Journal of Rajasthan Academy of Physical Sciences
ISSN : 0972-6306; URL : http://raops.org.in
Vol.17, No.3&4, July-December, 2018, 143-150

STATISTICAL ANALYSIS OF SOLAR POWER AS A SOURCE OF SUSTAINABLE ENERGY IN RAJASTHAN

Anil Kumar Bhardwaj* and **Mahender Kumar**
Department of Statistics, University of Rajasthan, Jaipur
*Email: anilbhardwaj66@gmail.com

Abstract: In India, energy problem is alarming and main objective is now to find solution to demand and supply energy sources. Therefore the need of conserving energy and developing alternative energy is must. Solar power generation systems are emerging renewable energy technologies and can be development as viable options for electricity generation in future. With its abundance of sunlight, India has tremendous potential to emerge as one of the leaders in solar power generation. According to the government of India's policy for solar sector, a target of 100 GW of solar installation by 2022 has been set. Rajasthan is blessed with abundant natural sources with more than 325 days of sunshine every year. So it has a huge potential of solar energy due to its climatic conditions.

This paper provides a detailed description of Rajasthan's solar energy, its current status and future forecast. In this paper on the secondary data taken from various sources, time series analysis is done. The response variable is taken as volume of generation of solar power in MW. The least square method to find out the year wise trend of solar power generation is applied on the time series data. The model considered in the paper is tested using $\chi 2$-test. For verification of autocorrelation in time series data D-W test is applied.

Keyword: Solar energy, installed capacity, solar policy.

1. Introduction

Rajasthan has a huge potential of solar energy, the climatic conditions of state makes it ideal for capturing the solar rays in sufficiency. The climate of Rajasthan is semi-arid; the desert of Thar is spreads on the 66.66 % of total area of state. These climatic specialties makes it suitable to receive almost 300-325 sunny days in a year and 6-6.4kwh/m2/sun radiation per day, which is second highest amount of sun radiation all over the world. The average temperature of western cities of Rajasthan is between 35-40 degree, and in summer it reaches above 45 degree. To promote the renewable energy sector[4] in general and solar energy in particular, Government of Rajasthan has taken several important initiatives. To begin with — Policy for Promoting Generation of Power through Non-Conventional Energy Sources[7] was enacted on 11 March 1999, which was updated in every year. Also, Government of Rajasthan issued Rajasthan Solar Energy Policy, 2014 to promote Solar Energy.[3] The main objectives of this policy include

vision is to reduce the dependence on conventional sources of energy by promoting the development of non-conventional sources particularly the solar power[5], it's aim is to create the environment for installation of 5700 MW of solar power through state or private enterprises or through public private partnership or through individual efforts by 2022. It also includes to develop Solar Power Plants for meeting renewable purchase obligation of Rajasthan as well as other States, promote off-grid applications of solar energy[6] and the other projects by simplifying the official restrictions making it investor friendly. It want to ensure easy process for allocation of land and other formalities for setting up solar parks in the state.

1. Methodology and Data analysis Tools

In this paper, the study is based on secondary data. On the basis of scattered diagram it is observed that a straight line trend is best suited to forecast the solar power installed projects. We consider the straight line equation

$$Y = a + bX$$

Where X represent the time variable and Y be the solar energy produced, a and b are constants to be obtained using the method of least squares.

The normal equations to calculate tese constants for n observations (x_i , y_i), i = 1,2,3,……..n are :

$$\sum y_i = n\,a + \sum b x_i$$

$$\sum x_i y_i = a\sum x_i + b\sum x_i^2$$

To test the goodness of the fit for the curve the χ^2 – test used is given by:

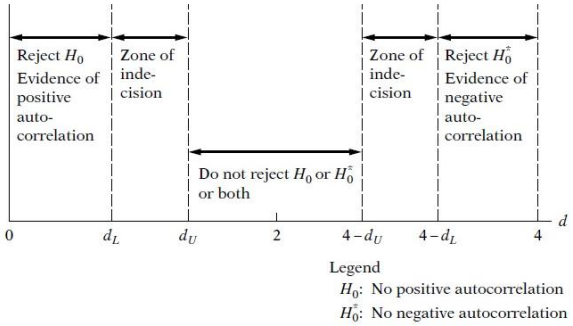
$$\chi 2 = \sum (O_i - E_i)^2 / E_i$$

where O_i are the observed values and E_i are the expected values of the solar energy.

For detecting auto correlation in the time series data Durbin Watson d statistic is defined by:

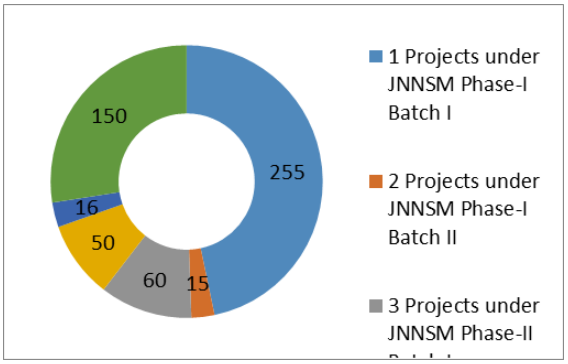
$$d = \frac{\sum_{t=2}^{t=n}(\hat{u}_t - \hat{u}_{t-1})^2}{\sum_{t=1}^{t=n}\hat{u}_t^2}$$

Limits of Durbin Watson d-statistic is 0 to 4.

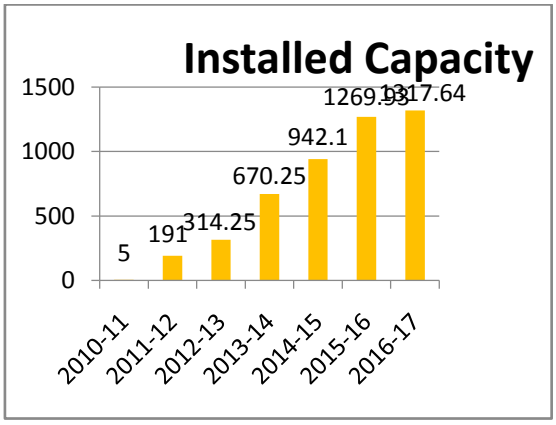


2. Graphical Representation

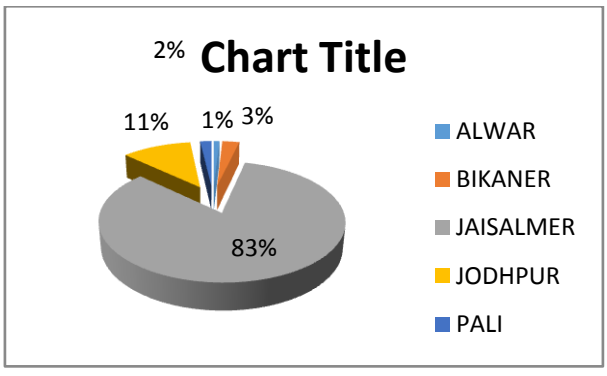
(1) The figure given below shows the details State Government Ongoing Grid Connected Solar power projects in Rajasthan under various scheme capacity MW[2].



(2) Figure shows that Rajasthan's installation of solar power capacity is increasing as par year:

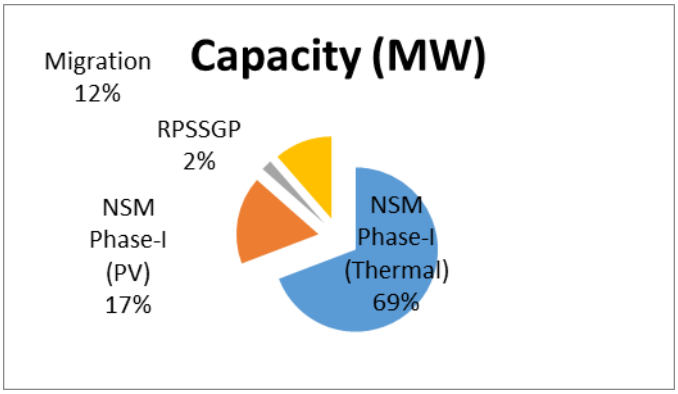


(3) Rajasthan Gird Connected Solar Power Projects in Rajasthan by district Commissioned.



The Geographical distribution of the estimation potential of renewable power as on 31.05.2015 reveal that In State Jaisalmer district the highest share of about 83 %, followed by jodhpur with 11%, mainly on account of solar power potential.

(4) Details of Solar Power Project in Rajasthan under Various Scheme



It can be seen that state government achievement under raj. Policy for solar power project scenario in Rajasthan under various schemes allotted capacity.

1. Statistical analysis[1]

Trend Analysis & forcasting by Least Square method

Year (x)	t=(x-2014)	Y_t('00) MW	t^2	ty_t	Trend values $Y=a+bt$ (E_i)
2012	-2	1.9765	4	-3.953	1.718
2013	-1	5.529	1	-5.529	4.701
2014	0	7.301	0	0	7.684
2015	1	9.421	1	9.421	10.667
2016	2	12.6993	4	25.3986	13.65
2017	3	18.1293	9	54.3879	16.633
Total	3	55.0561	19	79.7255	55.053

Using formula for trend analysis by least square method we get:

$\Sigma Y_t = na + b\Sigma t$ ...(i)

$\Sigma tY_t = a\Sigma t + b\Sigma t^2$ ...(ii)

On solving these equation we get, a=7.684 and b=2.983

Equation of trend is :

$Y_t = 7.684 + 2.983\ t$

$\chi 2$ Test for Goodness of Fit : We want to test that how better our data fit into expected curve i.e. Straight Line. For that we use $\chi 2$ Goodness of fit

Null hypothesis H_0: there is no significant difference between the observed and the expected value of installed capacity.

Alternative hypothesis H_1: there is a significant difference between the observed and the expected value of installed capacity.

Year	Oi	Ei	$(Oi - Ei)^2/Ei$
2012	1.9765	1.718	0.038895373
2013	5.529	4.701	0.145837907
2014	7.301	7.684	0.019090187
2015	9.421	10.667	0.145543827
2016	12.6993	13.65	0.066214688
2017	18.1293	16.633	0.134606727
Total	55.0561	55.053	0.550188708

From Above table $\chi 2$ (calculated) = 0.550 with 5 degrees of freedom

χ^2 (tabulated) = 11.070 at 95% confidence interval with 5 degrees of freedom

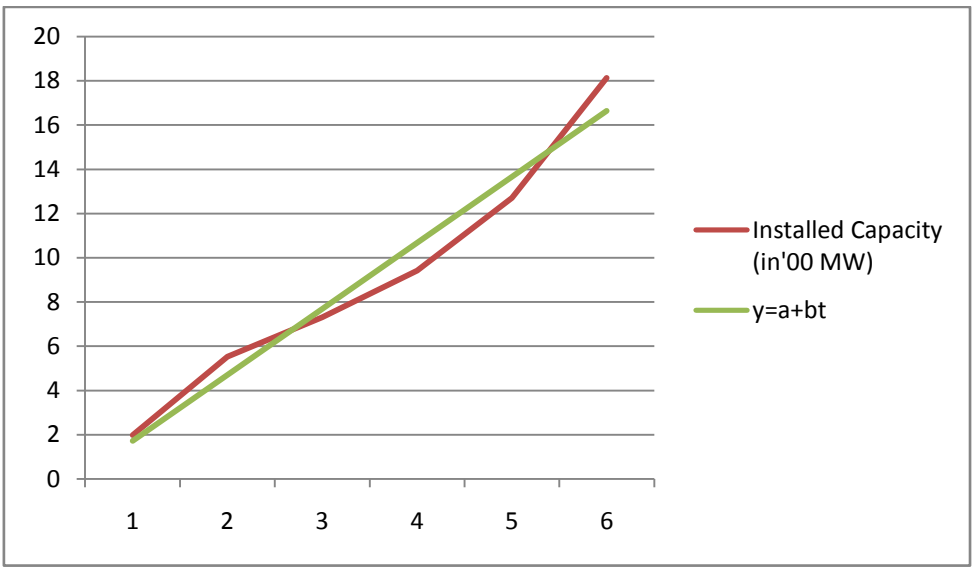
χ^2 (tabulated) = 15.086 at 99% confidence interval with 5 degrees of freedom

Since,

χ^2 (calculated) $\leq \chi^2$ (tabulated) at 5 d.f.

Therefore, There is No Significant Difference between observed and expected frequency i.e. it certifies that Straight Line is best fitted for data of year wise Installed Capacity of Grid Interactive in Rajasthan.

Graph showing fitted straight line.



Forecast

From above explanation best fitted trend curve is given by least square method which is :

$Y_t = 7.684 + 2.983\ t$

Installed Capacity of Grid Interactive in Rajasthan in year 2018 as forcasted using above equation is :

$Y_t = 7.684 + 2.983*4$

= 19.616(‘00)MW

= 1961.6MW

Installed Capacity of Grid Interactive in Rajasthan in year 2025[8] as forcasted using above equation is :

$Y_t = 7.684 + 2.983*11$

= 40.497(‘00)MW

= 4049.7MW

Now checking autocorrelation in Data by Durbin Watson d- statistics[9]:

H_o: ρ=0 (No autocorrelation)

H_1: $\rho \neq 0$ (Presence of autocorrelation)

Year	Installed capacity(’00)MW Y_o	t	Y_e	Residuals $\hat{u}=Y_o-Y_e$	$(\hat{u}_t - \hat{u}_{t-1})^2$	$\hat{u}_t^2$
2012	1.9765	-2	1.718	0.2585		0.066822
2013	5.529	-1	4.701	0.828	0.32433	0.685584
2014	7.301	0	7.684	-0.383	1.466521	0.146689
2015	9.421	1	10.667	-1.246	0.744769	1.552516
2016	12.6993	2	13.65	-0.9507	0.087202	0.90383
2017	18.1293	3	16.633	1.4963	5.987809	2.238914
	55.0561	3	55.053		8.610631	5.594355

d = 8.610631/5.594355

= 1.539164

For n=6 and at 95% level of significance (From Durbin Watson table)

d_L = 0.610 d_U =1.400

For n=6 and at 99% level of significance (From Durbin Watson table) we have

d_L=0.390 d_U=1.142

As our d-statistics lie between d_U and 2, so following decision rules we do not reject H_0. So our null hypothesis is accepted that there is no evidence of presence of autocorrelation.

3. Conclusion

On the data obtained from the FY 2011-2012 to 2016-2017 a linear trend is obtained using the method of least squares for curve fitting. Using Chi square test for goodness of fit on the actual data and forecasted data obtained from the trend, it is observed that the trend is of best fit and there is no significant difference between observed values and the expected values of installed capacity of grid interactive in Rajasthan. As the target of the installation of solar projects after 2015 are reset by the government of India, so the forecasted values are somewhat lower for coming years. By applying Durbin Watson's d-test it is found that there is no presence of autocorrelation in data as our d statistic lies between d_u and 2.

Acknowledgement: The authors are thankful to the Referee for valuable comments and suggestions.

References

[1] Barun, M.R., Altan, H. and Beck, S.B.M. (2014). Using regression analysis to predict the future energy consumption of a supermarket in the UK. Applied Energy, **130**, 305-313.

[2] Kapoor, K., Pandy, K.K. (2018). Jain A.K. and Nandana (2014). Evolution of Solar Energy in India, A review. Renewable and Sustainable Energy Reviews. **40**, 475-487.

[3] Kumari, R.O. (2011). Power Crisis in Rajasthan: Strategies to attain sustainable development. *Indian Journal of Science and Technology*, **4(3)**, 291-294.

[4] Lalwani, M. and Singh, M. (2010). Conventional and renewable energy scenario of India: Present and future. Can. J. Elec. Electron Eng. **1**, 122-140.

[5] Pandy, S., Singh V.S. et al. (2012). Determinant of success for promoting solar energy Rajasthan, India. Renewable and Sustainable Energy Reviews, **16**, 3593-3598.

[6] Razykev, T.M., Ferekides, C.S et al. (2011). Solar photovoltaic electricity: Current status and future prospects. Sciencedirect. **85**, 1580-1608.

[7] Singh and Payal Singh (2014). A review of wind energy in India. Int. Res. J. Environment Science. **3(4)**, 87-92.

[8] Sorensen, P. Unnikrishnan, A.K. et al (2001). Wind farms connected to weak grids in India. Wind Energy. **4**, 137-149.

[9] Statistics Office Central (2017). *Energy statistics report*. Retrieved from http://www.mospi.nic.in/sites/default/files/publication_reports/Energy_Statistics_2017r.pdf