5.

Year	0	1	2	3
Investment	$ 259,571.00	$ -	$ -	$ -
Power production		460,859	457,633	454,407
CELs		460	457	454
Maintenance		$ 1,350.00	$ 1,451.25	$ 1,560.09
Insurance		$ 26,000.00	$ 27,950.00	$ 30,046.25
Energy cost		$ 0.06	$ 0.06	$ 0.08
CEL cost		$ 18.00	$ 18.00	$ 18.00
Avoid cost		$ 27,651.55	$ 28,088.10	$ 34,658.22
CELs earnings		$ 8,280.00	$ 8,226.00	$ 8,172.00
EBITDA	-$ 259,571.00	$ 34,581.55	$ 34,862.85	$ 41,270.13
Depreciation		-$ 259,571.00	$ -	$ -
Loan Interest		$ -	$ -	$ -
Tax Base		-$ 224,989.45	$ 34,862.85	$ 41,270.13
Taxes		$ -	-$ 10,458.85	-$ 12,381.04
Net Revenue		-$ 224,989.45	$ 24,403.99	$ 28,889.09
Discount in total Balance	$ 77,871.30			
Debt Principal		$ -	$ -	$ -
Net Cash Flow	-$ 181,699.70	$ 34,581.55	$ 24,403.99	$ 28,889.09
Cumulative Cash Flow	-$ 181,699.70	-$ 147,118.15	-$ 122,714.15	-$ 93,825.06

Payback	7.21	years
IRR	14%	
Debt Payment	$ -	
NPV	$ 128,215	USD

4	5	6	7	8	9
$ -	$ -	$ -	$ -	$ -	$ -
451,181	447,955	444,729	441,503	438,277	435,051
451	447	444	441	438	435
$ 1,677.10	$ 1,802.88	$ 1,938.10	$ 2,083.46	$ 2,239.72	$ 2,407.70
$ 32,299.72	$ 34,722.20	$ 37,326.36	$ 40,125.84	$ 43,135.28	$ 46,370.42
$ 0.08	$ 0.08	$ 0.08	$ 0.08	$ 0.08	$ 0.08
$ 18.00	$ 18.00	$ 18.00	$ 18.00	$ 18.00	$ 18.00
$ 37,209.44	$ 35,308.22	$ 34,499.01	$ 33,538.33	$ 33,589.27	$ 36,111.90
$ 8,118.00	$ 8,046.00	$ 7,992.00	$ 7,938.00	$ 7,884.00	$ 7,830.00
$ 43,650.34	$ 41,551.34	$ 40,552.91	$ 39,392.87	$ 39,233.55	$ 41,534.21
$ -	$ -	$ -	$ -	$ -	$ -
$ -	$ -	$ -	$ -	$ -	$ -
$ 43,650.34	$ 41,551.34	$ 40,552.91	$ 39,392.87	$ 39,233.55	$ 41,534.21
-$ 13,095.10	-$ 12,465.40	-$ 12,165.87	-$ 11,817.86	-$ 11,770.07	-$ 12,460.26
$ 30,555.24	$ 29,085.94	$ 28,387.04	$ 27,575.01	$ 27,463.49	$ 29,073.95
$ -	$ -	$ -	$ -	$ -	$ -
$ 30,555.24	$ 29,085.94	$ 28,387.04	$ 27,575.01	$ 27,463.49	$ 29,073.95
-$ 63,269.83	-$ 34,183.89	-$ 5,796.85	$ 21,778.16	$ 49,241.64	$ 78,315.59

10	11	12	13	14	15
$ 5,000.00	$ -	$ -	$ -	$ -	$ -
431,825	428,599	425,373	422,147	418,921	415,695
431	428	425	422	418	415
$ 2,588.27	$ 2,782.39	$ 2,991.07	$ 3,215.40	$ 3,456.56	$ 3,715.80
$ 49,848.21	$ 53,586.82	$ 57,605.83	$ 61,926.27	$ 66,570.74	$ 71,563.55
$ 0.09	$ 0.09	$ 0.09	$ 0.09	$ 0.09	$ 0.09
$ 18.00	$ 18.00	$ 18.00	$ 18.00	$ 18.00	$ 18.00
$ 37,547.63	$ 38,270.66	$ 36,990.28	$ 36,726.40	$ 36,445.74	$ 36,477.40
$ 7,758.00	$ 7,704.00	$ 7,650.00	$ 7,596.00	$ 7,524.00	$ 7,470.00
$ 37,717.36	$ 43,192.27	$ 41,649.20	$ 41,107.00	$ 40,513.18	$ 40,231.60
$ -	$ -	$ -	$ -	$ -	$ -
$ -	$ -	$ -	$ -	$ -	$ -
$ 37,717.36	$ 43,192.27	$ 41,649.20	$ 41,107.00	$ 40,513.18	$ 40,231.60
-$ 11,315.21	-$ 12,957.68	-$ 12,494.76	-$ 12,332.10	-$ 12,153.96	-$ 12,069.48
$ 26,402.15	$ 30,234.59	$ 29,154.44	$ 28,774.90	$ 28,359.23	$ 28,162.12
$ -	$ -	$ -	$ -	$ -	$ -
$ 26,402.15	$ 30,234.59	$ 29,154.44	$ 28,774.90	$ 28,359.23	$ 28,162.12
$ 104,717.74	$ 134,952.33	$ 164,106.78	$ 192,881.68	$ 221,240.90	$ 249,403.02

16	17	18	19	20
$ -	$ -	$ -	$ -	$ -
412,469	409,243	406,017	402,791	399,565
412	409	406	402	399
$ 3,994.48	$ 4,294.07	$ 4,616.13	$ 4,962.34	$ 5,334.51
$ 76,930.81	$ 82,700.62	$ 88,903.17	$ 95,570.91	$ 102,738.72
$ 0.09	$ 0.09	$ 0.09	$ 0.09	$ 0.09
$ 18.00	$ 18.00	$ 18.00	$ 18.00	$ 18.00
$ 35,982.29	$ 35,738.62	$ 35,501.49	$ 35,177.53	$ 34,908.86
$ 7,416.00	$ 7,362.00	$ 7,308.00	$ 7,236.00	$ 7,182.00
$ 39,403.81	$ 38,806.55	$ 38,193.37	$ 37,451.20	$ 36,756.35
$ -	$ -	$ -	$ -	$ -
$ -	$ -	$ -	$ -	$ -
$ 39,403.81	$ 38,806.55	$ 38,193.37	$ 37,451.20	$ 36,756.35
-$ 11,821.14	-$ 11,641.96	-$ 11,458.01	-$ 11,235.36	-$ 11,026.90
$ 27,582.67	$ 27,164.58	$ 26,735.36	$ 26,215.84	$ 25,729.44
$ -	$ -	$ -	$ -	$ -
$ 27,582.67	$ 27,164.58	$ 26,735.36	$ 26,215.84	$ 25,729.44
$ 276,985.69	$ 304,150.27	$ 330,885.63	$ 357,101.47	$ 382,830.91

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