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EMPIRICAL INVESTIGATION OF FIXED AND DUAL AXIS SUN TRACKING PHOTOVOLTAIC SYSTEM INSTALLATIONS IN TURKISH REPUBLIC OF NORTHERN CYPRUS

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ABSTRACT

This paper reviews the potentials of photovoltaic system technology as a viable alternative to the 100% use of imported fossil fuel for electricity generation in Northern Cyprus. It presents an experimental investigation of two installed 100Wp photovoltaic systems design in block A building of faculty of business in Cyprus International University. The fixed system was inclined at angle of 36˚ in the northern hemisphere while the dual axis sun tracking system uses a solar tracker with satellite control to follow the path of the sun. Both systems measure local energy generation, solar radiation and power output. The result generated from the systems shows that the fixed system produced 712.85Wh/day.m^2 with average power output of 91.9W, while the tracking system produced 999.39Wh/day.m^2 with power output of 124.5W, respectively. Comparison of the systems also shows that the tracking system produce nearly 40.2% more energy than the fixed system under Northern Cyprus climatic conditions, which is parallel with most of the literature, reviewed. Conclusively both systems performed optimally hence should be adopted as source of electricity generation mix in the residential sectors. However, the dual axis tracking system has the capability of enhancing productivity therefore its installation favor houses with limited area of installation, while the fixed system has the advantages of lower installation cost and requires little or no maintenance.

Keywords: Efficiency, Empirical investigation, Local energy generation, Photovoltaic systems, Turkish Republic of Northern Cyprus, Solar radiation

INTRODUCTION

Electricity generation in Turkish Republic of Northern Cyprus (TRNC) depends solely on burning of imported fossil fuels and petroleum products contributing greatly to irreparable damage to the environment in the form of Greenhouse Gases (GHG). Currently the energy generation capacity of the country is nearly 350MW and over 44% of this generation is consumed by residential sector alone for electricity (Abbasoğlu *et al.*, 2010). This generation is controlled and distributed by TRNC electricity board named Kib-Tek.

In anticipation of expectant increase in population based on trend and according to development of construction sectors, 1 GW would be required to meet the country's demand by 2020 (Ozerdem and Biricik, 2011). It is important that most of this anticipated generation be from renewable energy technologies for sustainable environment, hence effort has been intensified by many research on different renewable energies that would serve this purpose.

Solar energy sources potentials is very high in TRNC according to studies by (Balasubramanian and Cellatoglu, 2009; Ozerdem and Biricik, 2011) yet under-utilized as most solar installations are specifically for water heating purpose especially during the winter period. The country has annual solar radiation estimated 1970 kWh/m^2 at fixed angle of 28° with nearly 300 sunny days (Poullikkas, 2009). This solar irradiation is much higher when compared to the sunniest area of Germany one of the world's solar photovoltaic largest market. (Makrides *et al.*, 2010). Sadly to note that despite this huge solar potentials, the country still depend entirely on imported fossil fuel notwithstanding its global price trend (BP, 2011) and associated GHG emissions (IPPC, 2007; Anomohanran, 2011).

Apparently there is need to encourage the residential sector of the economy which is the highest consumer of the generated capacity to be energy producer, feed in tariff system mechanism would be a viable tool as it has been successfully implemented in many neighboring European countries. Comprehensive detailed comparison of PV promoting scheme of different European and Mediterranean countries have been presented by Giakoumelos *et al.* (2008).

The existing Renewable energy law of Turkish Republic of Northern is yet to be implemented and enforced. This study focuses on photovoltaic systems technology because of its numerous advantages such as; modular in nature hence easiness of expansion, it can also be integrated into the building or mounted on roof top, and direct conversion of solar radiation to electricity thus requires little or no maintenance.

The paper aimed at investigating the performance of roof mounted PV systems of different mounting orientation under TRNC operating conditions and compare the local energy generation of the two designs in-order to offer policy makers real empirical results on which to base decision for favorable deployment of PV systems as against simulated and numerically calculated results. It will as well serve as a veritable guide to potential installers so as to assist them in decision making on the choice of installation.

Production of Electricity and Photovoltaic Systems Technology

Electricity production from solar radiations depends on the choice of technologies and available solar radiation of the area under consideration. Trieb *et al.* (1997) presented detailed description of the various technologies that can be employed to convert solar radiation into electricity in their study, they emphasize that electricity are generated from solar via solar thermal plants and photovoltaic systems. However, no matter the method adopted and the technology used, available evident still shows that solar energy is inexhaustible, environmentally friendly and is capable of supplying the energy needs of the entire universe.

Brief descriptions of various ways of converting solar radiations to electricity using some of technologies list by Trieb *et al.* (1997) are as follows;

1. Solar thermal systems employ solar collectors (flat plate or concentrating) and working fluids to convert solar radiation into heat energy; the heated transferred fluid is then used to generate steam that drives the heat engine, thus producing electricity.
2. Solar chemical systems employ solar reactors to produce chemicals which can be converted directly or indirectly to electricity via electrolysis and heat engines respectively.
3. Solar photovoltaic system is the only technology that converts solar energy from the sun directly to electricity. It uses solar cells made of silicon material which can be combined in parallel and series to form module.

Photovoltaic are notable renewable solar energy generation technology that has come to stay, it is believed by many scholar to be capable of playing a very important role in future global energy generation mix. This technology has history dated as back as 1839 when Henry Becquerel discovers the emission property of electron, subsequently in 1954 it was developed to terrestrial application in Bells Laboratory by Chapel et al. (see Joshi *et al.* (2009) for detailed explanation). It works on the photovoltaic principle as explained by Green (2002).

Despite high initial capital cost, that is reflected in cost per kWh of the energy produced, and the low conversion efficiency of the photovoltaic systems. There has tremendous increase in the use of photovoltaic technology globally, from 1.8 GW in 2000 to 67.4 GW in 2011 as installed capacity (EPIA, 2012; IRENA, 2012). This number is driven by attractive policy incentives of feed in tariffs and tax breaks, Fig. 1. Show the installation share of different parts of the world in the last 11years. Even with this increase, TRNC share the smaller part of installation with the rest of the world. Worthy to mention is that there exists a PV farm installment of 1.3MWp Peak production capacities installed by the European Union and commissioned for operation in May 2011. It is the first PV installation in TRNC and largest so far in the Mediterranean region although the production do not account to even 1% of the total energy generation capacity.

To increase the efficiency of PV technologies and lower the cost of its production, research has been intensified on development and utilization of recent technologies in the development of high efficiently low cost PV cells and providing incentives to customers that wish to install. A comprehensive analysis of current state of the Art of and future outlook of PV system technologies with regard to costs, market penetration and environment were presented by (Raugei and Frankl, 2009). Compaan (2006) explained that the cost of manufacturing of PV solar module has significantly diminished over the years with the advancement of technology. Photovoltaic technologies are classified into first generation PV systems (fully commercial) of Mono and poly crystalline which use the wafer based silicon (c-Si) technology, the second generation PV systems (early market deployment) of amorphous silicon a-Si, cadmium telluride (CdTe), copper indium selenide etc. that are based on thin film technology and the third generation PV systems which includes technologies of organic PV cells and concentrating PV (CPV) that are still under demonstration (Raugei and Frankl, 2009). A detailed description and review of these technologies were also performed and presented by Chaar *et al.* (2011). These technologies are however grouped as either standalone (uses energy storage) or on grid connected systems (Okoye *et al.*, 2012).

Photovoltaic components and performance

The basic component of PV systems comprises of the photovoltaic module or panel, mounting stands, other balance of system (BOS), and battery depending on the systems design such as standalone etc. The performance of the systems depends entirely on the following, mounting orientation such as fixed, single axis tracking and dual axis tracking system, the efficiency of module used, and solar radiation of the area of installation. According to Sungur (2009) "the amount of electric energy produced from PV Systems is directly proportional to the intensity of sunlight which falls on the panel even though, the change observed in sun light does not occur linearly". Therefore, it is desired that solar panels be fixed in a way that they face the sun or have a system that tracks the sun for optimal performance. Solar radiation data is used in sizing and estimation of performance of photovoltaic system over time and it varies from one location to the other depending on the hemisphere. However, it is highly impracticable to purchase and install Pyranometers at all orientations to obtain required solar radiation data, thus many scholars have developed different mechanism used in estimating solar radiation of any location such as loss of load probability, observed time series, and bright sunshine hours with solar angles, respectively. (Egido and Lorenzo, 1992; Markvart *et al.*, 2006; Li *et al.*, 2008). Most PV studies are aimed at improving the efficiencies and reducing the cost of installation, so as to enable photovoltaic systems competes favorably with other conventional energy generation means.

The two main types of mounting systems are briefly described below;

I. Sun tracking systems - An array mounting system, that automatically orients the array to the position of the sun. Here the PV module is installed on a tracker with an actuator to follow the sun. The movement of the tracker is produced by either active (uses electric motor and gear drives) or passive means. There are two types of sun trackers: one/single axis tracker that follows the sun from east to west during the day, and the two axis tracker which follows the sun from east to west during the day and from north to south, during the seasons of the year (azimuth and solar altitude). The sun tracking PV systems is costly because additional cost of trackers and requires more maintenance due to complexity in its design and operations.

II. Fixed systems - An array mounting system, that permanently secures module on a non-movable position, horizontally or at a specific tilt angle. The advantages of the fixed system over the tracking systems are; it's cost effective, easy to install and requires less maintenance.

A review of literatures on the two mounting orientations of photovoltaic systems design shows that generally the sun tracking systems increases yield over the years when compared with the fixed array design operating under the same conditions. The results of these studies were present in Table 1. The reference efficiency is the result of the fixed system generated at different locations and is compared to the tracking systems (single axis or/and dual axis). It is clearly seen that both single and dual axis tracking systems, produce higher amount of energy when compared with the fixed systems, this efficiencies are between 10 to 55 %. It is also observed that dual axis sun tracking systems produce much more energy than single axis systems as expected. The variation in efficiencies in Table 1 is due to locations of studies, tracking methods and different types of module used in the studies.

METHODOLOGY

- Data of instant local Energy generation, power output and solar radiation of the area are collected every 5 minutes from the systems software for both the fixed and dual axis tracking systems
- The data are collected for the month of January, February, March, April, May, June, July, August, September, October, November and December.
- These data are analyzed for the months under consideration to determine the Average energy generation, Average Power, Month solar radiation and Average sunshine duration.
- The result are collected and presented for both fixed and tracking system designs
- Performance comparison were made between the installed fixed system and tracking system in-terms of energy generation capability and power output
- Then the efficiency of the tracking system is calculated and checked with the available literature in-order to enable conclusion

Data Collection Procedure

Two photovoltaic systems, fixed and dual-axis sun tracking, are located over the roof of block A building in Cyprus International University (CIU). Both systems were installed and commission for operation in 2010 and it comprises of mono-crystalline solar panel, data acquisition and control unit, Power-tech inverter, Net book, battery and charger as depicted in system block diagram Fig. 2. The system analyzes solar radiation, energy generation by the fixed and tracking solar PV panels and total power outputs. The data from the PV system were collected; evaluated and local energy generation is presented. Also, the influence of tracking system is considered and results related with mounting systems are discussed for different months of the year.

Both the fixed and dual axis systems comprises of following; S190M model modules with maximum power and voltage rating of 190W and 1000V respectively, 200Ah battery capacity, Power-tech inverters, Compaq net-book and other Balance of systems (BOS). In addition the tracking system also uses a dual axis Trek Sun tracker. The systems PV panel details and battery specifications are shown in Table 2 and 3 respectively. The fixed system is titled at an optimal angle of 36˚ facing the northern hemisphere, so that the sun makes an incidence angle of 0˚ with the panel during the winter, while the tracking system uses dual axis solar tracker model SM44M1V3P satellite control to follow solar path. A sun tracker with time derived astronomical positioning for the automatic sun tracking. The solar cell turns the trackers elevation angle from 15˚ to 90˚ to allow full tracking of the sun. The solar tracking model also has the ability to synchronize with the solar time and the battery for internal clock & date. The tracker uses integral USB 2.0 communication interface for the control and parameter setting via external PC over a web interface. The battery, onset Hobo data loggers, winds and solar hybrid controllers, uninterrupted power supply (UPS) and the mini net-book are housed as control box to protect them from adverse weather conditions (see Fig. 3).

Systems Data Acquisition Software Architecture

The installed systems uses Advanced intelligent wind/solar hybrid charge controller and HOBO pro (Pyranometer software) supplied by the product suppliers. Advance intelligent wind/solar hybrid charge controller software is used to query and launch data obtained from the data loggers (Fig. 4). The data loggers are connected to the computer using an optic USB serial cable and it records data at a time interval of 5 minutes and HOBO pro to record solar radiation. The more quickly the logging interval, the quicker the memory fills and more battery power is consumed.

The software features are system menu, user manager, view, tool and settings.

The system menu permits different users the right to operate each function of the software

The user manager perfects the safety and operation traceability, as it uses manager module

The view feature many interfaces that ensure user to view variety data of operating system conveniently such as view trend, data grid and true drawing.

The tool and setting allows for querying of data, logs, powers and parameter adjustment such as currents, voltage, area and node etc.

The system uses the HOBO ware Pro for launching, reading out and plotting data from data loggers, the HOBO ware Pro is an intuitively graphical user interface that allows users to select parameters, to display and format graphs, to perform analysis, to save project for future use and to export data to Microsoft excel. This data acquisition system software uses a complex algorithm as developed and supplied by the product manufacturers for recording strategies, the view of reporting file is shown in Fig.5

RESULTS AND DISCUSSION

The results of the data collected from the installed fixed and tracking systems, are analyzed technically to evaluate the average local energy generated and the power output of the systems so as to enable the comparison of both systems. The summary of these results are presented in Table 4. The table considers the monthly Average of the solar insolation of the mounting area, solar duration, energy production and power out for all months of the year. It is observed that the daily energy production (Wh/m².day) increases parallel with solar duration and solar radiation for both systems. Energy production increases during summer period and decreases in the winter season. It has the highest values of 900.99Wh/m^2.day and 1,420.25Wh/m^2.day in the month of June and lowest values of 579.02Wh/m^2.day and 752.70Wh/m^2.day in the month of December for the fixed and tracking systems, respectively. These values are due to highest and lowest solar insolation data of the months as obtained in Table 4. It was also observed that the average power output of the systems increased accordingly from January to July. However, in August there was sudden drop in the average power output for both systems from 101.0W to 95.4W for the fixed system design and 142.3W to 136.9W for the dual axis sun tracking system. It was seen that only the average solar power value is slightly higher with fixed system in September (nearly 97 W) than August (95 W), but the generated energy is higher in August due to longer solar duration. Lower power value in August could be related to higher temperature effect on PV system design (Makrides *et al*., 2009). The local energy production is high in all the months for tracking system than fixed system.

However, this difference increases in summer months up to nearly 50 percent and above. This is probably related with the inclination angle of the fixed system. Variation in the energy generation for the month of December is found to be higher than that of January even though the solar insolation values, energy production and solar duration values of the former is greater than the later as a result of higher average power output. The average variation in energy production is estimated 40.2 % under TRNC operating condition according to Eq. 1, which is in line with the literature presented in Table 1

$$E = (\varepsilon_T - \varepsilon_F) / \varepsilon_F * 100 \qquad (1)$$

Where; E represents the % variation of the average local energy generation of the photovoltaic systems, ε_T is the average local energy generation of the dual axis sun tracking system while ε_F is the average local energy generation of the fixed system design.

However, due to the problem with the installed pyranometer, the Average solar insolation was taken from local meteorological station of TRNC government. The other parameters such as solar duration, local energy generation, power output were measured from the system data acquisition. Fig. 6 presents the variation of the power output according to the Table 4. The gap between the fixed and tracking systems increases in the summer time, due to the variation in the azimuthal angle of the solar radiation thus it implies that 36˚ inclination of the fixed system is suitable for winter period but need to be decreased to about 28˚ in summer for optimal production.

Average electricity production is presented in Fig. 7. It is clearly seen from the Figure that the electricity production decreases in winter and increases in summer as expected due to solar radiation values. The increase in the difference between the fixed and tracking systems in summer time may be due to higher path of sun.

CONCLUSION

Empirical investigation has been carried out on the 100Wp capacity fixed and dual sun tracking photo voltaic system designs installed in Cyprus International University. The results of the performance analysis shows that both systems perform satisfactorily producing substantial amount of electrical energy, the fixed system produces average of 712.85Wh/day.m^2 while the dual axis tracking systems produced an average 999.9Wh/day.m^2 of electrical energy, respectively. Comparison of both system designs show that the dual axis tracking is 40.2% more efficient than the fixed system design under Northern Cyprus climate. However, other parameters come into play as the cost of installation is lower for the fixed system design. It can be concluded that increasing the capacity of these installed photovoltaic designs would obviously cater for the demand of residential sectors in Northern Cyprus hence solar PV should be included in the energy generation mix as a viable alternative to the imported fossil fuel currently in use.

Table-1. Summary of percentage yield of sun tracking over fixed systems

Date	Tracking system		Location	Reference
	Single axis	Dual axis		
2012	50.1%> fixed system	55.7% > fixed	Canada	(Mehrtash *et al.*, 2012)
2012	38% > fixed system	_	Romania	(Tudorache *et al.*, 2012)
2009	10 - 35% > fixed system	25 - 45% > fixed system	Turkey	(Sefa *et al.*, 2009)
2009	_	29% > fixed system	Turkey	(Rustemli *et al.*, 2009)
2008	_	30 - 45% > fixed system	Jordan	(Mazen *et al.*, 2008)
2008	10 - 20% > fixed	_	Estonia	(Tomson, 2008)
2008	42.6% > fixed system	_	Turkey	(Sungur, 2009)
2006	46.46% > fixed system	_	Greece	(Bakos, 2006)
2004	15.69 - 37.53% > fixed system	43.87% > fixed system	Jordan	(Abdallah, 2004)

2004	_	41.34% > fixed	Jordan	(Abdallah and Nijmeh, 2004)
2000	11 - 18% > the fixed system	30% > fixed system	Egypt	(Helwa *et al.*, 2000)

Table-2. PV panel details

Model	S190M
Max System Voltage	1000 V
Standard Test Condition	1000 W/m^2, am 1.5, 25 ° C
Max Power	190W
Size	1580 × 808 × 46 mm

Table-3. Battery properties for fixed and tracking system

Series	General standby /gel
Type	Eg 12 200
Voltage	12V
Capacity	200 Ah

Table-4. Daily Energy production and Average power of the fixed and tracking system.

Months	Average solar insolation (Wh /m^2)	Average solar duration (h)	Average Energy production (Wh /day.m^2)		Average Power (W)		Variation in Energy production (%)
			Fixed	Tracking	Fixed	Tracking	
JAN.	2,473.8	7.0	596.90	763.80	85.2	109.1	28
FEB.	3,315.4	7.3	624.37	810.26	85.7	110.4	30
MAR.	4,422.2	7.4	628.66	851.33	85.8	114.0	35
APR.	5,163.9	8.0	660.45	894.73	89.1	122.0	36
MAY	6,089.4	8.3	712.98	996.16	94.0	132.4	40
JUN.	6,747.7	10.3	900.99	1,420.25	97.0	140.2	58
JUL.	6,592.5	10.5	876.90	1,323.30	101.0	142.3	51
AUG.	5,966.4	8.9	831.18	1,239.76	95.4	136.9	49
SEPT.	5,216.4	8.2	798.72	1,179.38	96.9	136.0	48
OCT.	4,093.2	7.7	731.86	976.56	95.8	124.7	33
NOV	3,052.8	6.9	612.16	784.42	90.4	113.8	31
DEC.	2,326.8	6.7	579.02	752.70	86.8	112.5	30
Avg.		8.1	712.85	999.39	91.9	122.5	

Figure-1. Global cumulative PV installations from 2000 to 2011 (EPIA, 2012)

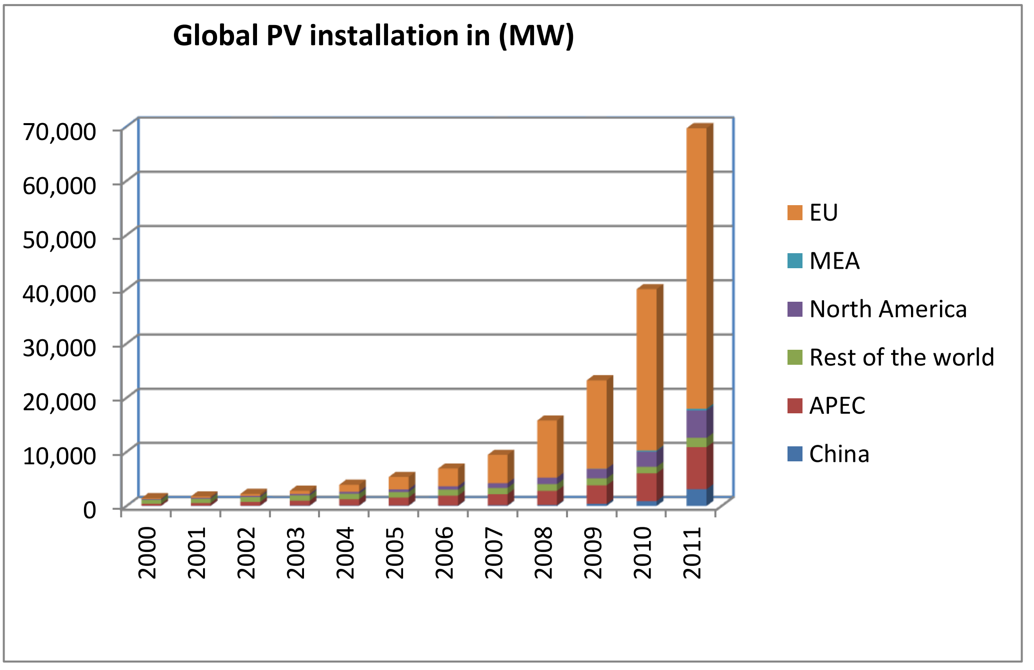


Figure-2. Photovoltaic and Data Acquisition systems Block diagram

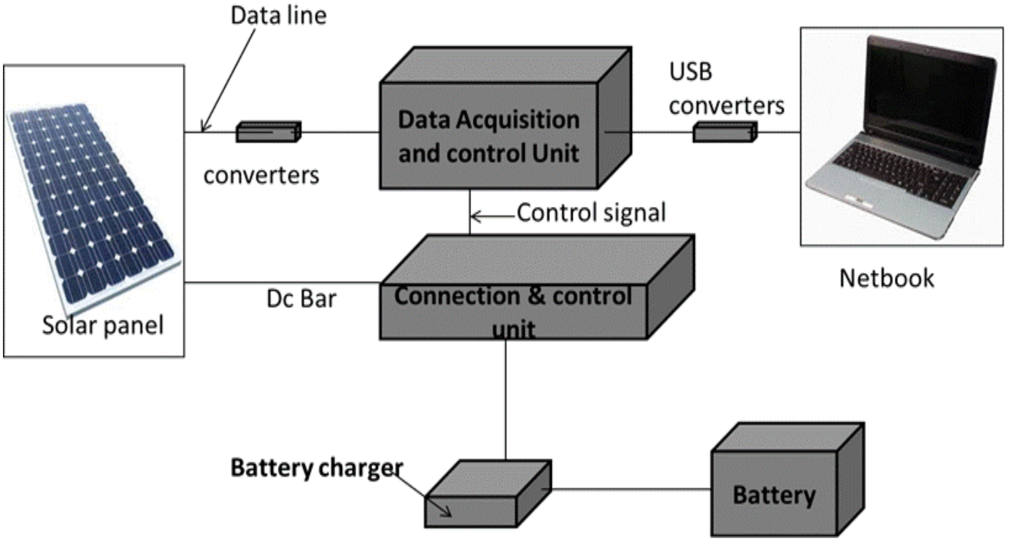


Figure-3. Experimental set-up of the fixed and dual axis sun tracking system

Figure-4. Systems menu interface of neo-energy adv intelligent software

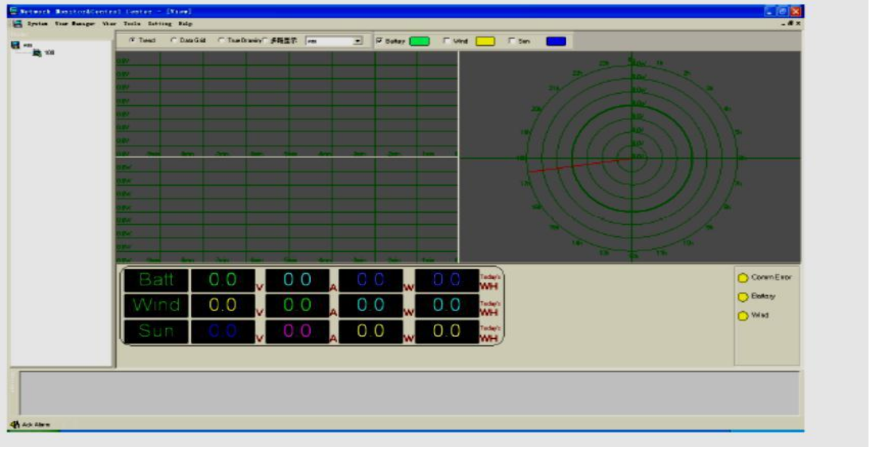
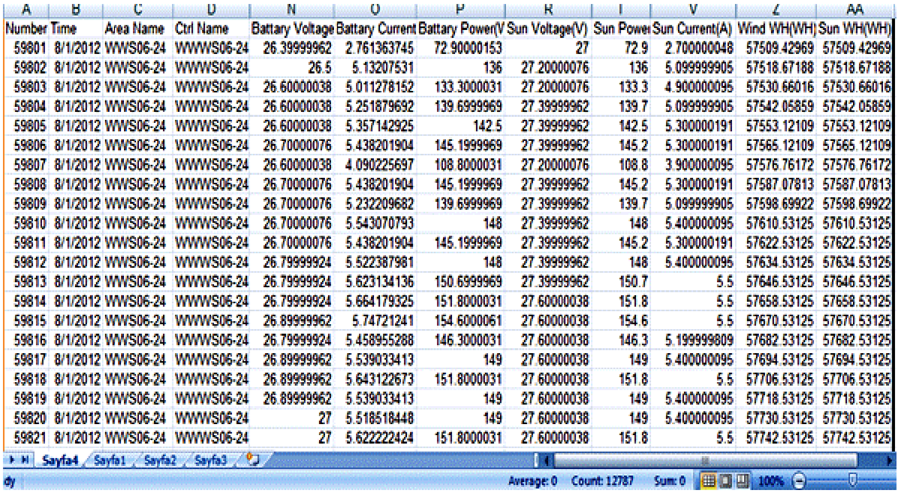


Figure-5. View of the software reporting format

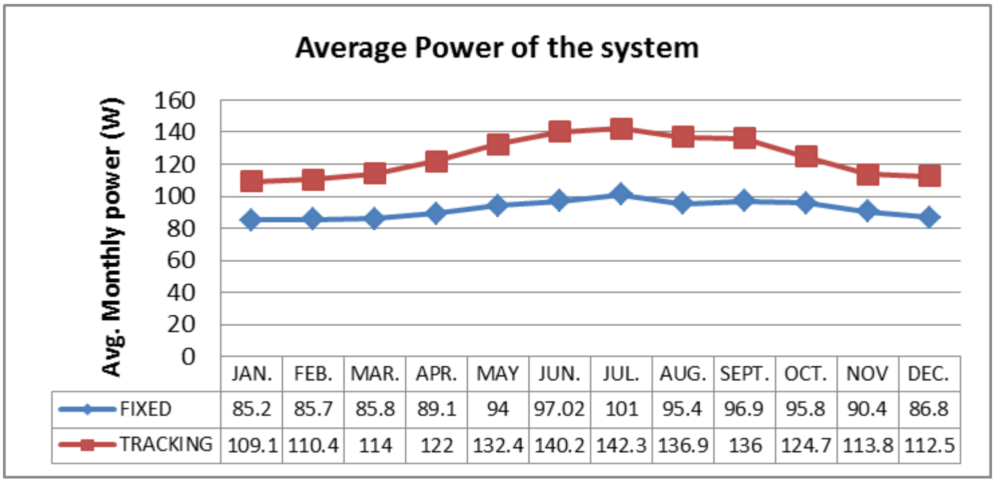


A	B	C	D	N	O	P	R	T	V	Z	AA
Number	Time	Area Name	Ctrl Name	Battary Voltage	Battary Current	Battary Power(V	Sun Voltage(V)	Sun Powe	Sun Current(A)	Wind WH(WH)	Sun WH(WH)
59801	8/1/2012	WWS06-24	WWWS06-24	26.39999962	2.761363745	72.90000153	27	72.9	2.700000048	57509.42969	57509.42969
59802	8/1/2012	WWS06-24	WWWS06-24	26.5	5.13207531	136	27.20000076	136	5.099999905	57518.67188	57518.67188
59803	8/1/2012	WWS06-24	WWWS06-24	26.60000038	5.011278152	133.3000031	27.20000076	133.3	4.900000095	57530.66016	57530.66016
59804	8/1/2012	WWS06-24	WWWS06-24	26.60000038	5.251879692	139.6999969	27.39999962	139.7	5.099999905	57542.05859	57542.05859
59805	8/1/2012	WWS06-24	WWWS06-24	26.60000038	5.357142925	142.5	27.39999962	142.5	5.300000191	57553.12109	57553.12109
59806	8/1/2012	WWS06-24	WWWS06-24	26.70000076	5.438201904	145.1999969	27.39999962	145.2	5.300000191	57565.12109	57565.12109
59807	8/1/2012	WWS06-24	WWWS06-24	26.60000038	4.090225697	108.8000031	27.20000076	108.8	3.900000095	57576.76172	57576.76172
59808	8/1/2012	WWS06-24	WWWS06-24	26.70000076	5.438201904	145.1999969	27.39999962	145.2	5.300000191	57587.07813	57587.07813
59809	8/1/2012	WWS06-24	WWWS06-24	26.70000076	5.232209682	139.6999969	27.39999962	139.7	5.099999905	57598.69922	57598.69922
59810	8/1/2012	WWS06-24	WWWS06-24	26.70000076	5.543070793	148	27.39999962	148	5.400000095	57610.53125	57610.53125
59811	8/1/2012	WWS06-24	WWWS06-24	26.70000076	5.438201904	145.1999969	27.39999962	145.2	5.300000191	57622.53125	57622.53125
59812	8/1/2012	WWS06-24	WWWS06-24	26.79999924	5.522387981	148	27.39999962	148	5.400000095	57634.53125	57634.53125
59813	8/1/2012	WWS06-24	WWWS06-24	26.79999924	5.623134136	150.6999969	27.39999962	150.7	5.5	57646.53125	57646.53125
59814	8/1/2012	WWS06-24	WWWS06-24	26.79999924	5.664179325	151.8000031	27.60000038	151.8	5.5	57658.53125	57658.53125
59815	8/1/2012	WWS06-24	WWWS06-24	26.89999962	5.74721241	154.6000061	27.60000038	154.6	5.5	57670.53125	57670.53125
59816	8/1/2012	WWS06-24	WWWS06-24	26.79999924	5.458955288	146.3000031	27.60000038	146.3	5.199999809	57682.53125	57682.53125
59817	8/1/2012	WWS06-24	WWWS06-24	26.89999962	5.539033413	149	27.60000038	149	5.400000095	57694.53125	57694.53125
59818	8/1/2012	WWS06-24	WWWS06-24	26.89999962	5.643122673	151.8000031	27.60000038	151.8	5.5	57706.53125	57706.53125
59819	8/1/2012	WWS06-24	WWWS06-24	26.89999962	5.539033413	149	27.60000038	149	5.400000095	57718.53125	57718.53125
59820	8/1/2012	WWS06-24	WWWS06-24	27	5.518518448	149	27.60000038	149	5.400000095	57730.53125	57730.53125
59821	8/1/2012	WWS06-24	WWWS06-24	27	5.622222424	151.8000031	27.60000038	151.8	5.5	57742.53125	57742.53125

Sayfa4 Sayfa1 Sayfa2 Sayfa3

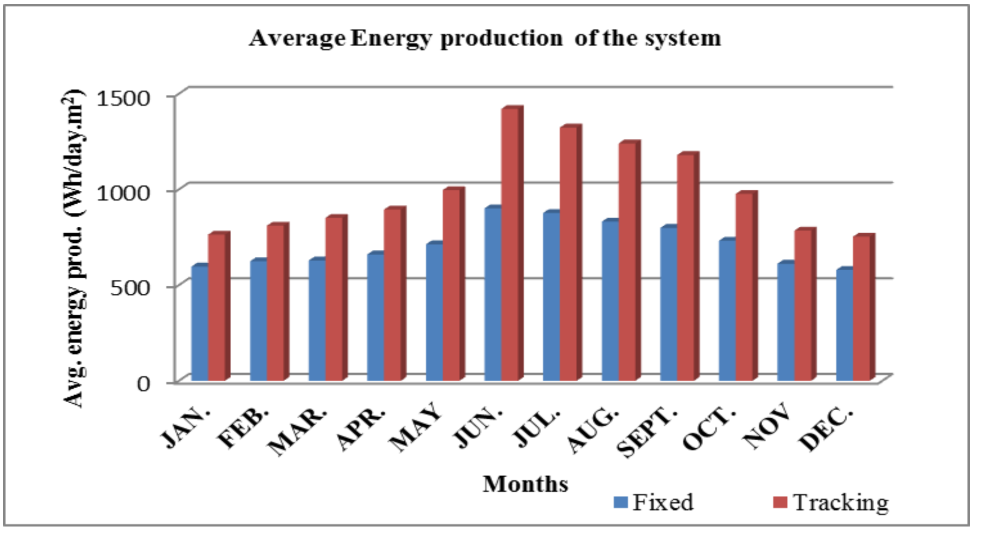
Average: 0 Count: 12787 Sum: 0 100%

Figure-6. Monthly Power Variation



	JAN.	FEB.	MAR.	APR.	MAY	JUN.	JUL.	AUG.	SEPT.	OCT.	NOV	DEC.
FIXED	85.2	85.7	85.8	89.1	94	97.02	101	95.4	96.9	95.8	90.4	86.8
TRACKING	109.1	110.4	114	122	132.4	140.2	142.3	136.9	136	124.7	113.8	112.5

Figure-7. Monthly Energy generation



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