



Addis Ababa University
Addis Ababa Institute of Technology
School of Multidisciplinary
Energy Center Department

**Bussing Machine Improvement of 20MW/Year Solar Panel
Production Line:**

**A case study of Ethiopian Power Engineering Industry
(Sandafa)**

A Thesis Submitted to the School of Graduate Studies of Addis Ababa University
in Partial Fulfillment of the Requirements for the Award of the Degree of Master
of Science in Energy Technology

By: Samrawit Temesgen

Advisor: Kassahun Yimer (PhD)

SEPTEMBER, 2022

CERTIFICATION

I, the undersigned, certify that I read and hear by recommend for the acceptance by Addis Ababa university, Addis Ababa Institute of Technology, Energy Center a thesis entitled “Bussing Machine Improvement of 20MW/Year Solar Panel Production Line: A case study of Ethiopian Power Engineering Industry (Sandafa) ”. This certificate used as a partial fulfillment of the requirement for the degree of Master of Science in energy technology.

Signature _____

Date _____

DECLARATION

I, **Samrawit Temesgen** , I declare that this thesis is the result of my own work and that all source and material used for this thesis have been duly acknowledged. This thesis is submitted in partial fulfillment of the requirement for master's degree in energy technology at Addis Ababa university and to be made available at the at the university's library under the role of the library. I confidently declare that this thesis has not been submitted to any other institutions anywhere for the award of any academic degree, diploma, or certificate.

Candidate

Name:

Signature _____

Date _____

Adviser

Name: Kassahun Yimer (PhD)

Signature _____

Date _____

Addis Ababa University
Addis Ababa Institute of Technology
School of Multidisciplinary
Energy Center

**Bussing Machine Improvement of 20MW/Year Solar Panel Production Line:
A case study of Ethiopian Power Engineering Industry (Sandafa)**

By: Samrawit Temesgen

Approved by Board of Examiners:

Kassahun Yimer (PhD)
Advisor

Signature

Date

Internal examiner

Signature

Date

External examiner

Signature

Date

Chairman

Signature

Date

Director of post Graduate Program

Signature

Date

ACKNOWLEDGMENT

I would like to thank God, for giving me this blessed opportunity. I would sincerely like to thank my advisor Dr. Kassahun Yimer and also head of our department Dr. Solomon for all the support, encouragement and technical guidance they gave me. I would like to thank employees of Ethiopian Engineering Industry specifically Ato Habtamu for having trust in me and providing the necessary resources and support without hesitation which this thesis wouldn't be accomplished. Moreover I am indebted to my husband, friends and my parents whose support confidence in me and helped me to complete this study.

DEDICATION

I am feeling honorable to do a research on the first PV panel production industry in our country Ethiopia the Ethiopian Power Engineering Industry. So I would like to dedicate this research paper to my lovely and adorable daughter.

ABSTRACT

Ethiopia has plenty of sunshine months compared to the developed world and other African countries by recording 80% of solar energy potential. However, currently the one and only renewable energy industry is the “Ethiopian Power Engineering Industry” that stopped the production of the PV panels, due to lack of management skills and economic problems to be competitive on the PV market in assembling the solar cell in the industry continuously. On this research, knowledge based technical solutions given to the management and the supervisor of the industry, while the industry has faced a technical problem on the solar cell connecting machine/bussing machine which means the machine has stopped connecting the solar cells. Data collected from the internet, site survey and questionnaire in order to analyze the problems. Based on the data collected this paper presents innovative solutions with three solar cell connecting technology for the technical problem of the bussing/solar cell connecting machine of the 20MW/year PV panel production line in the industry. By comparing these innovative solar cell connecting technologies for the bussing machines simulation run with the software Griddler 2.5 for the bus bars variations the I-V characteristics, power output and the Fill Factor effect of the solar cells simulated. However, currently the industry is using the 2 Bus Bars (2BB) technology produced by the bussing machine but from the output of the software smart wire solar cell connecting technology is preferable. A recommendation was made for the industry economically to apply the smart wire solar cell connecting technology and it is recommended that to do more researches on this technology.

Key words: *Solar cell connecting technologies, PV module production line, bussing machine, Solar cell Bus bars*

ACRONYMS

ARRI	Automation Robotics Research Institute
BB	Bus bars
BEC	Battery Eliminator Circuit
BOS	Balance of System
CAGR	Compound Annual Growth Rate
EEP	Ethiopian Electric Power Cooperation
EJ	Emitter Junction
EVA	Ethylene Vinyl Acetate
FF	Fill Factor
GW	Giga Watt
KWH	Kilo Watt Hour
KWP	Kilo Watt Power
METEC	Ethiopia's Metals and Engineering cooperation
MW	Mega Watt
PPA	Power Purchase Agreement
PV	Photo-Voltaic
R&D	Research and Development
SCARA	Selective Compliance Assembly Robotic Arm
SWCT	Smart Wire Connecting Technology
TW	Terra Watt
USD	United States Dollar

TABLE OF CONTENT

CERTIFICATION	ii
DECLARATION	iii
ACKNOWLEDGMENT.....	v
DEDICATION	vi
ABSTRACT.....	vii
ACRONYMS	viii
LIST OF FIGURES	xi
CHAPTER ONE	1
INTRODUCTION	1
1.1. BACKGROUND OF THE STUDY	3
1.2. PROBLEM STATEMENT	5
1.3. RESEARCH OBJECTIVES	6
1.3.1. General Objectives	6
1.3.2. Specific objectives	6
1.4. RESEARCH QUESTIONS.....	6
1.5 SIGNIFICANCE OF THE STUDY.....	6
1.6 SCOPE OF THE STUDY	6
1.7 ORGANIZATION OF THE STUDY	7
CHAPTER TWO	8
REVIEW OF RELATED LITERATURE	8
2.1 PV PANEL PRODUCTION LINE.....	8
2.2 SOLAR BUS BAR – DEVELOPMENT TRENDS AND FUTURE	9
2.3 PV CELL BUS-BAR TECHNOLOGIES.....	9
2.3.1 Multi Bus Bars Cells.....	11
2.3.2 Smart Wire Connecting Technology (SWCT).....	13
2.4 PV Cell IV Characteristics.....	16
CHAPTER THREE	17
RESEARCH METHODOLOGY.....	17
3.1 RESEARCH DESIGN	17
3.2 DATA COLLECTION	17
3.2.1 Primary Data Collection Methods.....	17

3.2.2	Secondary Data Collection Methods.....	19
3.3	DATA ANALYSIS.....	19
CHAPTER FOUR.....		21
RESULTS AND DISCUSSION.....		21
4.1	RESULTS.....	21
4.2	DISCUSSION.....	26
CHAPTER FIVE.....		27
CONCLUSION AND RECOMMENDATION.....		27
5.1	CONCLUSION.....	27
5.2	RECOMMENDATIONS.....	27
BIBLIOGRAPHY.....		29
ANNEX – I.....		31
ANNEX – II.....		32

LIST OF FIGURES

Figure 1 Ethiopia's PV capacity in MW from 2013-2017[4].....	2
Figure 2 Champion efficiencies reported for cells and commercial modules for the established PV manufacturing technologies. [10].....	4
Figure 3 PV Module Production Line Process Flow Chart	9
Figure 4 Old Polycrystalline Silicon PV module with 3BB cells.....	11
Figure 5 Polycrystalline Silicon PV module with 5BB cells.....	11
Figure 6 Diagram representing the enhanced optical performance of using rounded wires over flat Busbars.	12
Figure 7 Worldwide market share trends for more and multi bus bar (bus barless) technology. 13	
Figure 8 Polymer Foil for solar cell connecting technology.....	14
Figure 9 Evolution of standard c-Si cell contacting from 2 bus-bars, 3 bus-bars to 6 bus-bars and ultimately the Smart Wire concept.	15
Figure 10 Equivalent circuit of a solar cell.....	16
Figure 11 Two Bus Bars Connecting Technology IV Out Put.....	21
Figure 12 Five Bus Bars Connecting Technology IV Out Put	23
Figure 13 Smart Wire Connecting Technology IV Out Put	24
Figure 14 Two Busbar technology losses output.....	24
Figure 15 Five Busbar technology losses output	25
Figure 16 Smart Wire Connecting Technology losses output	25

CHAPTER ONE

INTRODUCTION

Solar energy is an energy that the nature gives us freely. It is one of the renewable energy sources that generate electricity. Even if solar energy is complimentary its cost of electricity is not free. The primary concern on the solar energy technologies is the practical use of the solar radiation in which all other non-geothermal renewable energies obtain their energy from the sun's energy. According to how they capture, generate and distribute sunlight, solar technologies can be characterized as either passive solar or active solar. Photovoltaic modules also known as photovoltaic panels are used to convert the available solar radiation into useful energy.

PV systems are currently too expensive to be competitive with consumer electricity pricing. It is necessary and feasible to significantly lower the cost of turn-key systems. Solar electricity costs currently range from € 0.50/kWh in North West Europe to € 0.35/kWh in Southern Europe. By 2015, PV generation costs of 0.15 €/kWh must be achieved in Southern Europe in order for solar electricity to be competitive with consumer electricity (also known as "grid parity"). This equates to a turn-key system cost of €2.5/Wp. This system's cost is the result of normal manufacturing and installation expenses that are under €2.0/Wp. [1]

If you take into account Ethiopia's aptitude for off-grid energy systems, it has a big potential to become the center of the solar energy technologies market. More than 75% of Ethiopians reside in rural areas, making it extremely difficult for the national grid to supply all of their energy requirements. One of the main justifications for policymakers to take into account the use of off-grid energy systems, such as solar home systems and mini-grids, is the dispersed nature of rural communities. Ethiopia now has a 44% electricity access rate, with 33% of that coming through grid connections and 11% coming from off-grid options.[2]

This benefit is made possible by Ethiopia's geographic location, which demonstrates that sunshine can reach up to 106GW, depending on the longitude and 40.48970 in the latitude or equator. The amount we obtain through water and hydropower is more than 20,000 times greater. Ethiopia consumed 1.3EJ of energy in 2010, according to the most recent national energy balance. This was produced by burning biomass (92% of the fuel), hydrocarbons (7%) and electricity (1%). Figure 1 below illustrates that the primary users of energy were the residential

and service (93%) and transportation (5%) sectors, with the remainder going to industrial and other applications. [3]

Given the high degree of solar PV capacity in Ethiopia (Figure 1), the creation of solar PV projects provides investors an extremely lucrative opportunity. Since the Ethiopian government wants at least 500 MW of solar installed capacity by 2020, if it wants to meet its ambitious goal, it will have to speed up the development of solar projects.

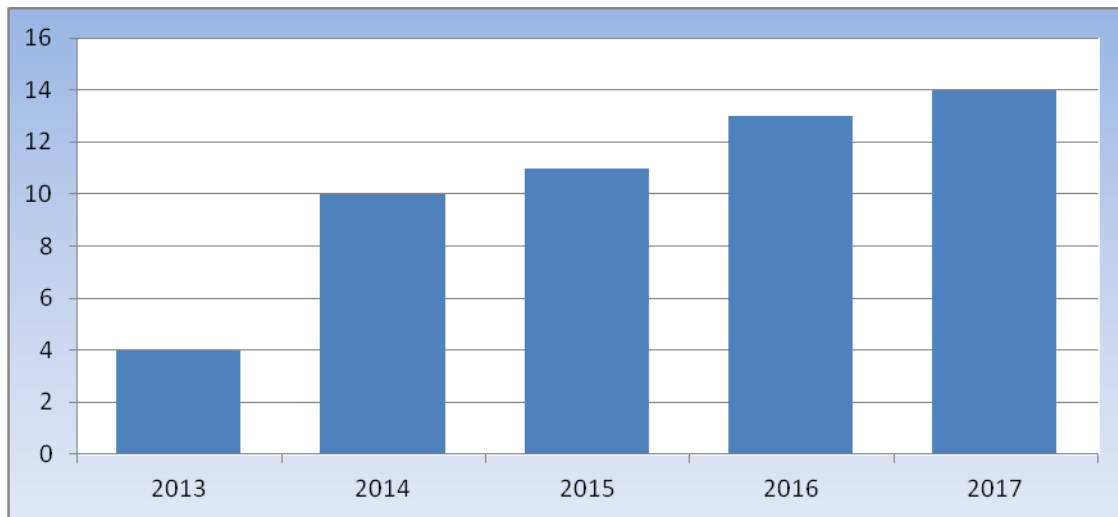


Figure 1 Ethiopia's PV capacity in MW from 2013-2017[4]

Ethiopia's solar PV capacity has nearly tripled over the past five years. Despite the country's abundant solar resources, however, as of now, only 14 MW have been installed, representing 0.3% of the total energy capacity of the country. Nonetheless, from 2016-2017, it was the only that class of renewable year-on-year, as opposed to the stagnant 4.1 on-grid activities, no utility-scale solar photovoltaic projects are currently underway in Ethiopia. Ethiopia's solar energy sector is still in its earliest stages of development, as hydropower plants produce an overwhelming part of the country's electricity. Also, compared to the stagnant growth of wind and hydro-energy applications, it was the only rising class of renewable year-on-year from 2016-2017. With several large-scale projects under construction, solar capacity in Ethiopia is expected to boom in the near future. [4]

PV industry enhances manufacturing processes, accelerates manufacturing cost reductions for PV modules, and increases the quality of commercial products. In our country's reality, the Ethiopian solar power engineering factory is the only and first of its kind for the production of PV modules which will initiate its use in Ethiopia, mostly for rural area. In the Ethiopian solar

power engineering factory there are two solar panels in the factory, each equipped with 20MW, 72MW and a variety of watt-size solar panels. But the machines mentioned above failed to produce the annual production needed for the factory. 50% of the employee worked but could not be employed for up to 3 years due to the above barriers.

The use of renewable energy to keep it alive and to keep electricity running for a second is extremely lucrative and easy for Ethiopia, as it makes life easier and easier. The Ethiopian solar power engineering factory is part of the Power Engineering Corporation of Ethiopia (BEC), the latest powerhouse of the modern era and is a good opportunity to be installed in Ethiopia. It is estimated that 85% of the Ethiopian population lives in rural areas. And, as Ethiopia is a developing country, it is known that electricity is not available throughout Ethiopia. [5]

1.1.BACKGROUND OF THE STUDY

Solar PV Production worldwide

For the past decade solar photovoltaic has been increase at an average rate of > 40 % per year with annual loads in 2009 exceeding 8 GW; this number will double in 2010. By supporting the transition of PV market financially for the next decade complete economic benefit for additional development. [6]

By setting double the magnitude of PV manufacturing production levels increased by TW/year transforming the community from the use of fossil fuels to renewable energy sources. Even though the challenges are discouraging the chance to take in is limitless. With an average power of more than 1000 W/m^2 flux the sun provides at peak hour. By considering the generation, transportation and storage the net conversion efficiency assumed to be 10% which will cover approximately 10^{12} square meter which needs 30 TW of clean energy. Considering the lifetime of the PV panel with an average of 30 years leads to an approximation of $5 \times 10^{10} \text{ m}^2 / \text{year}$ power production. The production of a flat glass globally is $6 \times 10^9 \text{ m}^2 / \text{year}$ which covered by the construction and automotive companies. [7]

During the past seven years two significant changes have been experienced. In the PV market silicon has increased 99% which directed by Japan and Europe by 2003. While crystalline silicon still leads the PV market taken by the China as the top manufacturer for about 85%. [8]

By taking the lead in the PV market China become 50% supplier of PV modules in the world. At a lower labor costs the Chinese government investment, access to cheap capital for module production at lower costs which increased its competitors in Japan, Europe and the US. [9]

The most significant point is that the existence of CdTe demonstrates to the rapid change of the PV industry go through contained by a relatively short period of time. As shown on Figure 2 that displays the champion generally power conversion efficiencies for laboratory solar cells and commercial modules for the conventional PV manufacturing technologies. Thus values are from the latest compendium by Green et al. [10]

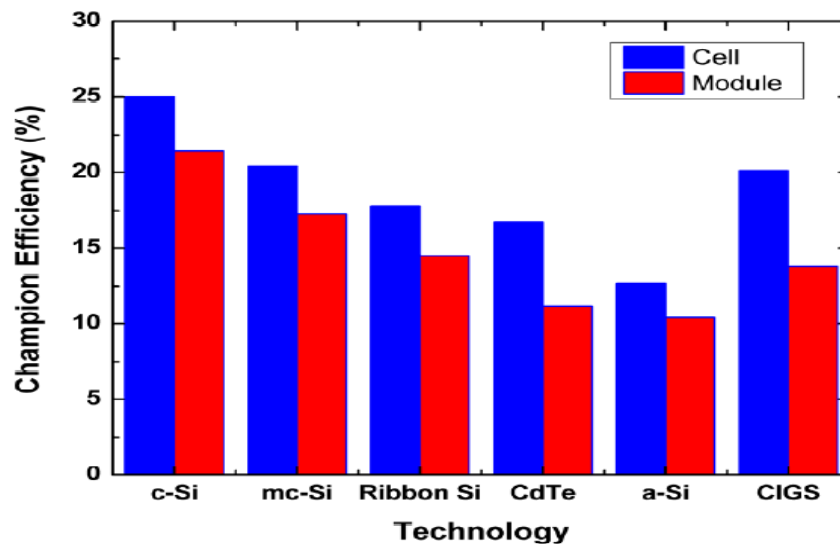


Figure 2 Champion efficiencies reported for cells and commercial modules for the established PV manufacturing technologies. [10]

PV Panel Production in Ethiopia

In February 2013, a 20 MW module manufacturing plant was opened in Addis Ababa, **Ethiopia**. The factory is a joint project between SKY Energy International and Ethiopia's Metals and Engineering Corporation (METEC). As seeing from the journals factory was upgraded to 100 MW manufacturing capacity in 2015 [Eth 2015]. Press reports confirmed the Ethiopian Electric Power Corporation (EEP) approved three solar plants with a capacity of 300 MW in the eastern region of the country [Ven 2013]. In August 2016, EEP announced to tender the three projects, which will be located in Metahara, Humera and Mekelle [Ena 2016].

In 2016, EEP signed an agreement with IFC to advise on the development of up to 500 MW of solar power under the Scaling Solar initiative. The pre-qualification bid for two 125 MWAC PV plants as part of the World bank's Scaling Solar program in November 2017 resulted in the announcement of a dozen qualified bidders in March 2018. In October 2017, it was announced that a consortium with Enel and the Ethiopian infrastructure company Orchid Business Group, had been selected as the developers of the 100 MWAC Metahara project [Ene 2017]. The plant is expected to enter into operation in 2019. It is estimated that a solar PV capacity of about 30 MW was operational at the end of 2017.

In our country's reality, the Ethiopian solar power engineering factory is the only and first of its kind for the construction or operation of a solar plant which will provide an alternative source of energy for the Ethiopian people. In the Ethiopian solar power engineering factory there are three PV panel production lines in the factory, each equipped with 20MW and 72MW solar panels and Solar Lantern joints, but the PV production line of 20MW and 72 MW mentioned above failed to produce the annual production needed for the factory. In which 50% of the employee worked but could not be employed for up to 3 years due to the above difficulty. [11]

1.2. PROBLEM STATEMENT

However there are two solar panel production lines in the Ethiopian Power Engineering Factory in Sandafa, those are 72MW/Year and 20MW/Year. Those production lines were purchased by US firm Spire. In which the PV production line with 20MW/Year was exposed to the current problem as stated below.

Bussing Machine Problem

Bussing machine is one of the components of the PV panel production line. This component has major contribution to the surface of the solar cells. In which the current bussing machine of the 20MW/Year PV panel production line has faced a problem. The main problem of this bussing machine is the 6k6 controller lose physical link with the mobile planner software that cause power not to be recalculated with the PLC and optical computer.

The assembly line of 20MW PV panel production line is unable to produce the expected product for various reasons; currently with temporary solution the rate of this machine would produce 2 bytes even though the production capacity of the assembly line is failed. Based on the level of the current problems of the bussing machine of 20MW PV production line will be the focus of this paper. [12]

1.3. RESEARCH OBJECTIVES

1.3.1. General Objectives

To suggest a solution for the bussing machine of the 20 MW/year PV Panel production line in Ethiopian Power Engineering Industry

1.3.2. Specific objectives

- To identify failures of the bussing machine for the 20MW/Year PV module production line.
- To show the basic difference between bus bars technologies using Griddler software output and recommend one technology for the bussing machine of 20 MW/year PV Panel Production Line.

1.4. RESEARCH QUESTIONS

The following research questions have been stated to be analyzed in the research paper:

1. By which aspect of the bussing machine performance of solar PV panels' production line can be affected?
2. How the performances of the solar cells connector (bussing machine) could affect the feature of solar PV panels?
3. Which technologies are crucial for connecting solar cells to overcome the existing problems by increase the performance of solar PV panels?

1.5 SIGNIFICANCE OF THE STUDY

In our country, Ethiopia does not have solar company like assembling of solar cells from refining the cell to assembling it except the Ethiopian Power Engineering Industry. This research paper will focus on the three basic purposes. First, identify failures of the assembly line of 20MW PV panel production line. Second, propose reliable solar cell connecting/bussing machine technology on the production line of 20MW PV panel. At last, this research paper may used as a reference for further research.

1.6 SCOPE OF THE STUDY

This research paper intended to find novel technology based 20MW PV panel assembly line with the objectives of identifying the failures of the assembly line and propose bussing machine technology. **PV cell manufacturing, used raw materials and effect of radiation and**

temperature on the solar cell are not included in this research project. However, a detailed comparison of each technology has been presented in the literature review section.

1.7 ORGANIZATION OF THE STUDY

This research paper contains five chapters. The first chapter stated the introduction of the study, statement of the problem, objective of the study and etc. The second chapter contains the theoretical and empirical literature review on the production line of 20MW PV panel and solar cell connecting technologies. The third chapter includes the research methodology, data sources, data collection methods, data analysis techniques and used software. Chapter four focuses on the results or findings of the study. At last, the fifth chapter discusses on the summary of findings, conclusions and recommendations of the study.

CHAPTER TWO

REVIEW OF RELATED LITERATURE

2.1 PV PANEL PRODUCTION LINE

By considering the production line of PV panel the 92 kg (203 lbs) is heavy to lift the module glass by one person. Consequently these the module glass and the covers moved by roller transports to make the module production easy. There should be 68 inches of a transport width to take the 62 inch wide glass. In general the test direction for the module is in face down direction, so there is no compelling reason to turn the module over.

Photovoltaic Module Production process

- By using the Film Cutting Machine the cutting EVA and placing on the glass substrate.
- Tabber and stringer used as assembling and soldering the strings of cells that interconnected with metal ribbons. EVA glass holds the strings on the lighting table and unloaded it for visual inspection placed directly.
- The lay out machine can align and placing strings on EVA on glass and as an option of the Tabber and stringer)
- At the bussing station by soldering the bus ribbons to connect the strings together by completing the module laminate circuit and provide the outputs.
- I-V characteristics at the inspection station can be measured by visual inspection and electrically testing the module laminate circuits.
- For encapsulation preparation the cutting EVA and back sheets to lengthen and assemble them on the glass and cells circuits.
- Using the laminator the EVA can be laminated and cured.
- The JB station used to frame assembly and attaching a junction box. To complete the final assembly includes edge trimming at the trimming station, installing and edge gasket and the frame.
- Performing a high voltage isolation test in order to measure the voltage isolation between the cells circuit and the module frame, and testing the frame ground continuity.
- Solar Simulator used as measuring the performance electrically tested the module at the simulated sunlight.
- The last process for module production is visually inspected for quality of materials and workmanship. The module line process flow is shown below in Figure 4 [13]

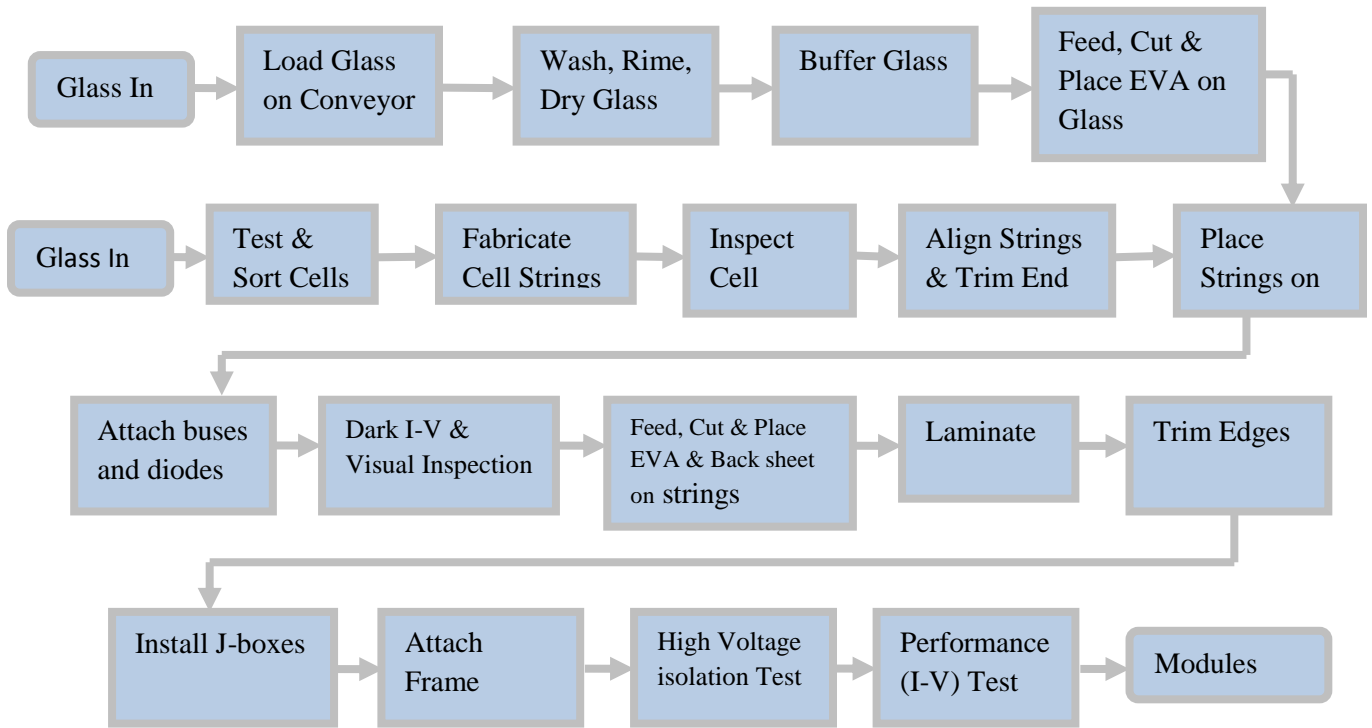


Figure 3 PV Module Production Line Process Flow Chart

2.2 SOLAR BUS BAR – DEVELOPMENT TRENDS AND FUTURE

The 2 or 3 full line bus bars imprinted onto the cell which makes the sun oriented cell configuration the most well-known. Most of all PV modules utilize the 3 bus bar (3BB) cells as they are generally reduced. While working on the improvements on the existing sunlight based cell advancements is getting gradually harder as scientists argue on the additional regular cells. In order to get a steady quality on the business of cell and additional efficiency, there should be new sun based cell advances in standard sight. The main points of these standard bus bars activities. There are some methodologies are more complex and occupied to cell performance and reliability. In addition to the decrease in material expense with respect to the silver glue that can be utilized in making normal bus bars- just as for some texture upgrades.

2.3 PV CELL BUS-BAR TECHNOLOGIES

The most common PV module fabrication technology is the 2 - sided stringing contacted photovoltaic cells. The produced electrical current is accumulated into two or more busbars in metal fingers distributed across the cell. To form a cell string the soldered tin lead (Sn62Pb36Ag2) coated copper ribbons to these busbars and the cells are electrically connected in

series. The content of the silver vary but the rest of the alloy composition relatively stable to maintain the formulation required for reliability. The width of these ribbons is a compromise between shadowing and resistive losses on the illuminated cell surface. Each cell strings are connected together using string connection ribbons and laminated to form the PV module.

The producer modifies the ribbon size for every module product. The soldered ribbons used as in different applications, like hot bar, laser, hot air, infrared, and induction. Throughout the process the alloy temperature must be elevated above the melting temperature of the solder alloy $>185^{\circ}\text{C}$ to form a solder joint between the ribbons and the cell. This can be reached by gradually heated stages in industrial tabber and stringers in order to minimize the thermal stress on the cell and increase production yield. The number of busbars increased in order to improve both the growing trend to update the electrical performance and optical losses. [14]

For the same loss the lower resistive losses can be found for the same amount of material by decreasing the finger losses. Less reflection out of the module occurred according to the size of the ribbons with narrow ribbons that improves sunlight recovery and yields a higher current. To increase the solder use and the Pb content in the PV module by increasing the number of busbars on the cell and interconnection ribbons on the module. In order to increase the volume of PV module from 5 to 10% led by increasing the number of the busbars on the cell and interconnection ribbons on the module. The peak point for the trend is a multi-wire interconnection technology by eliminating the busbars on the cells and significantly decreasing the conductivity of the fingers, lowering the cost of silver metallization at the cell level.

The advantages of the electrical and optical the aesthetics of the module surface improved by resulting darker with the reduced optical losses and more uniform module. On the market these two multi-wire interconnection technologies are available. The one method to simulate effectively the standard technology by soldering SnPbAg coated ribbons on fingers solder pads and replacing the busbar with SnPbAg coated ribbons. [15]

By using the numbers of busbars on the PV cells is usually a challenge. The more busbars means more electrons can be gathered and the cells mechanical strength is increased; though it means on the cell surface the more inactive area which can be reduced in efficiency. By increasing the multi busbars to 12% to the future and the smart wire connection technology can be used as optimization to collect the electron and reduce the shading on the cell surface. [16]

2.3.1 Multi Bus Bars Cells

The predictable amount of the modules bus bar increased from three to four or five when the ribbons thickness lowers down to 0.9mm. In which the interconnection ribbons has been narrower than the original width and this results the more busbars the less the module efficiency by increasing the shading loss. The width of the ribbons used the interconnection ribbons than using the copper wires by reducing the width to 0.3mm with the increasing in the number of busbar. By reducing the shading loss the copper wire reflect particular incident light back to the solar cells. [17]

The most important solar cell and module are the multi bus bar cells than that of the 5 bus bar (5BB) cells. PV module producers like Sun Based World and Trina Sun Powered increased their production on the sun based PV modules by using the Passive Producer Back Contact (PERC) sun based on the 5BB front side contacts. Due to the lesser distance between the bus bars that extended the bus bars which decreased the inside disapproval misfortune.



Figure 4 Old Polycrystalline Silicon PV module with 3BB cells



Figure 5 Polycrystalline Silicon PV module with 5BB cells

According to the increasing the numbers of bus bars which enlarges the sun oriented cell, in general implementing the multi bus bar cells is higher to that of the traditional 2BB or 3BB cells. This situation happens due to the decrease of the effective finger length between the bus bars which reduces the finger obstacles with the lesser effects on miniature breaks.

The aims of the Multi-Bus Bars approach are to reduce the resistive losses by decreasing the amount of the current that flows in both sides of fingers and the busbars. While the busbars printed on the wafer there exist the space between them reduces, reducing the length that current flows in the fingers which is a large source of series resistance losses. As the resistive power loss P_{loss} scales with I^2R , this means that if the current is reduced by half, the resistive losses are reduced by a factor of four. The MBB approach thus allows both bus bars and fingers to be smaller in size and hence, a smaller volume of silver, one of the most expensive consumables, is used in solar cell manufacturing. From 50% - 80% reduction of silver occur while using the MBB approach. It also the finger shading reduces with the less silver in the front. Bus bars are normally printed flat and require soldered flat ribbons to carry the current away from the cell, introducing more shading and resistive losses. MBB are thin, rounded copper wires that do not require ribbons across the solar cell, than to carry the current from the fingers through the interconnecting ribbons outside the front surface of the cell. As shown in Figure 11, their rounded cross-section also increases optical performance, allowing for more light to reflect onto the solar cell.

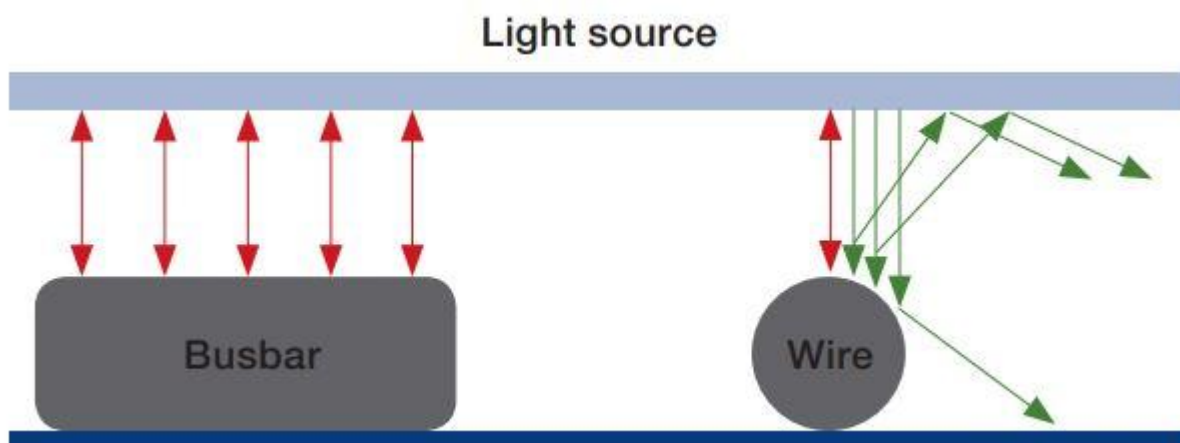


Figure 6 Diagram representing the enhanced optical performance of using rounded wires over flat Busbars.

Additionally, the global market share has a bifacial technology gains that the potential to increase the bifaciality of the PERC cells with the MBB approach. While the front and rear power ratio gives Bifaciality. By using MBB approach which gives smaller rear aluminum fingers that can be printed and decrease the shading of the rear side of the cell. Generally the bifaciality of the cell is less vulnerable to micro cracks. This is because MBB decreases the chances of cracked parts of the cell maintaining electrical contact with the rest of the cell.

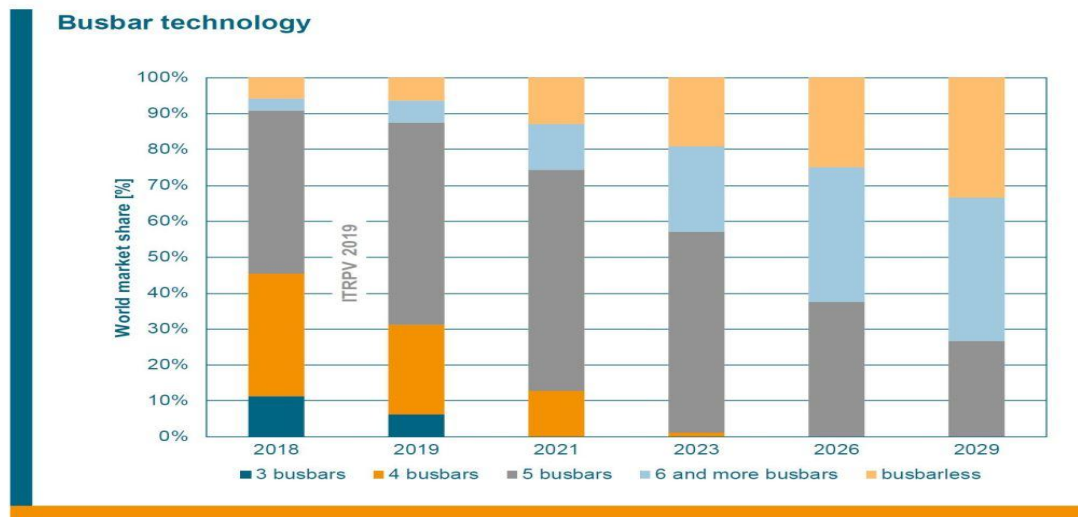


Figure 7 Worldwide market share trends for more and multi bus bar (bus barless) technology.

MBB technology has been implemented by two different techniques. Smart Wire Connection Technology (SWCT), which is Meyer Burger’s approach, and a more traditional soldering method originally developed by Schmid. [18]

2.3.2 Smart Wire Connecting Technology (SWCT)

The Smart Wire Connecting Technology (SWCT) is a creative interconnection innovation for translucent silicon sunlight based cells. It was begun by Day4 Energy, in Canada, and is currently developed and industrialized by Meyer Burger. In order to get the benefits of expansion in productivity, cell reaching at low temperature, diminished utilization of silver and upgrade of module dependability, by using the Keen Wire. At the present day Meyer Burger suggests entirely computerized Savy Wire module line with 90MW/year limits.

By comparing the benefits of the Smart Wire Connecting Technology with the other technologies it makes it preferable, considering the following benefits:

1. Increasing the productivity of the solar cell by bringing down the ohmic value with the improved light administration.
2. Module overlay can cause low temperature
3. The value of the silver can be decreased by 85%.
4. Improved modules with quality.
5. The distribution of the improved power.

The record module shows an exceptionally superior with an ensured MPP of 327 Wp, comparing to 20% module productivity, one of the greatest confirmed proficiency for 60 cells modules. [19]

As shown from Figure 1 the copper wires includes a polymer foil in which the wires are covered by slight low dissolving point combination layer, by softens during the module overlay cycle and develops a patch contact to the phone metallization. The procedures were first proposed by Day4 Energy. Which replaces cutting edge bus bars and the strips innovation and is applied to cells with front metallization not carrying out bus bars though completely fingers, as bus bar-less cells. Figure 1: Image of a Smart Wire foil over a bus bar-less cell.

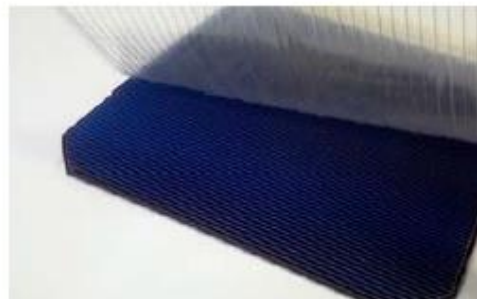


Figure 8 Polymer Foil for solar cell connecting technology

The SWCT enables using the more current removal ways of opposite to the phone metallic fingers than in the standard bus bar innovation because of the low wire optical measurement and to its immediate interconnection to the attached cell. This empowers to go from the 2, 3 or 6 bus bars commonplace plans to in excess of 18 wires interconnection, as demonstrated in Figure 8, without expanding shadowing misfortunes.



Figure 9 Evolution of standard c-Si cell contacting from 2 bus-bars, 3 bus-bars to 6 bus-bars and ultimately the Smart Wire concept.

At low temperature the SWCT preparing conditions allow to complete the interconnection at the module overlay, which vary the temperature of around 140-160 °C, with bus bar strip innovation (See Figure 3), along these lines instigating less thermo-mechanical weight on the cells. [20]

The front pads of the solar cells shade the incident light and the soldering process that may increase the breakage rate of the cells. On the side of the MBB technique called the Smart wire Connection Technology (SWCT) which avoid the obstacles that most of the solar cells faced. The solar cell bus bars can be avoided and the wires are constrained onto the cells by the composite films while encapsulation and form ohmic contact with the fingers. The low melting point coatings can cause the wires to increase the contact reliability. [21]

At the present the innovating different technologies happens for the reason to reduce the production costs and higher efficiency solar modules into the market. While Meyer Burger is one of the earlier researchers who have been introduced Smart Wire Connection Technology (SWCT) to the solar industry. According to the technology different benefits were introduced for PV manufacturing companies. On the other side the 2 to multi bus bars technology can be replaced by connecting solar cells electrically used thin copper wire for both sides of the cell. Using this technology will benefit the company the following four main improvements on the PV m module:

- 5% higher module power and 10% more energy yield (kWh/kWp)
- Reduction of production costs up to -0.25 USD/cell
- Universal cell compatibility
- 5% higher module power and 10% more energy yield (kWh/kWp)

2.4 PV Cell IV Characteristics

The basic factors can determine whether PV cell bus bar technology is superior to another using the IV characteristics of those PV cell bus bar technologies. The output of current and voltage as well as efficiency are these fundamental characteristics. The PV cell bus bar technology is better the higher the fundamental characteristics. The equivalent circuit of solar cell is sometimes known as a two-diode model since it uses two diodes. To detect the light-induced current and detect any shunt current, if any, parallel shunt conductance will be placed between these diodes and another current source. The following equation can be used to determine the equivalent circuit's IV characteristics.

$$I(V_{\text{diode},i}) = I_{L,i} - I_{01,i} e^{(qV_{\text{diode},i}/KT)} - I_{02,i} e^{(qV_{\text{diode},i}/2KT)} - G_{\text{shunt},i} V_{\text{diode},i}$$

- $V_{\text{diode},i} = V_{\text{node},i} - V_{\text{ref},i}$
- V_{diode} ; voltage across the circuit
- q ; elementary charge
- K ; Boltzman constant
- T ; cell temperature in kelvin
- $I_{L,i}$; light induced current
- $I_{01}, I_{02,i}$; saturation current for $n=1$ & $n=2$ diodes
- G_{shunt} ; shunt conductance
- $V_{\text{node},i}$; voltage of node i
- $V_{\text{ref},i}$; voltage of opposite side of semiconductor node i

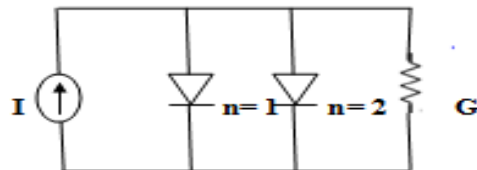


Figure 10 Equivalent circuit of a solar cell

I = induced light current

n = number of diode

G = shunt conductance

CHAPTER THREE

RESEARCH METHODOLOGY

The current chapter describes the process of designing the testing methods required to complete the current study's section. The various stages of developing the methodology for the current study will be discussed in depth in this chapter. Furthermore, the chapter discusses the research design, and also discusses the data collection approach, which includes the selection of interviewee. The chapter comes to with a summary of the data analysis methods that will be used.

3.1 RESEARCH DESIGN

This study used a series of well-structured interview for the management and employee representatives of the industry. A field observation was conducted at the industry site found at Sandafa, Ethiopia.

As a result, this study employs a descriptive research design to reach an agreement on the effects of the bussing machine that could affect the parameters of the solar cells. This design provides researchers with a profile of described relevant aspects of the phenomena of solar cell connecting technologies standpoint. As a result of this research design, there were situations to collect data from a range of respondents on the impact of the current solar cell connecting technology in the Ethiopian Engineering Industry. Which leads to analyzing the responses on how the problem occurred by the bussing machine of the PV panel production line could affect the parameters of the solar cells.

3.2 DATA COLLECTION

On this research paper data can be collected through both primary and secondary data collecting methods. From the primary data collection method interview methods provided effective information for this topic. Personal or telephone interview with the employees of the company as well as a questionnaire were given to the limited employees. Secondary data collected by searching and reading some publications of the company by visiting the site as well as using internet.

3.2.1 Primary Data Collection Methods

This method includes both qualitative and quantitative information. While the qualitative data sources are field observations, interviews, and informal discussions. Whereas, survey and

interview questionnaires are quantitative data sources on this research. The following sections explain how the data was obtained from primary sources.

3.2.1.1 Work Place Site Observation Data Collection

In this dissertation, the observation has been applied as one tool for gathering information and data, prior to the design of the questionnaire as well as after the start of the research. This method discussed the working environment which the PV panel assembly industry specifically the bussing machine problems of the production line.

Site Survey

As I visited the Ethiopian Engineering Industry at Sandafa, Ethiopia has two PV panel production lines which are the 70MW and 20MW. According to the interview with the manager of the industry, the priority has given to the machine to be researched is the one with 20MW PV panel production line, due the difficulty of the available problems. The problem of the 20MW PV panel production line is very difficult which has huge impact to the output (parameters of the solar cell) of the production line, while the research applied directly. As stated above on the statement of the problem which are shown clearly at the industry is as the bussing machine failed (missed to link with the software) to solder the copper plated bus bars on the solar cell properly.

3.2.1.2 Data Collection through Interview

This dissertation was conducted with a qualitative approach and conducting interviews. In order to allows respondents to raise issues that I didn't imagine before about the problems of the bussing machine of the 20MW PV panel production line. Phone interview has been conducted with the manager of the industry, it was easiest way of collecting for determination of specific problems of the 20MW PV panel production line.

1. Which PV panel production line is needs a solution first, is it 20 MW or 70MW?
2. What are the specific problems of the 20MW PV panel production line?
3. Which one of the problems needs priority to be solved first in the 20MW PV panel production line?
4. Why the stated problems of the 20MW PV panel production line should be solved first?
5. What kind of bussing machine technology currently used and is it appropriate for the production line?

3.2.2 Secondary Data Collection Methods

In order to achieve the dissertation's objectives, data's were collected from extensive document review and company reports in both online and offline modes. Literature reviews can be used as content analysis from a methodological stand point, where quantitative and qualitative aspects are combined to assess structural (descriptive) as well as content criteria.

3.3 DATA ANALYSIS

The primary and secondary sources that were covered earlier in this chapter were used to create quantitative data. Based on the data nature, Griddler 2.5 was mostly used for this data analysis. The bus bar technologies and their properties were analyzed using the software Griddler 2.5 to get results with specific criteria. The main focus of this data analysis is on numerical data..

When Griddler software is used three main pages can be displayed as follows: for detail input parameter steps see also Annex-II.

1. H-pattern page: the input parameters for this page will be;

- Wafer shape and size

- Rear and front busbars

- Front fingers

2. Meshing Page

- Post editing- edit the fingers using mouse click on the surface of the solar cell.

- Analyze pattern/front fingers

- Mesh the solar cell, meshing the front and rear semiconductor by analyze the front and rear.

3. Simulation page

- Front metallization

- Metal optical transparency

- Front and rear current extraction

- Front diode parameters

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 RESULTS

I-V Characteristics

In this study's Solar Cell I-V Characteristic Curves, output voltage against current graphs. Because of this, it can reveal a lot about a PV cell's or panel's ability to turn solar energy into electrical energy. It is simple to recommend the solar cell bus bar technology that is best for the current issue that the factory's bussing machine was experiencing by utilizing the program Griddler 2.5 Pro.

Two Bus Bars Connecting Technology

The two bus bars connecting technology has effect on the physical properties of the solar cell. On this case this technology provides significant feature for the outputs of the solar cells. As the solar industry launched, the two bus bars technology for the bussing machine which is usually used for years in the industries of the PV panel production line.

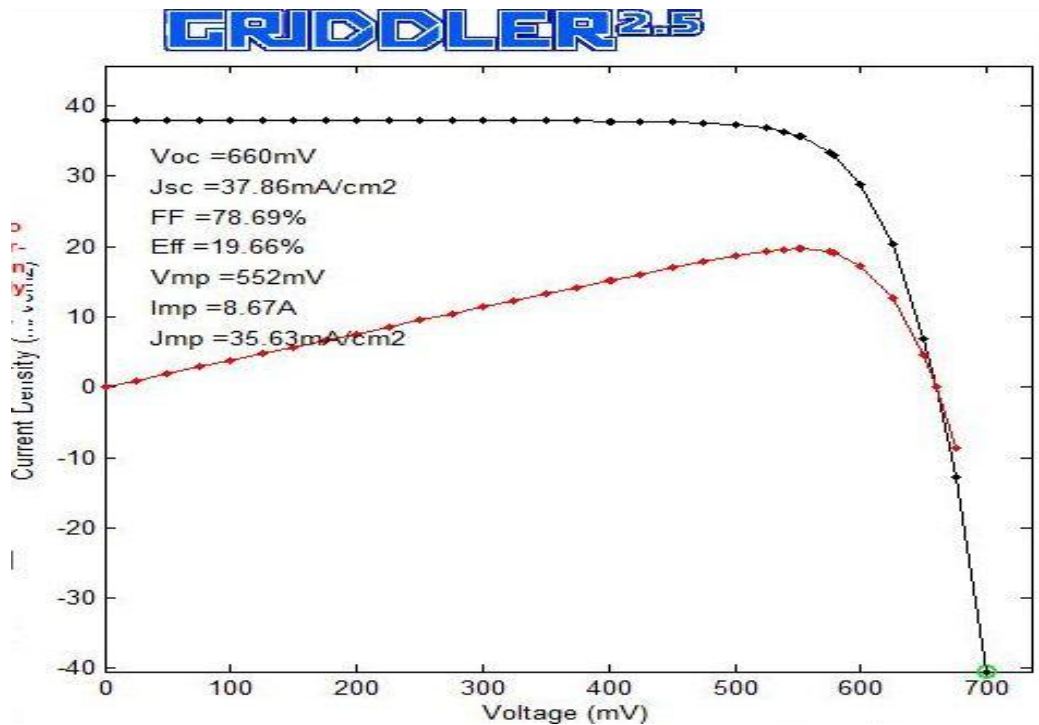


Figure 11 Two Bus Bars Connecting Technology IV Out Put

Graph of cell output current (red line) and power (blue line) as a function of voltage. Also shown are the cells short-circuiting current (I_{sc}) and open-circuit voltage (V_{oc}) points, as well as the maximum power point (V_{mp} , I_{mp}).

$$\mathbf{V_{oc} = 660\text{ mv}}$$

$$\mathbf{J_{sc} = 37.86\text{ m A/cm}^2}$$

$$\mathbf{FF = 78.69\%}$$

$$\mathbf{E_{ff} = 19.66\%}$$

$$\mathbf{V_{mp} = 552\text{ mv}}$$

$$\mathbf{I_{mp} = 8.67\text{ A}}$$

$$\mathbf{J_{mp} = 35.63\text{ m A/cm}^2}$$

The figure shown above is a graph that shows the relation between voltage and current density of the solar cell with two bus bars by using specific variable. The parameters voltage and current at the maximum points in which $V_{mp} = 552\text{ mV}$, $I_{mp} = 8.67\text{ A}$ will give maximum power point which can be calculated as follows;

$$\begin{aligned} \text{MPP} &= V_{mp} \times J_{mp} \\ &= 552\text{mV} \times 8.67\text{ A} \\ &= 4.785\text{ Watt} \end{aligned}$$

Five Bus Bars Connecting Technology

The five bus bars connecting technology has effect on the physical properties of the solar cell. On this case this technology provides significant feature for the outputs of the solar cells. With respect to the power output and efficiency five bus bar solar cell connecting technology have a better result for solar cell industries five bus bars connecting technology has greater value

$$\mathbf{V_{oc} = 657\text{ mv}}$$

$$\mathbf{J_{sc} = 36.52\text{ m A/cm}^2}$$

$$\mathbf{FF = 80.8\%}$$

$$\mathbf{E_{ff} = 19.38\%}$$

$$\mathbf{V_{mp} = 562\text{ mv}}$$

$$\mathbf{I_{mp} = 8.39\text{ A}}$$

$$\mathbf{J_{mp} = 34.47\text{ m A/cm}^2}$$

$$\begin{aligned} \text{MPP} &= V_{mp} \times J_{mp} \\ &= 562\text{mV} \times 8.39\text{ A} \\ &= 4.715\text{ Watt} \end{aligned}$$

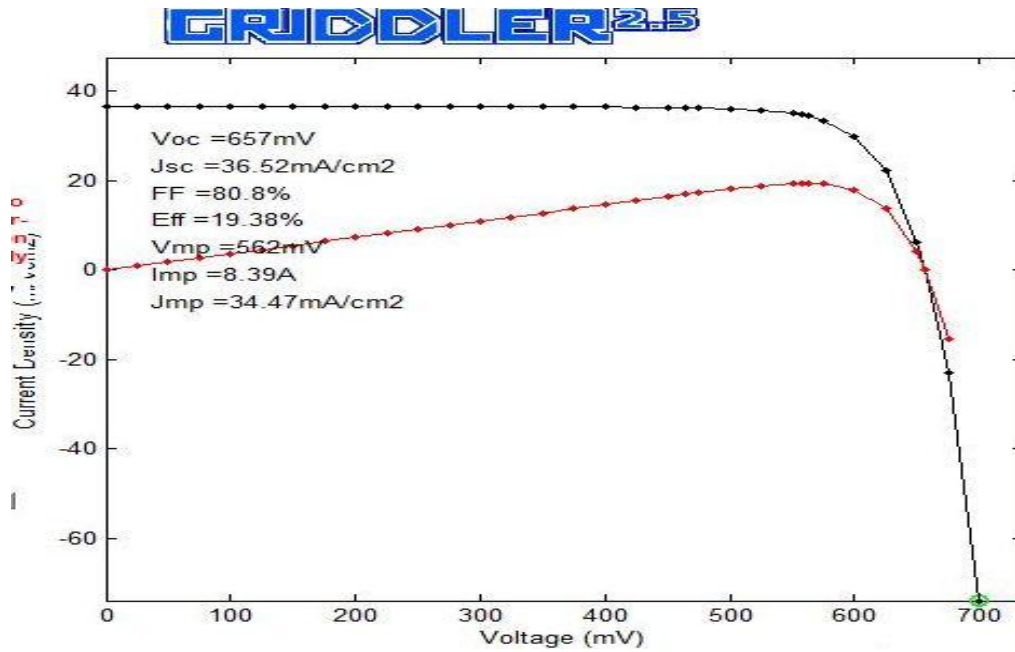


Figure 12 Five Bus Bars Connecting Technology IV Out Put

Smart Wire Connecting Technology/SWCT

The figure shown below is a graph that shows the relation between voltage and current density of the solar cell with smart wire connecting technology by using specific parameter. The parameters at the maximum point of voltage and current gives the maximum power point, $V_{mp} = 568 \text{ mV}$, $I_{mp} = 8.74 \text{ A}$ with the maximum power point can be calculated as follows;

$$\begin{aligned}
 \text{MPP} &= V_{mp} \times J_{mp} \\
 &= 568 \text{ mV} \times 8.74 \text{ A} \\
 &= 4.964 \text{ Watt}
 \end{aligned}$$

$$V_{oc} = 661 \text{ mv}$$

$$J_{sc} = 37.99 \text{ m A/cm}^2$$

$$FF = 81.24\%$$

$$E_{ff} = 20.39\%$$

$$V_{mp} = 568 \text{ mv}$$

$$I_{mp} = 8.74 \text{ A}$$

$$J_{mp} = 35.9 \text{ m A/cm}^2$$

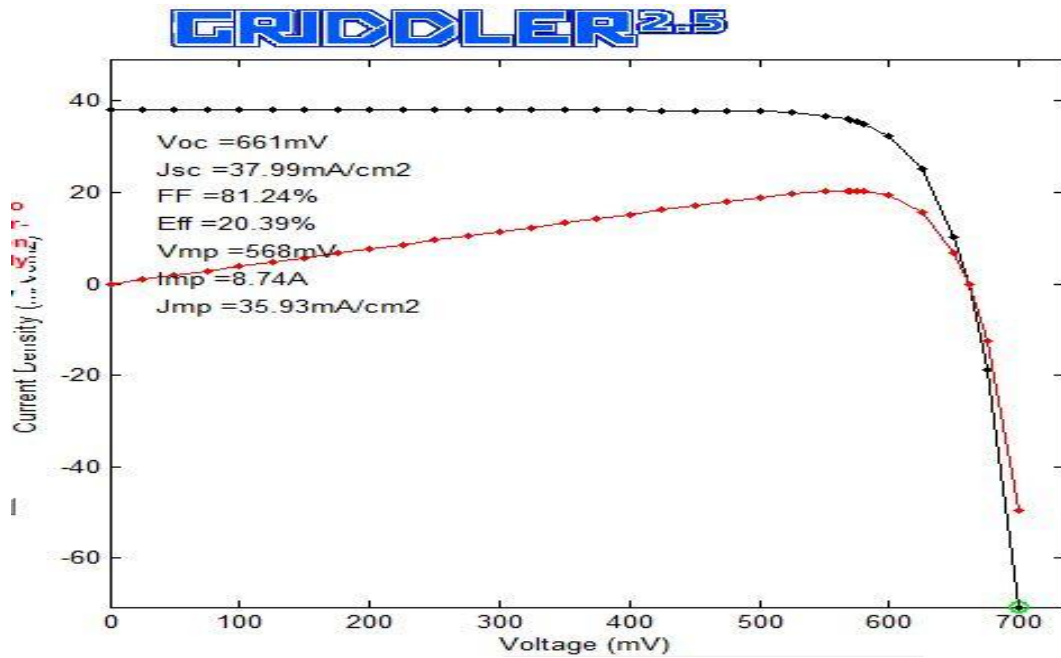


Figure 13 Smart Wire Connecting Technology IV Out Put

LOSS CHART

If there is current flow through the resistance and voltage across the diode of solar cell, some losses have been experienced. Those losses include the power output loss, front and rear resistive losses and front recombination losses.

Two Bus Bar Technology power and loss out puts

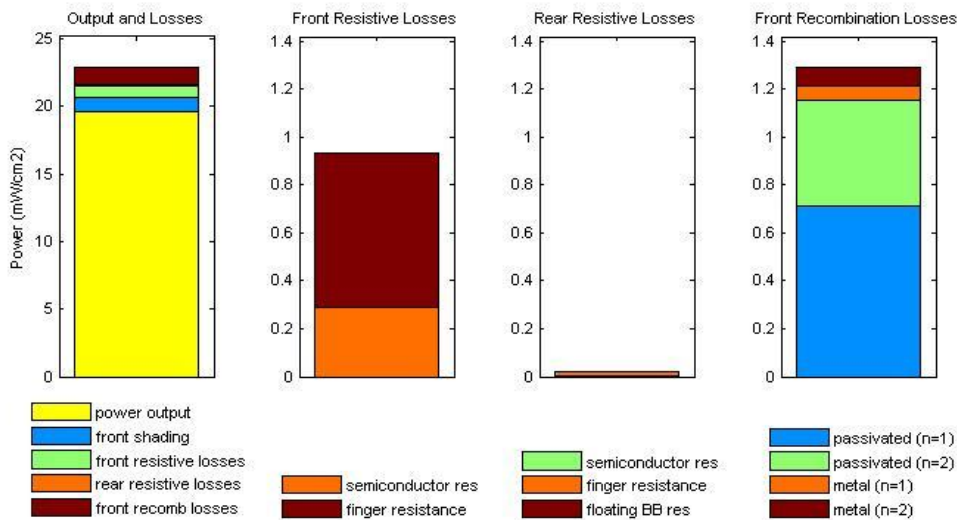


Figure 14 Two Busbar technology losses output

Five Bus Bar Technology power and loss out puts

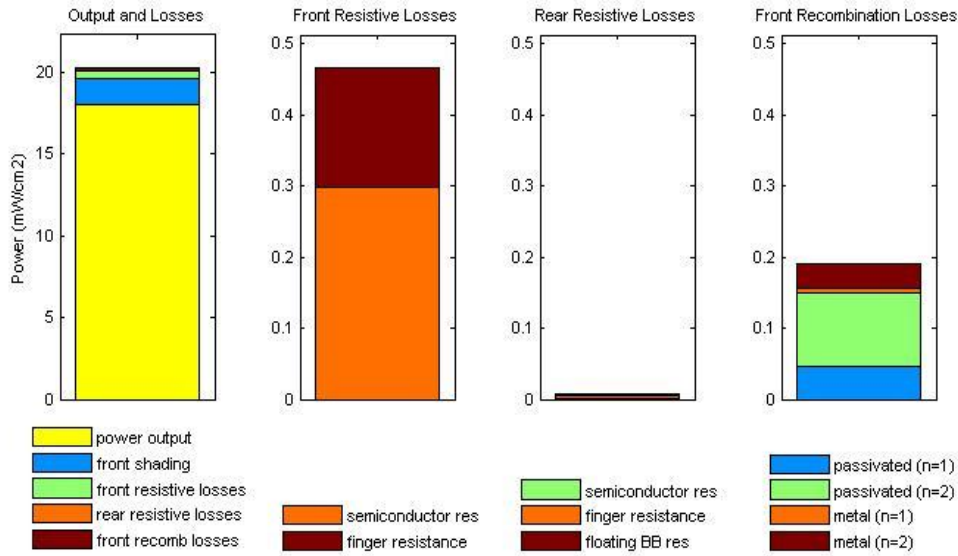


Figure 15 Five Busbar technology losses output

Smart Wire Connecting Technology power and loss out puts

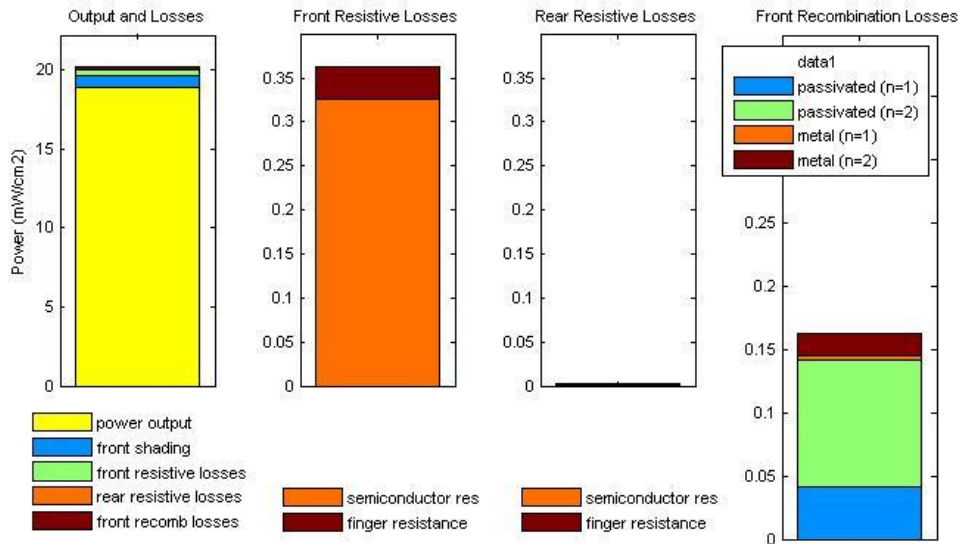


Figure 16 Smart Wire Connecting Technology losses output

4.2 DISCUSSION

The fundamental goal of this study is to discover a technology for the bussing machine of the 20MW manufacturing line of PV panel determined in Ethiopian Power Engineering Company. On the foundation outputs of the photo voltaic cells the find out about used the software Griddler that analyses the given quantity of busses which lead to the required bussing science was proven above. From the figures shown above the result of the power output of these busbar technologies has described. As the number of bus bars will increase the electricity output is almost the same, while the front shading increases. But the front and rear resistive losses are lowering with the increasing quantity of bus bars, for the SWCT as well. Front and rear resistive losses are indicated as the semiconductor and finger resistance losses. These losses lowered with the increasing wide variety of bus bars, in which it is very low for the SWCT. The front recombination loss also diminished with increased wide variety of bus bars, as the same as SWCT. This result will lead to an answer for the bussing machine to characteristic successfully the use of the SWCT. It is clear from the plan above for the SWCT efficiency of the solar cell will extend as compared to others. Those the front and rear resistive losses directly affected by means of the fill factor values, the greater fill factor the greater resistive losses. In which the higher the fill factor the higher semiconductor resistance loss, with decreasing of finger resistance. While the range of bus bars will increase quantity of semiconductor resistive losses will increase, with a decreasing in the finger resistive losses.

By considering the modern-day global market the encouraged photo voltaic connecting technology is smart wire. As referred to from the end result and evaluate from the literature these technologies have large influence on the PV panel market. With respect to the quantity of bus bars which brings a variations to the rate per cell. Some assumptions had been used when there is access to the written records or published documents had been limited, or to triangulate information obtained from other primary and secondary sources. Therefore it is more recommended that the usage of the Meyer Burger's innovative technology leads the Ethiopian Power Engineering Cooperation, on the basis of manufacturing 20MW photo voltaic panels to be fine in accordance to efficiency and costs.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

As a conclusion this research paper received precise records for the PV panel manufacturing line of the 20MW/year for the Ethiopian Power Engineering Industry which is gathered from the research papers, website survey and questionnaires. Therefore with the handy research query results and the accumulated information from the site it can advise for the 20MW/year PV panel production line an answer for the hassle especially on the cell contacting machine which is the ‘assembler’ machine. This solution helps the industry to be technically reliable with the aid of using the contemporary technological know-how and extend the available PV panel production performance per year. By considering the current market analysis from the solar cell connecting technologies the smart wire connecting technology is the exceptional and the least to be greater competitive on the market.

From the outputs of the technologies smart wire connecting technology has given the solar panel easiest efficiency than others. This parameter has an extraordinary impact on the PV panel production industry, by attract the market. Therefore smart wire connecting technology has effect on the 20 MW/year PV panel production line to function successfully with its higher efficiency.

5.2 RECOMMENDATIONS

From the results showed that smart wired connecting technology has a significant effect on the efficiency, cost of the bus bars (copper wires) and technical characteristics of the solar panels passes on this connecting technology. However, clearly indicated outputs of the software on the smart wire connecting technology are more preferable than two and multi-bus bars connecting technologies. This is due to the solar cell connecting section (assembler) can be changed by the smart wire than the bus bars technology in the production line of the solar panel that leads to less cost in the process. Further research is recommended to determine the maximum achievable enhancement of the solar panel production line while using smart wire connecting technology.

In general, from the marketing side of the PV panel production technology is one of the expensive renewable energy sources, whereas from the PV panel production line the solar cell contacting technology has its own impact on the market. This may cause constraint on the

production of PV panels in developing countries like Ethiopia, this kind of problems can be solved as lay man is by doing more research on each technologies. The industry is open to the research centers like universities but it should be promoted for known universities to get best results. Also from the information gathered using site survey and questionnaire it can be suggested that the industry like this should give a knowledge based training for employees who assist the production line, not only on how to run the production line but on how to fix when such kind of problems the machine confront. Also enlarge the research department to work with the universities corporately. The governments on the importation policy of spares for such technologies should give a priority while these technologies used to step up the country economy as well as to make our day to day life easy.

BIBLIOGRAPHY

- [1] P. d. J. I. J. B. T. P. V. J. B. A. V. M.Spath, "FIRST EXPERIMENTS ON MODULE ASSEMBLY LINE USING BACK-CONTACT SOLAR CELLS," in *23rd European Photovoltaic Solar Energy Conference*, Valencia, Spain, 2008.
- [2] M. G.selassie, "Comparative assessment of the challenges faced by the solar energy industry in Ethiopia before and during the COVID-19 pandemic," 01 July 2021.
- [3] E. R. Group, "United States Documents," 01 January 2017. [Online].
- [4] E. Africa, "Solar report on Ethiopia," 2019.
- [5] R. L. M. H. P. T. M. I. S. C. Edwin Witt, "MANUFACTURING IMPROVEMENTS IN THE PHOTOVOLTAICMANUFACTURING TECHNOLOGY (PVMAT) PROJECT," in *2nd World Conference and Exhibition on Photovoltaic Solar Energy conversion*, Golden, Colorado, 1999.
- [6] T. Surek, "Crystal Growth and Materials Research in Photovoltaics, Progress and Challenges," *Journal of Crystal Growth*, pp. 275, 292-304, 16 July 2015.
- [7] S. K. C. P. J. Marc Köntges, "Review of Failures of photovoltaic Modules," 2014.
- [8] P. d. J. I. B. T. V. J. B. M. Spath, "A novel module assembly line using back contact solar cells," 2008.
- [9] S. MEHTA, "2009 GLOBAL PV CELL AND MODULE," GTM RESEARCH, 2010.
- [10] M. E. K. H. Y. a. W. W. Green, "Solar Cell Efficiency Tables," *Progress in Photovoltaics*, pp. 18, 346, 2010.
- [11] Metec, “የሰንጠረዥ ስላር ፓኔል ማምረቻ ፋብሪካ አጠቃላይ ችግር፣ የችግሩ መፍትሄ አቅጣጫና አማራጭ ማሳሰቢያ,” 2019.
- [12] E. Lake and H. D. Zone, "OOITECH," Margret Cao Wuhan Ooi Photoelectric Technology Co., Ltd. [Online].
- [13] M. D. L. Antonin Faes, "SmartWire solar cell interconnection technology," *Interconnection of advanced solar cells*, 2018.
- [14] "VDMA," International Technology Road map for photovoltaic, 2018. [Online].

- [15] SOLARITY, "trends-for-pv-industry-in-2020," 2020. [Online].
- [16] "Ever Exceed Power your application," 18 August 2020. [Online].
- [17] S. G. G.Hah, "Solar Cell Improvement by using a Multi Busbar Design as Front Electrode," vol. 27, pp. 227-233, 2012.
- [18] J. Rodriguez, "Solar Choice," Solar Choice Pty Ltd , June 2014. [Online].
- [19] Z. L. P.-C. H. W. Z. R. C. Y. Y. P. P. A. Lennona, "Patterning for Plated Heterojunction Cells," *Energy Procedia*, vol. 67, pp. 76-83, 2015.
- [20] J. Rodriguez, "Solar Choice," 24 June 2014. [Online].
- [21] M. D. J. L. J. C. A. Faes, "SmartWire Solar Cell Interconnection Technology," in *EU PVSEC*, 2019.

ANNEX – I

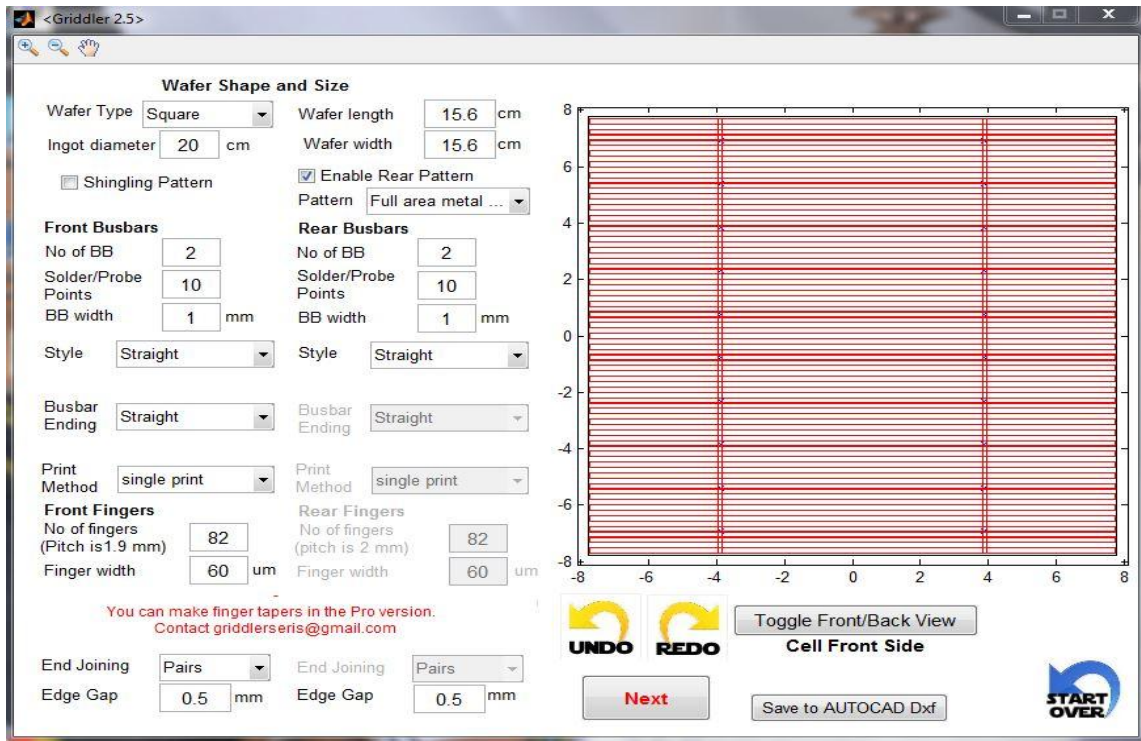
SAMPLE ANSWERS FOR THE INTERVIEW QUESTIONS from the manager

1. Which PV panel production line needs a solution first, is it 20 MW or 70MW?
 - Both the PV panel production lines are in needs of a solution, but depending on the marketing benefits 20MW PV panel production line should be given the priority.
2. What are the specific problems of the 20MW PV panel production line?
 - There are three problems that the 20MW PV panel production line has faced. Those are the bussing machine problems, the laminator and the sun simulator.
3. Which one of the problems needs priority to be solved first in the 20MW PV panel production line?
 - It is not about priority but the problem with the bussing machine couldn't solve. Therefore it is better to get the best solution for it.
4. Why the stated problem of the 20MW PV panel production line should be solved first?
 - It is because the two problems are about software, and it is a simple problem than the bussing machine.
5. What kind of bussing machine technology currently used and is it appropriate for the production line?
 - It is two bus bar technology that the factory using for the 20MW/year PV panel production line. Also it is appropriate for the production line but it is recommended to go with the technology.

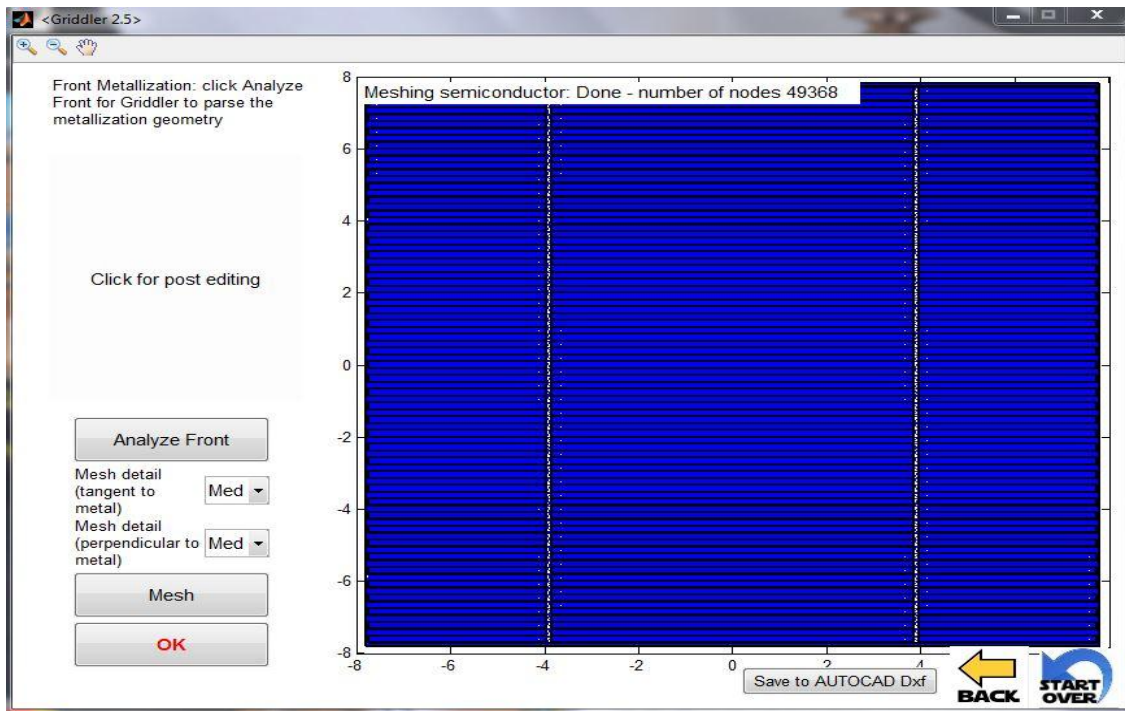
ANNEX – II

A. STEPS FOR GRIDDLER SOFTWARE

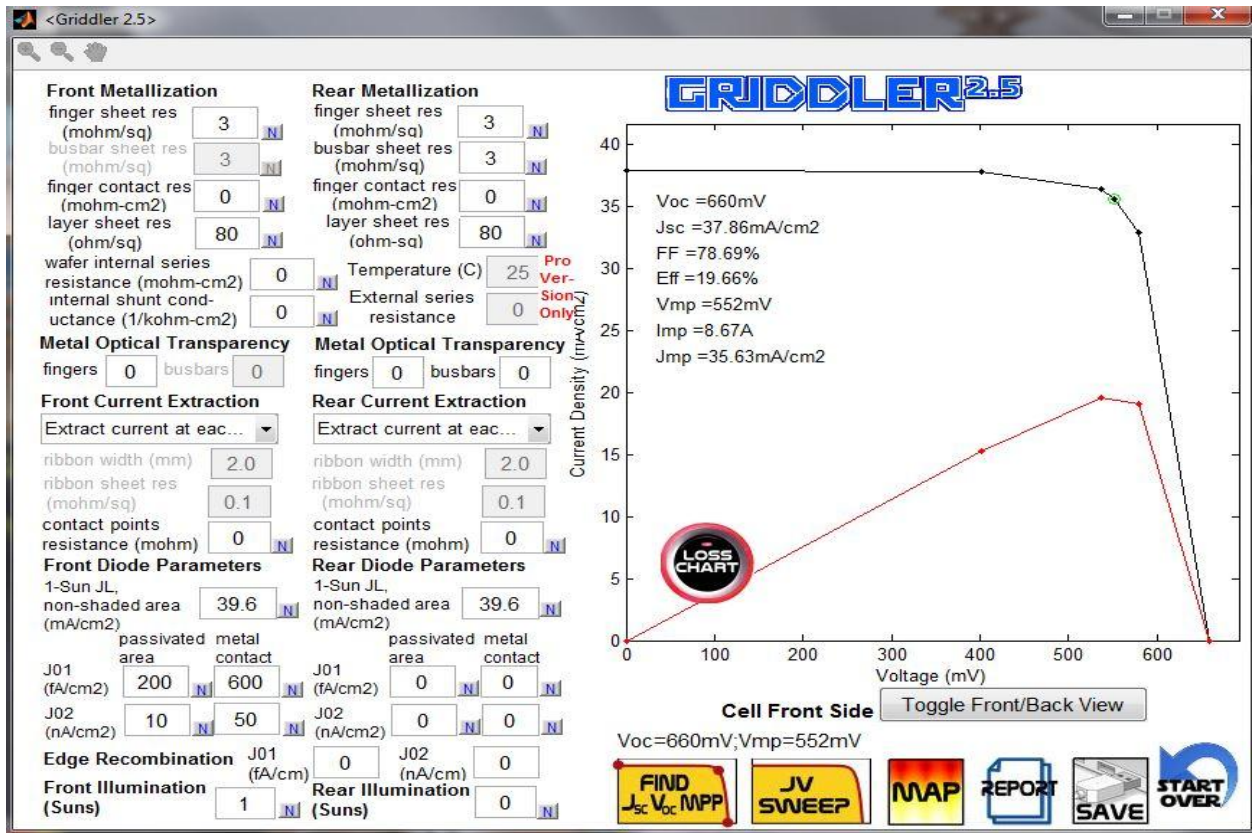
1. H-PATTERN PAGE



2. MESHING PAGE



3. SIMULATION PAGE



B. GRIDDLER SOFTWARE INPUTS

2 BB REPORT

Cell Parameters

wafer area	243.360086	cm ²		
front metal contact area	12.193957	cm ²	5.010665	%
rear metal contact area	240.250004	cm ²	98.722025	%
front optically inactive area	12.193957	cm ²	5.010665	%
rear optically inactive area	240.250004	cm ²	98.722025	%

IV Parameters

front JL(non-shaded regions)	39.600000	mA/cm ²		
front JL	37.615777	mA/cm ²		
rear JL(non-shaded regions)	0.000000	mA/cm ²		
rear JL	0.000000	mA/cm ²		
front Suns	1.000000			
rear Suns	0.000000			
Jsc	37.615769	mA/cm ²		
Voc	659.050798	mV		
FF	78.908765	%		
Efficiency	19.562037	%		
Vmp	552.417372	mV		
Imp	8.617794	A		
Jmp	35.411698	mA/cm ²		

Power analysis at terminal voltage of 0.400000 mV

Power Loss Pie Chart

Power output	15.025870	mw/cm ²	88.966695	%
External Rs	0.000000	mw/cm ²	0.000000	%

Front shading	0.817217	mw/cm2	4.838659	%
Rear shading	0.000000	mw/cm2	0.000000	%
Front resistive losses	1.000668	mw/cm2	5.924859	%
Rear resistive losses	0.023759	mw/cm2	0.140673	%
Front recomb losses	0.021806	mw/cm2	0.129113	%
Rear recomb losses	0.000000	mw/cm2	0.000000	%
Edge recomb (n=1)	0.000000	mw/cm2	0.000000	%
Edge recomb (n=2)	0.000000	mw/cm2	0.000000	%
Internal Rs	0.000000	mw/cm2	0.000000	%
Internal shunt	0.000000	mw/cm2	0.000000	%

Front Resistance Loss Pie Chart

semiconductor resistance	0.321834	mW/cm2	32.161952	%
finger resistance	0.678834	mW/cm2	67.838048	%
floating BB resistance	0.000000	mW/cm2	0.000000	%
ribbon resistance	0.000000	mW/cm2	0.000000	%
contact resistance	0.000000	mW/cm2	0.000000	%
pin contact resistance	0.000000	mW/cm2	0.000000	%

Rear Resistance Loss Pie Chart

semiconductor resistance	0.001295	mW/cm2	5.450558	%
finger resistance	0.021261	mW/cm2	89.487518	%
floating BB resistance	0.001203	mW/cm2	5.061924	%
ribbon resistance	0.000000	mW/cm2	0.000000	%
contact resistance	0.000000	mW/cm2	0.000000	%
pin contact resistance	0.000000	mW/cm2	0.000000	%

Front Recombination Loss Pie Chart

semiconductor (n=1)	0.001466	mW/cm2	6.722711	%
---------------------	----------	--------	----------	---

semiconductor (n=2)	0.016988	mW/cm2	77.905862	%
peripheral (n=1)	0.000000	mW/cm2	0.000000	%
peripheral (n=2)	0.000000	mW/cm2	0.000000	%
metal contact (n=1)	0.000127	mW/cm2	0.580981	%
metal contact (n=2)	0.003225	mW/cm2	14.790446	%

Rear Recombination Loss Pie Chart

semiconductor (n=1)	0.000000	mW/cm2	NaN	%
semiconductor (n=2)	0.000000	mW/cm2	NaN	%
metal contact (n=1)	0.000000	mW/cm2	NaN	%
metal contact (n=2)	0.000000	mW/cm2	NaN	%

JV Curve

V	J	power density
(mV)	(mA/cm2)	(mW/cm2)
0.000000	37.615769	0.000000
25.000000	37.615757	0.940394
50.000000	37.615737	1.880787
75.000000	37.615704	2.821178
100.000000	37.615651	3.761565
125.000000	37.615565	4.701946
150.000000	37.615424	5.642314
175.000000	37.615195	6.582659
200.000000	37.614822	7.522964
225.000000	37.614213	8.463198
250.000000	37.613221	9.403305
275.000000	37.611601	10.343190
300.000000	37.608945	11.282684

325.000000	37.604578	12.221488
350.000000	37.597345	13.159071
375.000000	37.585245	14.094467
400.000000	37.564675	15.025870
407.502026	37.555967	15.304133
539.499675	36.102756	19.477425
552.417372	35.411698	19.562037
578.000000	32.914683	19.024687
659.050798	0.000000	0.000000

5 BB REPORT

Cell Parameters

wafer area	243.360086	cm2		
front metal contact area	18.909649	cm2	7.770234	%
rear metal contact area	240.250004	cm2	98.722025	%
front optically inactive area	18.909649	cm2	7.770234	%
rear optically inactive area	240.250004	cm2	98.722025	%

IV Parameters

front JL(non-shaded regions)	39.600000	mA/cm2
front JL	36.522987	mA/cm2
rear JL(non-shaded regions)	0.000000	mA/cm2
rear JL	0.000000	mA/cm2
front Suns	1.000000	
rear Suns	0.000000	
Jsc	36.522984	mA/cm2
Voc	656.789585	mV

FF	80.799809	%
Efficiency	19.382190	%
Vmp	562.342550	mV
Imp	8.387861	A
Jmp	34.466874	mA/cm ²

Power analysis at terminal voltage of 0.500000mV

Power Loss Pie Chart

power output	18.074300	mW/cm ²	89.107872	%
external Rs	0.000000	mW/cm ²	0.000000	%
front shading	1.544949	mW/cm ²	7.616735	%
rear shading	0.000000	mW/cm ²	0.000000	%
front resistive losses	0.465782	mW/cm ²	2.296346	%
rear resistive losses	0.007213	mW/cm ²	0.035560	%
front recomb losses	0.191373	mW/cm ²	0.943486	%
rear recomb losses	0.000000	mW/cm ²	0.000000	%
edge recomb (n=1)	0.000000	mW/cm ²	0.000000	%
edge recomb (n=2)	0.000000	mW/cm ²	0.000000	%
internal Rs	0.000000	mW/cm ²	0.000000	%
internal shunt	0.000000	mW/cm ²	0.000000	%

Front Resistance Loss Pie Chart

semiconductor resistance	0.298686	mW/cm ²	64.125697	%
finger resistance	0.167096	mW/cm ²	35.874303	%
floating BB resistance	0.000000	mW/cm ²	0.000000	%
ribbon resistance	0.000000	mW/cm ²	0.000000	%
contact resistance	0.000000	mW/cm ²	0.000000	%

pin contact resistance	0.000000	mW/cm2	0.000000	%
------------------------	----------	--------	----------	---

Rear Resistance Loss Pie Chart

semiconductor resistance	0.001303	mW/cm2	18.068287	%
finger resistance	0.005144	mW/cm2	71.314251	%
floating BB resistance	0.000766	mW/cm2	10.617463	%
ribbon resistance	0.000000	mW/cm2	0.000000	%
contact resistance	0.000000	mW/cm2	0.000000	%
pin contact resistance	0.000000	mW/cm2	0.000000	%

Front Recombination Loss Pie Chart

semiconductor (n=1)	0.045926	mW/cm2	23.998183	%
semiconductor (n=2)	0.103758	mW/cm2	54.217396	%
peripheral (n=1)	0.000000	mW/cm2	0.000000	%
peripheral (n=2)	0.000000	mW/cm2	0.000000	%
metal contact (n=1)	0.007296	mW/cm2	3.812676	%
metal contact (n=2)	0.034393	mW/cm2	17.971745	%

Rear Recombination Loss Pie Chart

semiconductor (n=1)	0.000000	mW/cm2	NaN	%
semiconductor (n=2)	0.000000	mW/cm2	NaN	%
metal contact (n=1)	0.000000	mW/cm2	NaN	%
metal contact (n=2)	0.000000	mW/cm2	NaN	%

JV Curve

V J power density

(mV)	(mA/cm ²)	(mW/cm ²)
0.000000	36.522984	0.000000
25.000000	36.522974	0.913074
50.000000	36.522958	1.826148
75.000000	36.522931	2.739220
100.000000	36.522888	3.652289
125.000000	36.522817	4.565352
150.000000	36.522703	5.478405
175.000000	36.522516	6.391440
200.000000	36.522212	7.304442
225.000000	36.521717	8.217386
250.000000	36.520910	9.130227
275.000000	36.519593	10.042888
300.000000	36.517439	10.955232
325.000000	36.513908	11.867020
350.000000	36.508091	12.777832
375.000000	36.498434	13.686913
400.000000	36.482214	14.592886
425.000000	36.454484	15.493156
450.000000	36.405822	16.382620
464.520078	36.361135	16.890477
475.000000	36.317289	17.250712
500.000000	36.148600	18.074300
525.000000	35.809582	18.800030
550.000000	35.092061	19.300634
557.474200	34.743165	19.368418

562.342550	34.466874	19.382190
575.000000	33.506682	19.266342
575.800000	33.431736	19.249993
600.000000	29.947795	17.968677
625.000000	22.170736	13.856710
650.000000	6.352897	4.129383
656.789585	0.000000	0.000000
675.000000	-22.962938	-15.499983
700.000000	-74.001790	-51.801253

SWCT REPORT

Cell Parameters

wafer area	243.360086	cm2		
front metal contact area	9.922705	cm2	4.077376	%
rear metal contact area	240.250004	cm2	98.722025	%
front optically inactive area	9.922705	cm2	4.077376	%
rear optically inactive area	240.250004	cm2	98.722025	%

IV Parameters

front JL(non-shaded regions)	39.600000	mA/cm2
front JL	37.985359	mA/cm2
rear JL(non-shaded regions)	0.000000	mA/cm2
rear JL	0.000000	mA/cm2
front Suns	1.000000	
rear Suns	0.000000	
Jsc	37.985357	mA/cm2
Voc	660.723733	mV

FF	81.239916	%
Efficiency	20.389453	%
Vmp	567.883905	mV
Imp	8.737665	A
Jmp	35.904264	mA/cm ²

Power analysis at terminal voltage of 0.500000 mV

Power Loss Pie Chart

power output	18.832870	mW/cm ²	93.375573	%
external Rs	0.000000	mW/cm ²	0.000000	%
front shading	0.808563	mW/cm ²	4.008951	%
rear shading	0.000000	mW/cm ²	0.000000	%
front resistive losses	0.362384	mW/cm ²	1.796743	%
rear resistive losses	0.002477	mW/cm ²	0.012280	%
front recomb losses	0.162653	mW/cm ²	0.806454	%
rear recomb losses	0.000000	mW/cm ²	0.000000	%
edge recomb (n=1)	0.000000	mW/cm ²	0.000000	%
edge recomb (n=2)	0.000000	mW/cm ²	0.000000	%
internal Rs	0.000000	mW/cm ²	0.000000	%
internal shunt	0.000000	mW/cm ²	0.000000	%

Front Resistance Loss Pie Chart

semiconductor resistance	0.326458	mW/cm ²	90.086114	%
finger resistance	0.035926	mW/cm ²	9.913886	%
floating BB resistance	0.000000	mW/cm ²	0.000000	%
ribbon resistance	0.000000	mW/cm ²	0.000000	%

contact resistance	0.000000	mW/cm2	0.000000	%
pin contact resistance	0.000000	mW/cm2	0.000000	%

Rear Resistance Loss Pie Chart

semiconductor resistance	0.001290	mW/cm2	52.085851	%
finger resistance	0.001187	mW/cm2	47.914149	%
floating BB resistance	0.000000	mW/cm2	0.000000	%
ribbon resistance	0.000000	mW/cm2	0.000000	%
contact resistance	0.000000	mW/cm2	0.000000	%
pin contact resistance	0.000000	mW/cm2	0.000000	%

Front Recombination Loss Pie Chart

semiconductor (n=1)	0.041339	mW/cm2	25.415214	%
semiconductor (n=2)	0.100191	mW/cm2	61.597829	%
peripheral (n=1)	0.000000	mW/cm2	0.000000	%
peripheral (n=2)	0.000000	mW/cm2	0.000000	%
metal contact (n=1)	0.003607	mW/cm2	2.217781	%
metal contact (n=2)	0.017516	mW/cm2	10.769177	%

Rear Recombination Loss Pie Chart

semiconductor (n=1)	0.000000	mW/cm2	NaN	%
semiconductor (n=2)	0.000000	mW/cm2	NaN	%
metal contact (n=1)	0.000000	mW/cm2	NaN	%
metal contact (n=2)	0.000000	mW/cm2	NaN	%

JV Curve

V	J	power density
(mV)	(mA/cm2)	(mW/cm2)
0.000000	37.985357	0.000000
25.000000	37.985349	0.949634

50.000000	37.985335	1.899267
75.000000	37.985312	2.848898
100.000000	37.985275	3.798527
125.000000	37.985214	4.748152
150.000000	37.985116	5.697767
175.000000	37.984957	6.647367
200.000000	37.984697	7.596939
225.000000	37.984273	8.546462
250.000000	37.983583	9.495896
275.000000	37.982457	10.445176
300.000000	37.980616	11.394185
325.000000	37.977597	12.342719
350.000000	37.972624	13.290418
375.000000	37.964370	14.236639
400.000000	37.950509	15.180204
425.000000	37.926819	16.118898
450.000000	37.885262	17.048368
475.000000	37.809689	17.959602
477.625129	37.798645	18.053583
500.000000	37.665739	18.832870
525.000000	37.376366	19.622592
550.000000	36.762226	20.219224
563.894023	36.140981	20.379683
567.883905	35.904264	20.389453
568.591462	35.858945	20.389090
575.000000	35.396506	20.352991

579.600000	34.998784	20.285295
600.000000	32.281959	19.369175
625.000000	25.253154	15.783222
650.000000	10.290258	6.688668
660.723733	0.00006 00	0.000000
675.000000	-18.715557	-12.633001
700.000000	-70.686990	-49.480893