Design, simulation and installation of 100kWp bifacial solar panels at Nyabira Solar Farm, Zimbabwe for backup power in Harare's manufacturing industries

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Abstract-Renewable energy has come to light as a crucial way to reduce carbon emissions and move toward a more sustainable energy future as the world struggles with the effects of climate change. In this context, the use of solar photovoltaic (PV) systems has become increasingly popular because of its cost-effectiveness, environmental friendliness, and technological innovation. In order to provide backup power for the industrial businesses in Harare, Zimbabwe, this thesis focuses on the design, simulation using PVsyst and PVSOL simulation softwares and installation of 230 modules of bifacial solar panels at Nyabira Solar Farm on a model plane open area of 0.4km as to give out a annual energy generation of 182885 kWh which on ground becomes a successful project when we install the panels at an free open space of 60km .Furthermore a comprehensive financial analysis shows a total installation of USD100000 which includes the prices of the inputs which are bifacial solar panel, inverters and the labour cost.

Index Terms: Bifacial Solar Modules, Solar system, Industrial Sector

I. INTRODUCTION

The necessity to investigate renewable alternatives to meet the energy demands of industries worldwide has been highlighted by the global movement towards sustainable energy solutions. Zimbabwe, a developing nation plagued by frequent power outages for the past decades since 2000s till to date, depends on stable energy sources for critical sectors like manufacturing industries [1]. Despite possessing important power producing facilities like Hwange thermal power plant which is located in the country and Kariba hydroelectricity power plant located along the Zambezi River which divides the 2 countries, Zimbabwe and Zambia. Zimbabwe has a history of power shortages. Located on the Zambezi River, the 2010MW-capable Kariba hydro plant station provides electricity to Zambia as well as Zimbabwe [2]. In the same vein, the nation western Hwange thermal plant provides the national grid with about 1520Mw of electricity. The reasons for these shortages are numerous and include things like deteriorating infrastructure since some of these power plants have been constructed around the early 1900s, poor maintenance, a lack of investment in the power sector, and natural occurrence like drought that affect the production of hydroelectric power and due to all this, it has resulted in the reduction of the efficiency of these power plants. And also it has resulted in having negative impact on the status of the national economy and all of its pillars, including the agricultural and industrial sectors thereby causing the drought to the country. The majority of Zimbabwe's manufacturing sectors which generates significant amounts of revenue, are centered in Harare, the national's capital city. Traditional grid based power presents issues for the manufacturing industries of Harare, Zimbabwe's economic center, including high costs and disruptions that reduce output. This research paper focuses on implementing bifacial solar panels in Zimbabwe's Nyabira solar farm which is situated 40km away from Harare in Mashonaland west province of Harare, and implementation is done in order to improve energy sustainability and resilience for the city of Harare's manufacturing industries [3]. Compared to traditional solar panels, bifacial solar panels offer high energy production efficiency because of their dual sided designs which allow them to catch sunlight from both sides. Their capacity to absorb light from both front and rear surfaces is useful, particularly in regions where surfaces with high albedo, such as sand and snow, reflect light onto panels. Because they may be deployed in a variety of configurations, including rooftops, solar carports, and grounded-mounted vertically or horizontally systems, bifacial panels are adaptable to a variety of settings [4]. Even while they have advantages like increased energy output and effective installation alternatives, they also have drawbacks like greater initial prices, susceptibility to surround shade and environment, and the requirement for careful installation design and above all they need high level skilled engineers to install them [5]. So in general the secondary objective in this research paper is to maximize the energy output by utilizing the state of the art technology of bifacial solar panels. The installation at the farm offers a chance to highlight the potential of renewable in resolving the region's industrial power issue [6]. In this research paper, the vertically mounted bifacial solar panel have been conducted as they emerge as an efficient method of generation of electricity and using solar system. However the hardware installations without any usage of the softwares, might be hard and will result in causing so many problems during the installation process. Therefore ,solar simulation softwares –based presents a new scope of information gathering and idea generation enabling wise judgements to be taken prior to hardware implementation and due to the hardware installation job will becomes easier [7]. Thus in order to help with energy crisis, our primary goal is to design and construct a grid connected photovoltaic system using vertically mounted bifacial modules. 2 of the most well knows softwares have been used to accomplish this [8]. By speculating on system usability and practically, the software based study will help.

II. PROPOSED SYSTEM

A. *Site Assessment*

Nyabira Solar Farm is an operating solar photovoltaic farm in Zvimba, Mashonaland West Province which is located 37km outside Harare, Zimbabwe and its coordinates used to pinpoint its specific location on google maps is as follows latitude is -17° 40' 14"(-17, 67°) whereas its longitude is 30° 46' 56" (30 , 78°). It is an ideal location for the installation of bifacial solar panels due to its several reasons. Firstly the high albedo nature of the site is advantageous to this technology as it means that the region receives more solar reflection than average leading to a higher energy production by the bifacial panels. The site is characterized by an open area without much shade which is essential for optimizing the performance of the panels. Moreover, the site's spacious topography mostly flat at broad head provides ample space for placing the installations optimally such that the sunlight can hit them from any angle. Average annual solar global horizontal irradiance is1989 kWh/m²/year, whereas the irradiance onto tilted surface is 2025.6kWh/m²/year. Table I shows the global horizontal irradiance and the irradiance onto tilted surface from January to December.

TABLE I. Global Horizontal Irradiance, Irradiance onto the Tilted Surface and Temperature (From Meteonorm)

Month	Global Horizontal Irradiance (W/m²)	Irradiance onto the Tilted Surface (W/m²)	Temperature (°C)
Jan	176.5	146.9	21.3
Feb	157.9	163.9	21.2
Mar	166.8	179.7	20.6
Apr	160.2	183.7	18.7
May	149.2	172.2	17.0
Jun	131.8	180.0	14.6
Jul	141.3	190.1	14.5
Aug	163.4	188.2	17.1
Sep	180.5	182.1	20.1
Oct	196.7	153.3	22.4
Nov	183.4	144.6	22.0
Dec	181.3	140.9	21.6

The Nyabira Solar Farm sits on a plateau at an elevation of 1500metres above the sea level and its climate falls into the subtropical highland category, so rainfall will be frequent in few months mostly at the end of the year from December time to February of the following year.

B. *Design of the System*

At the site, an open free space of 5km is available, devoid of any shading, an ambitious plan is underway to install 230 units of bifacial solar modules. These panels will be meticulously arranged in a sophisticated layout featuring 23 units with each string comprising 10 panels connected in series. This configuration is strategically designed to optimize the energy generation capacity of the installation and take full advantage of the available solar resources.

Figure 1 shows the free open space without any shading close by at the site from the object view in PVSOL.

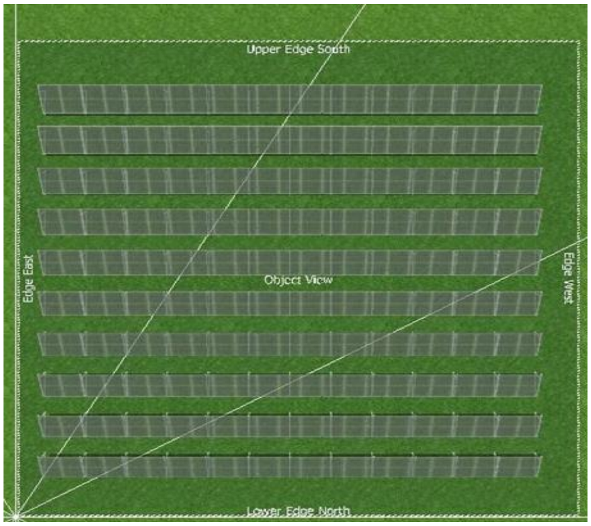

Fig.1 Object View Showing 230 Modules Installations in PVSOL

Each bifacial solar module boasts a nominal power rating of 100kwp, collectively targeting a substantial electricity output to meet the farm's need, local residential needs and most important the industrial sector of the country in Harare, Zimbabwe. With this setup the projected annual generation is estimated to reach an impressive 182538kWh/year. Such a significant output underscores the potential of bifacial solar panels to harness solar energy efficiently since if we arrange the panels of the same mode on the whole entire free open space which covers almost 60km.

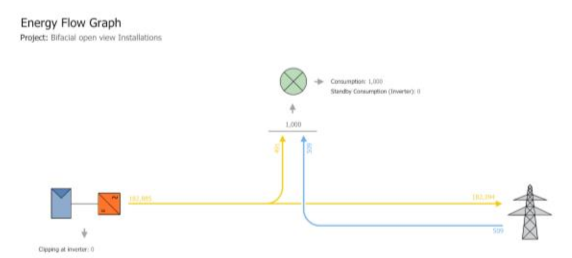

Fig.2 Schematic Energy Flow Diagram of the Proposed System

III. SOFTWARE SIMULATION AND RESULTS

Two of the most popular softwares in solar installations have been used to estimate the energy generated from the above proposed PV energy model. In PvSOL, the 3D model have been generated showing the open view area with 230 installed units of bifacial model as shown in figure 1. The simulation parameters have been the chosen type of panel are listed in table II. The meticulous simulations have been performed to achieve the monthly energy profiles from each of the softwares.

SOLARWATT Classic m3.0 rated at 450wp black copy panels have been used in this research paper as bifacial modules. The manufacture is SOLWATT. The reason why they have been chosen is because they exhibit relative low degradation and longer life [9-10]. Its PERC cells are inherently sensitive, thus thermal watt uses cutting edge manufacturing techniques to cover cells on two sides with thermally tempered glass and due to this, the panels becomes more durable than convectional glass-foil panels [8].

The type of the inverters used are SCT4000D (v1) manufactured by Wuxi SLD Power Technology Co, Ltd with a sizing factor of 112.5%. This brand of inverter have been chosen because its efficiency is good and it's a reliable brand with its power factor close to 1 and due to the power stability and equality is good [10]. Its configuration settings are MPP 1+2: 1×10 Thus the DC-AC ratio obtained from the optimum operation is considered to be 1.03.

In terms of simulation the simulation losses were limited to 5% since it was found out that vertical modules have less soiling loss than monofacial panels. The mounting height was determined to be 2 meters above the ground in order to receive the most possible reflected light from the ground. Tilt angle was adjusted to 30° whereas azimuth was determined at 0° as to keep alignment with road orientation. Conversely the default values for mismatch loss and diode loss were set at 2% and 0.5% respectively

TABLE II. Simulation Parameters for Bifacial Systems

Parameters	Values	Parameters	Values
Pv Model	Solar Watt Classic m3.0		
Panel Rating	450W	No. of Cells	70
No. of Panels	230	Operating Temperature	-40℃ to 85℃
Total Installed Capacity	103kW	Short Circuit Current	12.5A
Efficiency	22%	Weight	22kgs
Open Circuit Voltage	48V		

Table III shows the energy that have been generated monthly through using the simulation softwares which are PvSOL, Pvsyst and the average of the 2 softwares.

TABLE III. Monthly Energy Profile for Bifacial Panels

Month	PVSOL (kWh)	PVsyst (kWh)	Average (kWh)

Jan	13675.5	13081	13387.25
Feb	13071.3	12660	12865.65
Mar	15151.2	14812	14986.60
Apr	16227.1	16253	16240.05
May	15911.1	16908	16409.55
Jun	14621.1	16139	15380.05
Jul	15315	16882	16098.50
Aug	17050.4	17130	17090.20
Sep	17340.3	16960	17150.15
Oct	16787.8	16107	16447.40
Nov	14226.4	13616	13921.20
Dec	13497.8	13051	13274.40
Total	182885	183599	183447.00

In PVSOL and PVsyst, the yearly generation is 182885kWh and183599kWh, respectively. As a result, the average energy generated overall is 183447kWh. The highest generation has been recorded in September, a month with very high levels of both diffuse and direct radiation. Despite having the maximum direct and diffuse irradiation values in April, the panels' efficiency decreased due to the high temperature. The yield decreases steadily after October, until it reaches its lowest point in February as a result of rain and overcast skies. March marks the beginning of a rise in the mean energy generated, which is correlated with both a drop in temperature and an increase in global radiation. However before the exportation of the exact 182885kWh/year energy produced, there is some deduction of energy due to the appliances and also standby consumption (inverters) which will be also utilizing power from the grid

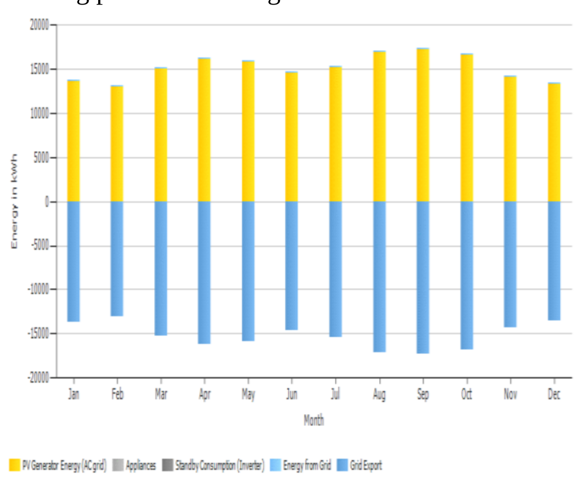

Fig.3 Production forecast with consumption

System output power distribution from the simulation given from the below graph

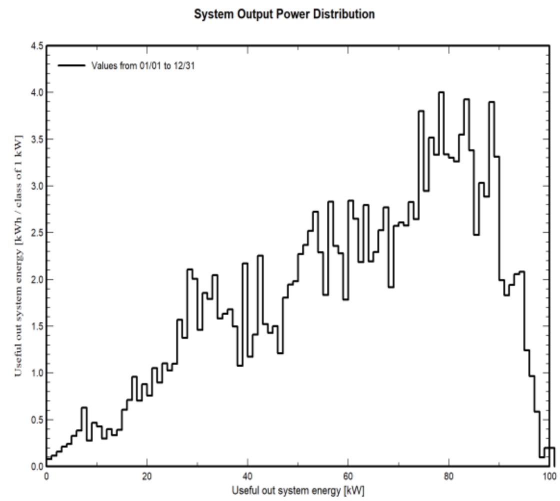

Fig.4 System Output Power Distribution

Detailed Losses and Inverter Losses

So on these modules, some losses are experienced due to the regular change of the weather and also other factors and due to this efficiency of the whole system of the panel drops [11]. The first 3 losses that are mentioned below considered to be the major losses that usually occurs in this system regularly.

Ohm Loss-This loss occurs because of resistance to the flow of ions in the electrolyte and resistance to the flow of electrons through the electrically conductive fuel cell components [10].

Module Quality loss-This type of loss in which you have to depict the discrepancy between the real modules by respect to the manufacturer's specifications Parameter left to the choice of the user [11]

Mismatch Loss- The losses caused by slight differences in the electrical characteristics of the installed modules, applied as fixed percentage reduction of the system's DC power output [12].

Some of the losses will be generated in the PV panels due to their daily exposure to regular changes in weather changes and fluctuations in irradiance levels and with overtime, these fluctuations will results in the reduction of the panels.

Most of the losses will occur in the inverters, which is why it is important to choose the best available inverters for the installations [13].

Losses at the Voltage Threshold- for inverters to operate at their best, certain voltage threshold and must be maintained. The inverter components may sustain damage and efficiency losses if the input voltage from solar panels is either too high or too low for the system. System efficiency may be negative impacted and heat generation may increase when operating outside the recommended voltage range [11]

Losses at Power Threshold- Since the type and model of the inverters used in this system is the same, they do have power thresholds that set the highest amount of power that they can effectively manage. When the power threshold is exceeded, the inverter may run longer than intended, resulting in higher losses, worse efficiency and possibly a shorter life span and this will result in affecting the whole system's overall performance

Over Nominal Inverter Voltage Losses-The nominal voltage is the range of voltages that inverters are intended to operate within, increased heat generation and losses can occur from straining components when the input voltage surpasses the nominal value or overusing the inverter under harsh conditions.

Fig.5 shows the losses that are experienced throughout the whole process of installation.

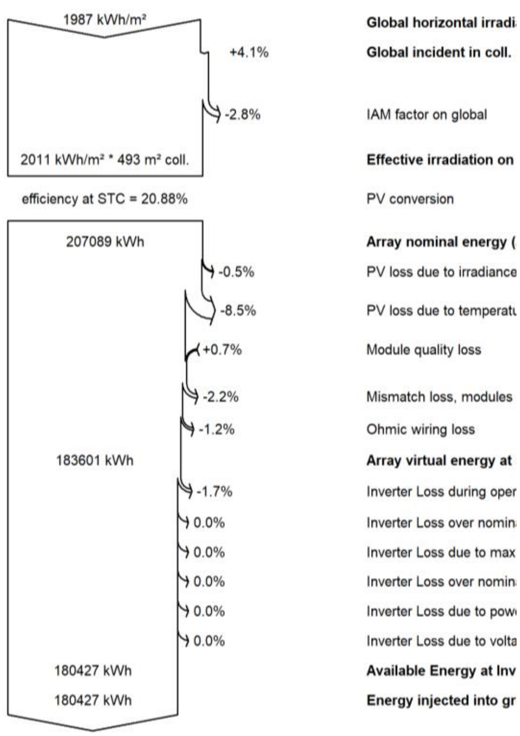

Fig.5 Loss Diagram

The increased albedo ensures that a certain significant amount of diffuse radiation is reflected back is reflected back to the surface and passes through both sides of the bifacial panels [14].

C. Comparative Analysis of Bifacial and Monofacial Panels

In this research paper, an estimation has been conducted on the potential of solar bifacial system in relation to convectional monofacial panel by analyzing its system's bifacial gain. Also for optimum results, this would necessitate inclination of monofacial system of about 24 degrees plus an azimuthal orientation of approximate 180°. This gives us required number of monofacial units rated at 305W each which amounts to installed capacity at around 70.15kwp which is lesser than 30% to bifacial panels.

The mean monthly energy production and bifacial gain between the 2 systems is given in table IV

Table IV Mean Monthly Energy Production and Bifacial Gain between the Two Systems

Month	Mean Energy Bifacial (kWh)	Mean Energy Monofacial (kWh)	Energy Gain (%) (kWh)
Jan	13387.25	9063.30	47.7
Feb	12865.65	8665.00	48.4
Mar	14986.60	10056.20	49.2
Apr	16240.05	10717.00	51.3
May	16409.05	10076.00	62.9
Jun	15380.05	8498.60	81.0
Jul	16098.50	9257.90	74.0
Aug	17090.20	11125.00	54.0
Sep	17150.15	11487.50	49.0
Oct	16447.40	11112.90	48.0
Nov	13921.20	9425.90	47.7
Dec	13274.40	8933.00	48.6
Total	183447.00	118418.00	54.9

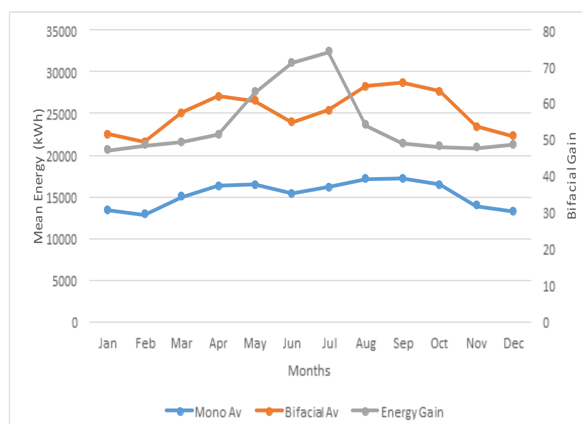

Fig.6 Graphical Representation of Mean Energy (kWh) of monofacial system, bifacial system and bifacial energy gain

IV. DISCUSSION

The costs are associated with the designing of PV modules for the Nyabira Solar Farm due to the panels that are prone to rusting and wearness because of the wind and regular change of seasons [15]. Moreover the mounting mechanism may break as a result of severe wind .The effect of these factors will results in a decrease in both annual energy generation and efficiency. However for a 0.4km open space the annual generation was 182885 kWh. The total energy produced if bifacial solar modules are arranged along the entire open space of 60km will be about 27432750kWh per year which will make the whole solar plant to be 3MW, which will transport a greatly beneficial effect on the industrial sector in Harare, Zimbabwe.

V. CONCLUSION

This research paper presents a design, simulation and installation of Bifacial Solar Panels with a 100kWp capacity at Nyabira Solar Farm, Zimbabwe, for Backup Power in Harare's Manufacturing Industries. Two distinct programs were used to create a comprehensive 3D design and simulate the solar panel’s yearly performance. The proposed design which uses 230 modules rated at 450W each, demonstrated a potential return of 182885kWh/year. When installed at the entire open space of 60km available at Nyabira Solar Farm, there will be an approximation yearly generation of 27432750kWh in total. A system using monofacial panel demonstrated an energy gain of 54.9%. As a result, the implementation also do have an advantage of avoiding the carbon emission from convectional fossil fuel based power plants.

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