International Journal of Scientific Engineering and Technology ISSN : 2277-1581
Volume No. 6, Special Issue 1, PP : 64-69 22-23 Dec. 2017

Energy Efficiency of PV Panels Under Real Outdoor Conditions – An Experimental Assessment in Kazakhstan

Ali Mubarakov[1], Sanzhar Sultan[1], Nurzhan Arkabayev[1], Dhawal Shah[2], Prashant K. Jamwal[1],*
[1]Department of Electrical and Electronic Engineering, and [2]Deparment of Chemical Engineering, Nazarbayev University, Astana, Kazakhstan.*prashant.jamwal@nu.edu.kz

Abstract : This paper provides an analysis of temperature effect on the performance of solar panels. Specifically, wider temperature range which prevails in Astana, Kazakhstan is considered. Previous work related with PV cell performance under extreme weather conditions had been carried out on a single PV panel in different temperature ranges. However, in the present research the performance, conversion efficiency and maintenance of different PV panels in Astana weather conditions are investigated. MATLAB simulation using existing PV panel models have been performed with various climate conditions and compared with the real data which is collected from Alfa-solar PV panels situated in techno-park of Nazarbayev University, Astana. Homer software® is used to assess financial aspects of PV system. The results from this research can help significantly in the evaluation of solar panels application in extreme conditions.

INTRODUCTION

Direct utilization of solar energy as power source have already experiencing massive worldwide commissioning and installation of PV plants, from 5W panels to supply rurallighting to large systems for modern towns. Massive adoption of new technologies, on the other hand, leads to additional issues formerly unaddressed and invisible. The current research in this area remains focused on mono and poly Si cells, because most of the PV systems nowadays are based on this technology. Further, PV panels works with higher efficiencies in direct sun irradiation with less obstacles and if cells are maintained at low temperatures. The location of installation (longitude, altitude and latitude) foremost defines the solar power accessible for a fixed PV panel. The terrain, exposure, and common environmental conditions also sufficiently impact the performance of the PV panels. Particularly, the dust has the strong obvious effect on PV panel efficiency [1]. The size of the PV system and the prevalent wind circulations would also define whether wind alleviates or aggravates dust settlement,inadditiontoheatexchangeprocess.

I. LITERATUREREVIEW

A. Influence ofdust

The influence of dust on the performance of Si PV panel is studied in [2]. Depending of amount, density and composition of dust, it can have different impact on the output panel. In particular, small amount of dust could actually benefit overall performance due to fact that it adsorbs part of unwanted wavelength of solar irradiation. This in turn results lower temperature of solar cells, and thus higher efficiency of the system (Fig. 1). In addition, this small particle of dust only catches undesirable light wavelength, while other ranges can participate in electricity generation. In fact, Si based panels generates electricity only with visible spectrum, whereas the rest converted to heat the system which can be stored by dust particles on the surface. As a result, utilizing this feature could also decrease the frequency of cleaning process of PV panels as well, through analysis of data from monitoring system. On the contrary, larger amount of dust on the top glass of the PV panel does not allow the light to reach the cell, resulting lower efficiency of the system.

B. Temperatureeffect

In [3] mathematical model of mono-crystalline Si PV cell is devised using classical single diode model. There solar cell is considered as a current source which produces current proportionaltotheirradiationcapacity.Inthesuggestedmodel,series $R_s$and shunt $R_{sh}$are responsible for ohmic losses in panel.

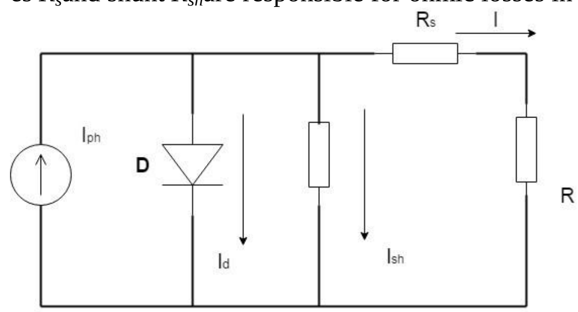

Fig. 1. Temperature difference between dusty and clean PV panels

Further this model is implemented in LabVIEW, which allows to study major PV panel parameters under different values of solar irradiance and cell temperature. In particular, designed simulation project calculates and plots power-voltage, current voltage curves, as well as system efficiency, fill factors (FF), open-circuit voltage, etc. The simulations are carried outunder constant irradiance of 1 $kW/m^2$and varying temperatures. In terms of results, well consistency with datasheet approves model accuracy. In addition, proposed design is flexible, and canbeutilizedforPVcellsfromdifferentmanufacturers.

The effects of solar irradiance and temperature on theperformance of different types Si solar panels are discussed in [4]. Particularly, solar intensity had been changed from 0.2 to
1.0 Sun, and have significant impact on current behavior. All of the following parameters including short circuit, photo current and maximum current increase linearly as solar irradiance goes higher. Therefore, the significance of

International Journal of Scientific Engineering and Technology ISSN : 2277-1581
Volume No. 6, Special Issue 1, PP : 64-69 22-23 Dec. 2017

concentrating system is noted which allows increase theoutputcapacity. However, as it is revealed, without cooling option output power of the systemalsodeclines.

Owing to concentratedlight and more heat, temperature of PV cells goes up. This decreases open circuit voltage and maximum voltage. The maximum output power falls by 14 to 25 per cent for poly and mono crystalline Si, under module temperature range of $10^{\circ}C$- $500^{\circ}C$.

A solar panel is a device, which consists of PV cells that are connected in series and parallel. Partial shading is a condition, when part of PV cells is covered by clouds or bythe shadows of nearest buildings. Under this condition, received solar irradiance of different PV cells varies. For each value of solar irradiance, a PV cell is able to produce current, that it less than its short circuit. Hence, if two parallel connected PV cells obtain different irradiances, reverse bias operation of several PV cells occurs. This condition brings hotspot formation in PV panel. Utilization of bypass diodes is one of the solutions of this problem. Operation of bypass diodesleads to appearance of multiple peaks in power curve. Therefore, partial shading condition leads to transformation of electrical characteristics of PV panel, comparing it to same of PV panels under normal conditions[5].

C. Effectofairvelocityandhumidity

The work of Mekhlief and Saidur has also considered such factors as air velocity and humidity that has a minor effect on PV performance [6]. The originality of their paper is in study of their effects in parallel and how they interact with each other. The air velocity was related to the temperature of the cells. As wind velocity increases cell temperature will decrease, as a result PV cell efficiency will increase. In addition, it was mentioned that performance is heavily dependent on cell type. Effect of humidity was considered in two different ways; first one affected irradiance level, while second one is ingressionof humidity to cell enclosure. Also, two module failure types and their impact on short circuit current and open circuit voltage were reported[6].

The effect of varying climates was described by Hermann and Bogdanski. Climatic impacts were considered in terms of three parameters, as irradiation, ambient temperature and relativehumidity.ThetestsiteswereGermany(moderateclimate), Indonesia(tropical climate), German Alps (high mountain climate) and Neged Desert of Israel (arid climate). The main objective of paper was to develop accelerated laboratory testing, to predict cell performance after 25 years of performance. The results from testing show that same cells have different degradation types[7].

PV field performance under different environmental conditions and atmospheric parameters was considered by Micheli, Muller and Kurtz. The main focus was made on soiling losses with complex mechanisms and interactions. PV cells were located in different locations to identify the most influencing factors that result in accumulation of dust. The calculations included such parameters as air-quality indexes, amount of rainfall, climate zone and recurrence [8].

II. METHODOLOGY

A. Datacollection

In order to make an assessment of PV panels under real outdoor conditions in Astana, data from real existing PVpanels have been collected and processed. Two PV plants that have been observed are located in Technopark at the Nazarbayev University, Astana. Their capacities are 10 and 15 kw. Current in phases A, B, and C of these 10 and 15 kW solar plants have been recorded within the month of January and March. Recording was conducted for every 30 seconds from 9 AM to 7 PM, due to the fact, that current during night is close to zero. After that, from all the numbers collected, average value for each daywas received by using MS Excel. By using received data, graphs that are provided wereplotted.

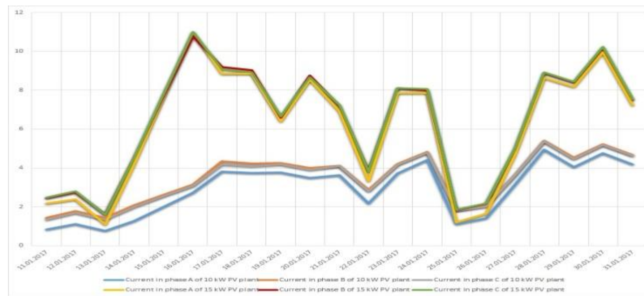

Fig. 2. Change of current in 10 kW and 15 kW PV plants within January.

Fig. 2 illustrates the change of current of 10 kW and 15 kW plants within a January. Current that was generated by 15 kW plant is bigger, than current that was generated by 10 kW plant. 10 kW plant produces relatively stable current, with average value around 4 A, with only fall on the 25th and 26th of January. At the same time, current of 15 kW plant is fluctuating during observed period, from less than 2 A to more than 11 A, which may be caused by several conditions, such as dust on the PV panel. On the 25th and 26th of March both PV plants showed poor performance, which was dictated byextremelycloudyweatherinAstana.

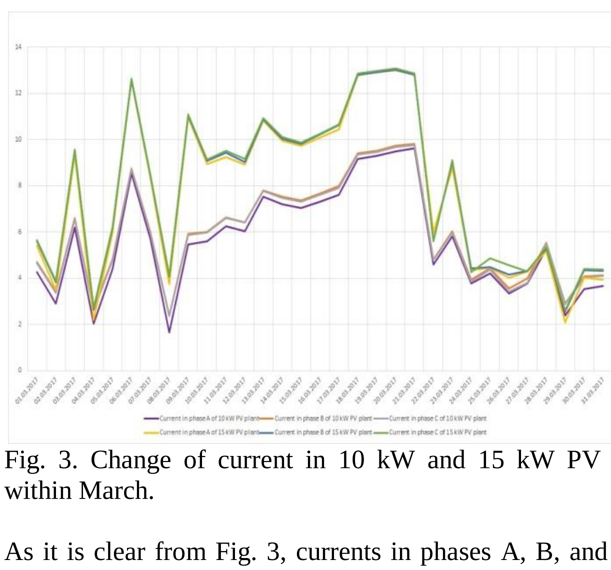

Fig. 3. Change of current in 10 kW and 15 kW PV plants within March.

As it is clear from Fig. 3, currents in phases A, B, and C are almost equal, and cannot be distinguished. Obviously, 15 kW solar power plants have higher current values, than 10 kW solarpowerplants.

International Journal of Scientific Engineering and Technology
Volume No. 6, Special Issue 1, PP : 64-69

ISSN : 2277-1581
22-23 Dec. 2017

A 15kWplanthasvaluesofcurrent nearly 10 A during observed period, whereas average value of 10 kW plant is around 7 A. But, on the 2nd, 4th, 8th, and from 22nd to 31st of March, values are lower than average. This may be explained by cloudy weather, with big amount of snow that was present during these days. Table I and Table II illustrate daytime and evening temperatures during January and March. Also, drop in generation of current can be caused bydust,whichgatheredonthePVpanel.

TABLE I
TEMPERATURE IN JANUARY [9]

Date	Daytime T(°C)	Evening T(°C)	Description
11.01.2017	-12	-16	Cloudy, snow
12.01.2017	-12	-17	Cloudy, snow
13.01.2017	-18	-18	Cloudy
14.01.2017	-14	-16	Cloudy
15.01.2017	-13	-17	Cloudy, snow
16.01.2017	-13	-19	
17.01.2017	-12	-16	
18.01.2017	-7	-12	
19.01.2017	-8	-10	
20.01.2017	-13	-14	
21.01.2017	-11	-13	Cloudy, snow
22.01.2017	-11	-17	Cloudy, snow
23.01.2017	-11	-14	Partly cloudy
24.01.2017	-14	-14	Cloudy, snow
25.01.2017	-6	-6	Cloudy, snow
26.01.2017	-4	-6	Cloudy
27.01.2017	-5	-6	Cloudy, snow
28.01.2017	-6	-12	
29.01.2017	-10	-12	
30.01.2017	-7	-13	
31.01.2017	-8	-8	Cloudy, snow

TABLE II
TEMPERATURE IN MARCH [9]

Date	Daytime T(°C)	Evening T(°C)	Description	
01.03.2017	-9	-9	Partly cloudy	
02.03.2017	-6	-6	Cloudy, snow	
03.03.2017	-3	-5	Cloudy, snow	
04.03.2017	-5	-7	Cloudy	
05.03.2017	-4	-6	Cloudy	
06.03.2017	+1	-6		
07.03.2017	-6	-11		
08.03.2017	-6	-7	Cloudy, snow	
09.03.2017	-11	-12	Cloudy	
10.03.2017	-9	-12		
11.03.2017	-5	-10		
12.03.2017	-5	-10	Cloudy	
13.03.2017	-7	-10		
14.03.2017	-6	-19		
15.03.2017	-4	-6	Cloudy	
16.03.2017	-5	-11		
17.03.2017	-5	-11		
18.03.2017	-4	-10		
19.03.2017	-3	-8		
20.03.2017	-1	-7		
21.03.2017	-1	-8		
22.03.2017	+2	-5		
23.03.2017	+4	+1	Cloudy	
24.03.2017	+2	+1	Cloudy	
25.03.2017	0	-2	Cloudy, snow	
26.03.2017	+1	0	Cloudy, snow	
27.03.2017	+3	+2	Cloudy, rain	
28.03.2017	+3	+3	Cloudy	
29.03.2017	+2	+1	Cloudy	
30.03.2017	0	-2	Cloudy	
31.03.2017	+4	+5	Partly cloudy	

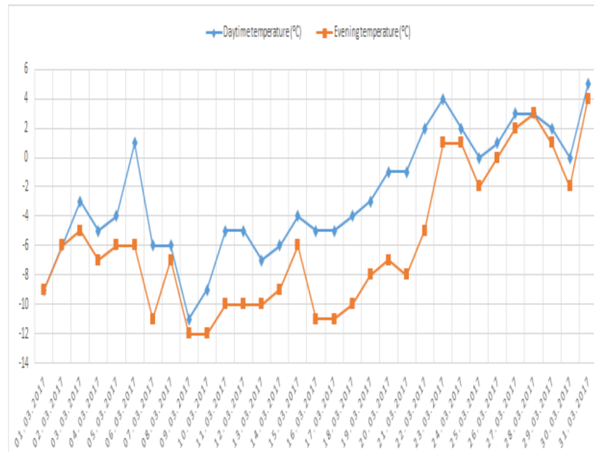

Fig. 4. Change of temperature within January

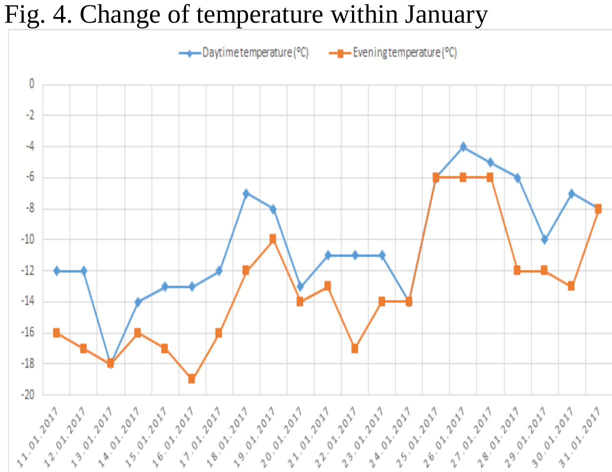

Fig. 5. Change of temperature within March.

Fig. 4 shows the weather conditions in Astana in January. It was plotted by using data obtained from weather diary [9]. Temperature grows from -16 to -8, with slight difference between daytime and evening temperatures. More than a half of the month was cloudy and snowy.
According to Fig.5, temperature in March grows from -10 to +5 at the end of the month. To sum up, primary weather factors that affect generation of current are cloudiness of the sky, and snowfall that covers PVpanel.

B. Simulation
As it said earlier, the power generated by PV modules depends on various conditions. A set of these conditions is called Standard Test Conditions (STC) and specified on Table III:

TABLE III
STANDARD TEST CONDITIONS

Parameter	ymbol	alue	nit
Irradiance at normal incidence		000	$/m^2$
Cell temperature		5	C
Solar Spectrum	M	.5	

The STC is related to the IEC 60904 standards, for PV modules following parameters are defined with 10% tolerance: open-circuit voltage V_{oc}, short-circuit current $I_{sc}$and maximum-point power (P_{mpp}). In reality, standard conditions occur seldom.
Common I-V curves and P-V curves are tested for different cell temperatures and irradiances by Simulink. Simulation settings are taken from Pyramid 60-240Wp solar cells'specifications which are installed on PV panels of Technopark. Table IVdisplaysthesolarcells'characteristics.

TABLE IV
SPECIFICATIONS OF PYRAMID 60-240WP PV MODULE ALFASOLAR

Specification	Symbol	Value
Short circuit current	I_{SC}	8.84A
Open circuit voltage	V_{OC}	37.37V
Maximum power current	I_{mpp}	8.11A
Maximum power voltage	V_{mpp}	30.19V
Maximum system voltage (IEC)	-	1000V
Maximum power rating	W_p	240W

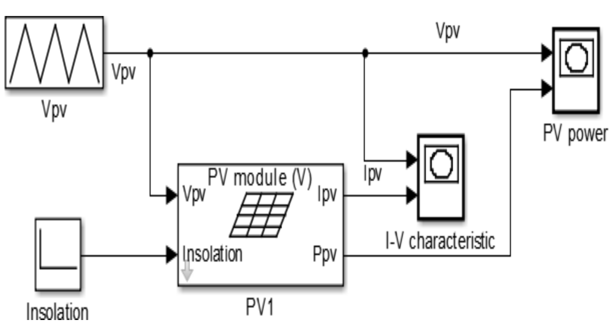

Fig. 6. A structure of PV module model [10].

The Voltage input PV model is taken from [10], utilizing two inputs and two outputs in addition to PV panel specification settlement for initialization of module. Using this model, various cell characteristics are generatedunder changing irradiance with constant temperature and vice versa. ThegeneralformofthemodelisshowninFig.6.
Themodule'sI-Vcurvesatconstanttemperatureandwithdifferent irradiances are depicted in Fig. 7. Thesolarirradiancewas changed from 200$W/m^2$to 1000W/m^2whereastemperature remained at 25$^\circ C$. Clearly, when theirradianceincreasestheI-Vcurvemovedhigher.Shortcircuitcurrentisalsoaffectedgreatly.Incontrast,opencircuitvoltageexperiencedsmallchangesinvaluethroughouttheirradiancevariation.Interms of P-V curves, similar relation to current isobservedforMaximum Power of PV cell under similar simulation(Fig.8).Similarly, Fig. 9 displays I-V curves fordifferenttemperatures and 400W/m^2constant irradiance.In particular,temperaturearechosen0$^\circ C$and+40$^\circ C$.AlsotheP-Vcurvesfor these module temperatures at constantI=400W/m^2areillustrated in Fig. 12. According to Fig. 9 and 12, itisobviousthatatlowertemperature,thevaluesofmaximumpower andopen circuit voltage get higher. In sharp contrast to that,shortcircuitcurrentdecreasedslightlyasthecelltemperature declined.

C. Evaluation withHomer

The economy is important function in designing solarpower systems. The main elements in cost system are solar panels, inverters and construction expenditures. The economic aspects of PV system were analyzed by HOMER Pro software. Net present value (NPV), payback period and leveled cost ofenergywereassessedinthissection.
The electric load in this research was set to residential type with peak month of July.Numerical value of load was found by considering each appliance in average house as shown in Table V. Daily and seasonal profiles for Astana are illustrated in Fig. 11.Electrical components for each solar power plant must be designed accurately.

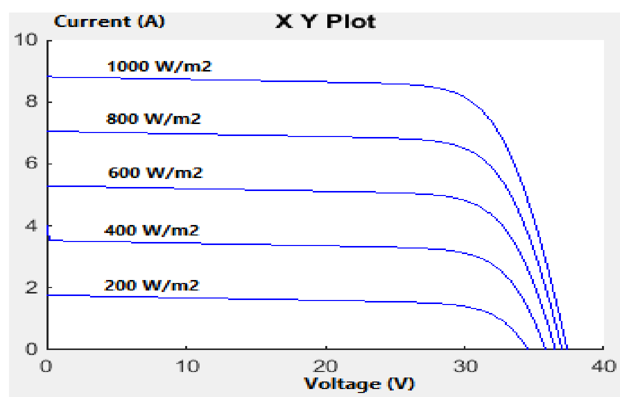

Fig. 7. I-V curves for various irradiances at T=25$^\circ C$.

ISSN : 2277-1581
22-23 Dec. 2017

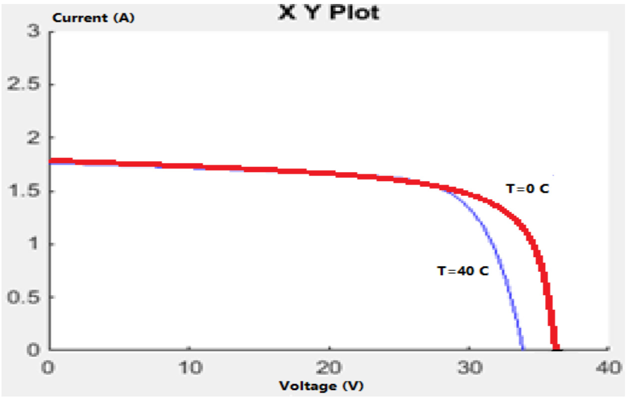

Fig. 8. P-V curves for various irradiances at T=25$^{\circ}C$.

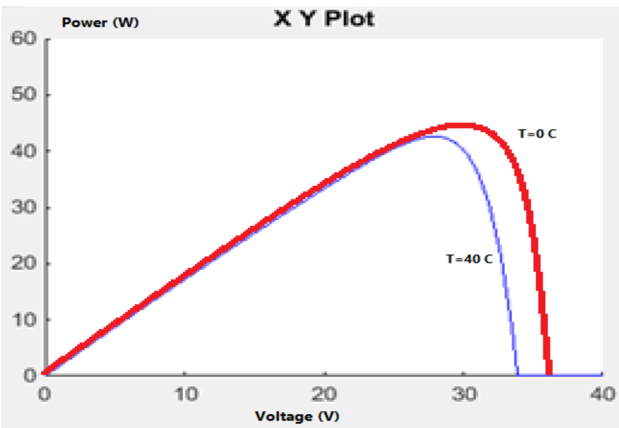

Fig. 9. I-V curves for various temperature and constant I=400W/m^2.

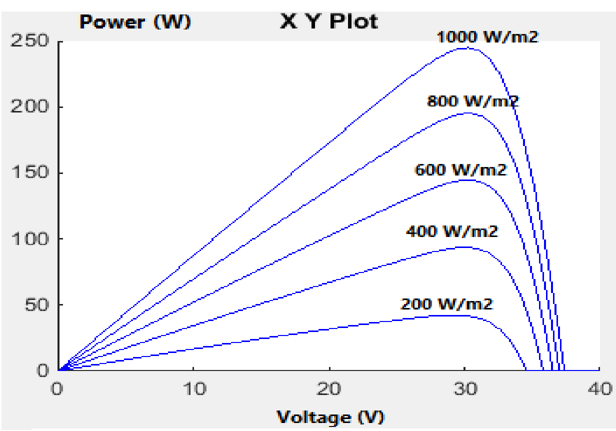

Fig. 10. P-V curves for various irradiances at T=25$^{\circ}C$.

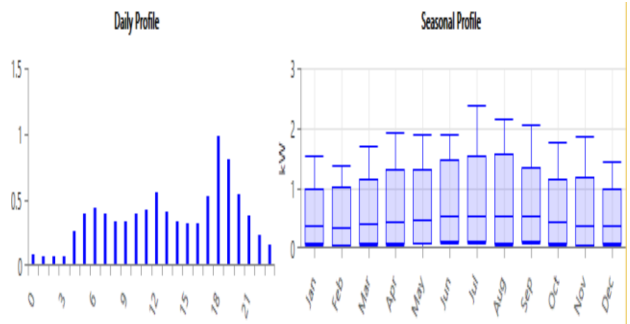

Fig. 11. Load profiles

For safety reasons inverter size must be 25-30% larger than total Watts of domestic appliances. In this case inverter size should be not less than 3.5kW. Therefore, for simulation purposes Leonics S-219Cp 5kW inverter with 48Vdc nominal voltage was chosen. Battery size (Ah) was calculated by the formulabelow:

$$Size\ (Ah) = \frac{7182W * Autonomy}{0.85 * 0.6 * Voltage} = 880Ah \qquad (1)$$

Autonomy value was set to 3 days and voltage to 48Vdc,which must have identical value with inverter nominal voltage. For simulation CELLCUBE R FB 20-40 with nominal capacity of 833Ahand with 48Vdc nominal voltage was selected.

The total cost of the system is illustrated in the Table VI. The PV panels cost include the installation, connections and panels cost itself. Results are discussed in Table VII.

TABLE V
POWER CONSUMPTION OF ONE HOUSE

Device	Power (W)	Hours used per day	Energy (Wh)
Lamp	18	4	72
Fan	60	2	120
Refrigerator	180	24	4320
Oven	2400	1	2400
TV	30	5	150
Others	20	6	120
Total	2708		7182

TABLE VI
TOTAL COST OF THE SYSTEM

Unit	Size	Capital cost	O&M cost
PV panels	2.5kW	5000$	4.09$/year
Inverters	3.5kW	600$	0
Batteries	833Ah	500$	20$/year

III. DISCUSSION

In data analysis section graphs that were obtained, show that although temperature influences the power generation in PVpanels,itseffectiscannotbecomparedtotheeffectof cloudiness of the sky and snowfall. For instance, generation of current by 15 kW PV plant in January, fall from 11 A to less

ISSN : 2277-1581
22-23 Dec. 2017

than 2 A, due to cloudy weather. Also, average generation of current in March is bigger than in January. This is the result oflargernumberofcleardays.

Fig. 12 illustrates I-V curves of Pyramid 60P for different irradiance at temperature $25^{\circ}C$. Simulated curves, particularly in Fig. 7, revealed that they are consistent with characteristics of Pyramid 60P from datasheet.

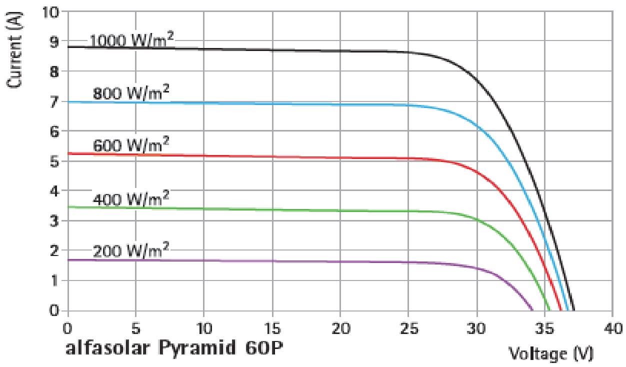

Fig. 12. I-V curves of Pyramid 60P solar module (reference: Alfasolar datasheet).

In economical part payback period was calculated by considering net present cost and savings of the entire project. Savings are total amount of money saved, because of autonomous energy generation, being independent from electrical grids of Astana with tariff of 0.067USD/kWh[11]. Economical result in terms of payback period is not attractive for investors or home owners. The reasons are aging of equipment and maintenance in Astana snowyconditions.

TABLE VII
ECONOMIC RESULTS

System	Savings($)	NPV($)	Payback	CoE
PV	2977	43372	13.1 years	0.399

IV. CONCLUSION

Mathematical model of PV panel was studied and model of voltage input PV module was devised. According to the results, temperature decrease had a positive impact on output power of the system. It was shown that irradiance at cold temperatures resulted in an increase in output power. General I-V and P-V curves were obtained using SIMULINK. Data was collected from Nazarbayev UniversityTechnopark.Thedatawasprocessedand graphs of current change were developed for March and January. Economic aspects were simulated in HOMERsoftware. Temperature data obtained from Technopark was used in simulations for one home condition. Payback period and NPV were later obtained.

Intermsoffutureworks,otherenvironmentalfactorsaswind speed and snowfalls shall be studied. The developed model can be improved in order to observe effect of extreme environmental conditions to accurately assess the performance of PV panels in central Kazakhstan. In addition, data from Technopark for full year can be further analyzed to observe system Behaviour under other extreme weatherconditions.

REFERENCES

i. *Rao, R. Pillai, M. Mani, and P. Ramamurthy, “Influence of dust de- position on photovoltaic panel performance,” Energy Procedia, vol. 54, pp. 690–700,2014.*

ii. *K. K. Khanum, A. Rao, N. Balaji, M. Mani, and P. C. Ramamurthy, “Performance evaluation for pv systems to synergistic influences of dust, wind and panel temperatures: Spectral insight,” in Photovoltaic Specialists Conference (PVSC), 2016 IEEE 43rd. IEEE, 2016, pp. 1715–1718.*

iii. *Nanjannavar, P. Gandhi, and N. Patel, “Labview based pv cell characterization and mppt under varying temperature and irradiance conditions,” in Engineering (NUiCONE), 2013 Nirma University Inter- nationalConferenceon.IEEE,2013,pp.1–6.*

iv. *El-Shaer, M. Tadros, and M. Khalifa, “Effect of light intensity and temperature on crystalline silicon solar modules parameters,” Interna- tional Journal of Emerging Technology and Advanced Engineering, vol.4,no.8,pp.311–326,2014.*

v. *M. Hasan and S. Parida, “Temperature dependency of partial shading effect and corresponding electrical characterization of pv panel,” in Power & Energy Society General Meeting, 2015 IEEE. IEEE, 2015, pp.1–3.*

vi. *S. Mekhilef, R. Saidur, and M. Kamalisarvestani, “Effect of dust, humidityandairvelocityonefficiencyofphotovoltaiccells,”Renewable andSustainableEnergyReviews,vol.16,no.5,pp.2920–2925,2012.*

vii. *W. Herrmann and N. Bogdanski, “Outdoor weathering of pv mod- ules—effects of various climates and comparison with accelerated laboratorytesting,”inPhotovoltaicSpecialistsConference(PVSC),2011 37th IEEE. IEEE, 2011, pp. 002 305–002311.*

viii. *L. Micheli, M. Muller, and S. Kurtz, “Determining the effects of environment and atmospheric parameters on pv field performance,” in Photovoltaic Specialists Conference (PVSC), 2016 IEEE 43rd. IEEE, 2016, pp.1724–1729.*

ix. *https://www.gismeteo.kz/.*

x. *“Pv module. simulink models,” in ECEN 2060. Colorado University, 2008, pp.1–11.*

xi. *http://www.astanaenergosbyt.kz/tarif/.*