Investigation of the Effects of Dust Accumulation, and Performance for Mono and Poly Crystalline Silica Modules

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Abstract- The future of world is with renewable energy sources, solar energy is clean and sustainable energy source. In a nation like India with its limited resources and geographical location of all non-conventional energy sources solar energy is most feasible. The present work is related to study on mono and poly crystallised silica PV cells its performance and efficiency under operation at Vellore, located at south east India, also investigation is biased on different orientation angles of modules. Dust accumulation on glass samples over a period of one month are investigated considering the impact on transmittance. The glass plates are never physically cleaned during experiment but may be subjected to natural to cleaning causes. Also the effect of inclination angles on dust deposition density and transmittance is also discussed.

Keywords- Solar energy, mono and poly crystalline PV cells, Transmittance and orientation angles.

Nomenclature

A	Area of the solar panel (m^2)
I	Short circuit current of the solar panel
P	power of the solar panel (w)
T	Atmospheric temperature (deg c)
V	voltage of the solar panel (mV)
Fd	Transmittance dust factor
τ	Transmittance of the glass sample with dust
τc	Transmittance of the plane glass sample
η	Efficiency of the solar cell(%)
ω	weight density of the dust on the solar panels. (g/m^2)
β	tilt angle of the solar panel (degrees)

1. Introduction

India is a third world country, one of the fastest growing nations to be supplemented by energy requirements. The current energy production meets only 60% of required energy leaving 400 million people of the country to blackouts.There is a stringent demand to improve power production by all sources of energy. For the nation to attain a sustainable development without degrading the environment, renewable energy generation techniques provide promising option. Renewable energy with a share of 13.5% globally is capable of meeting future energy requirements [1]. Research on various renewable energy sources is under progress to meet raise in consumption and price of fuel. These techniques include tidal, geothermal, wind, biomass and solar energy production [2], [3]. Most of these technologies are at demonstrative stage but shown promissory results to control greenhouse emissions [4]. Based on the country's geological location and economic conditions solar power has significant market than other techniques. Also currently solar power production can compete with other renewable energy technologies [5]. Data related to hourly diffused solar radiation and average incident radiation with tilt is collected at Delhi, India [6]. Sector wise energy requirement and solar energy consumption in south India is explained [7].

Mono crystalline and Poly crystalline silica are most commonly used PV cells [8]. Mono crystalline silica PV cells are made of pure or doped silicon containing very small impurities to affect its semiconducting properties. Performance of mono crystalline silicon is higher than poly crystalline silica [9]. Mono crystalline solar grade (Sog-Si) achieves 21% efficiency. The average efficiency of the poly crystalline solar cell is about 10%. The highest energy efficiency reported conversion so far for research crystalline silicon PV cells is 25%. The current range of commercial solar cells' efficiency is between 12 and 19% [10].

Solar radiation incident on PV collector mainly depends upon the inclination angle of the collector [11]. For proper designing of panel setup analysis of average radiation incident for various orientation of surfaces is to be done. Data regarding radiation respect to tilted angle is not available. Different techniques are being investigated to measure the radiation on tilted surfaces [12], [13], [14] and [15]. Maximum solar fraction is not only dependent on optimum tilt angle [16]; tilt angle should be adjusted as such solar fraction improves during non-peak hours of solar radiation

The study of power generated and efficiency of solar collector is complicated as it is greatly influenced by tilt angle, solar flux, humidity, wind speed and dust deposited on the collector. Wind has an important impact on natural degradation of collectors as high winds causes dust accumulation on cell causing decline in performance of cell but transmittance is higher during higher wind. Dust settlement on PV surface can be investigated by dust properties and environment conditions generally low wind can be a cause of dust settlement but high wind does a cleaning action. Various causes and effects of dust deposition on PV modules are explained [17]. Air borne dust mainly affects the performance of PV cells [18]. In arid and rainless climate reduction in transmittance is dependent on the dust accumulated on the surface, also dust deposition is related to tilt angle at lower tilt angles higher dust quantities can be observed [19].

Due to presence moisture content in air some amount of radiation is refracted, reflected and diffracted [20]. These effects plunges the reception level of the direct component of solar radiation Humidity alters the irradiance non-linearly and irradiance itself causes little variations in V_{oc} in a non-linear manner and large variations in I_{sc} linearly [21]. When PV cells are exposed to humidity for long term there will be degradation in performance. It has been observed that the high content of water vapour in the air causes encapsulate delamination [22]. The performance degradation is a result of passivized PV cells surface leading to I_{sc} degradation, while having no considerable effect on V_{oc} [23].

Absorbed radiation by PV module along with described factors also depends on transmissibility of glass. The performance of a PV cell depends on the ability of glass cover to transmit radiation. Transmittance of glazing surface depends on dust accumulated dust on the surface, intensity of radiation and tilt angle β [24]. Solar PV modules are not feasible for regular maintenance so prolonged exposure to dust leads to lower transmissivity and efficiency losses. As the β decreases large transmittance reductions are observed. Orientation of PV module surface to wind direction always affects the transmittance. H.K. Elminir et al. [25] Observed 12.38% transmittance variation with 300 change in β. F.M. Hussien et al. [26] performed similar experiments to determine effect of dust deposited density on power and performance of PV cell he observed that 250gm/m^2 density of accumulated dust leads to 84% drop in power output.

In the present study mean solar flux is measured for 28 days at Vellore India, voltage and current from three arrangements (0, 30 and 60 degrees) of south faced mono and poly crystalline silica PV cells are collected. Weekly accumulated dust density and transmittance is measured. The objective of the study is to observe the performance and efficiency of mono and poly crystalline silica PV cells with respect to tilt angles and naturally aspirated dust deposition. The effect of tilt angles and dust deposition on transmittance is also observed.

1. Experimental Setup

Experiment is conducted on the roof top of G.D. Naidu building in Vellore institute of technology at 12.9202° N, 79.1333° E Vellore India. Vellore is located on the banks of palar river in the north-eastern part of Tamilnadu 220m above from the sea level. Vellore city experiences three climates spring, rainy and summer seasons, which the experiment is conducted on summer in the mid of February to mid of March which the average temperature is 38^{0}C at mid-day and 26^{0}C at the night.

The experimental arrangement consisted of three monocrystalline and poly crystalline panels oriented south faced at angles of 0^0, 30^0 and 60^0 each which are equipped onto wooden frames that are designed to hold panels at desired inclination angles as seen from Fig. 1. The modules are of similar specifications with rated power of 4W, V_{oc}-11V, I_{sc}-0.4A and tolerance of 10%. Multimeter is incorporated to determine the power and efficiency of the panels. The data values are observed for every half an hour interval from 0900 hrs to 1700 hrs (15th February to 14th March 2014). To measure the quantity of dust settling onto the glass surfaces, the glass samples with the dimension of 7.5×2.5 cm^2 of 2 mm thickness is kept on the PV modules. To measure the dust weight the three glass samples is carried carefully and weighed under controlled conditions using an electric balance with an accuracy of 0.001 g. The samples are weighed for every regular interval of seven days for four weeks. The weight of the dust particles accumulated is calculated from the increase in mass of original cleaned glass sample.

Pyranometer is incorporated to setup used in determining normal solar flux density for every 30 min interval. The double beam UV-visible spectrophotometer is used for determining the transmittance. For transmittance the UV spectrum is passed through all glass samples. The transmittance is taken for every seven days interval for four weeks. The glass plates are left without cleaning throughout the duration of the experiment and they are subjected to natural impacts of dust deposition and cleaning.

Fig. 1. Experimental setup with wooden blocks

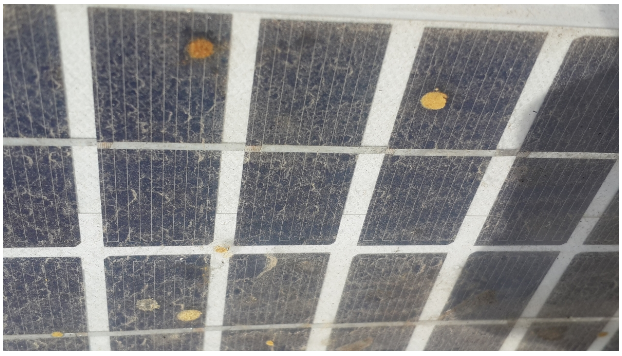

Fig. 2. Dust deposited on a PV module

2. Results and Discussion

The present study is carried out for a period of 28 days. Solar flux density is observed by using a Pyranometer for the duration of experiment and Fig. 3 indicates the mean solar flux observed for 4 weeks. Mean solar flux observed varies between 1075 w/m^2 and 750 w/m^2.

Similarly atmospheric temperature T is also measured at regular intervals and mean temperature observed on the day is plotted in Fig. 4. The temperature also varies from 22^{0}C to 31^{0}C. T is an indirect indication of intensity of radiation and climatic conditions prevailing over the testing.

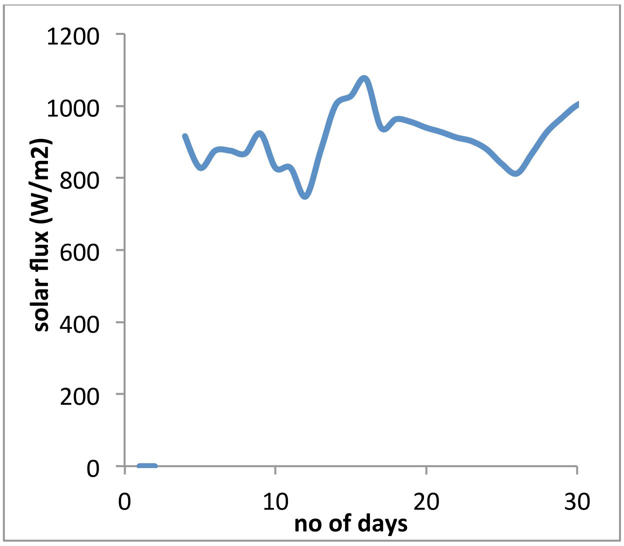

Fig. 3. Solar flux (W/m^2) vs. No of days

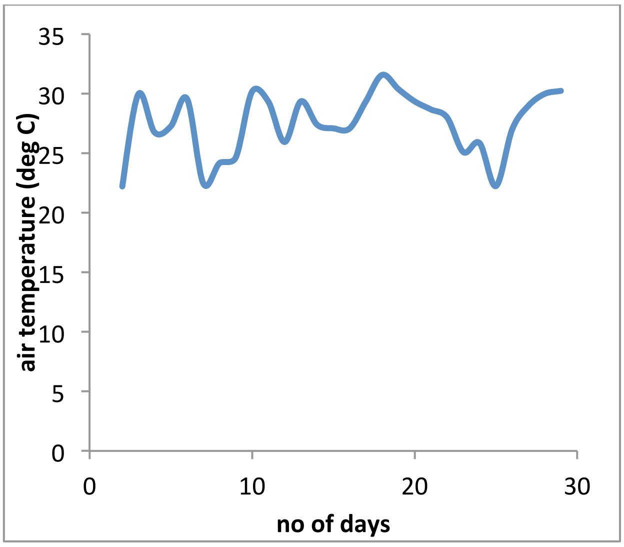

Fig. 4. Air temp (^{0}C) vs. No of days

Relative humidity and wind have significant effects on performance of the modules. Humidity deflects some amount of radiation resulting in the loss of direct radiation and wind at lower speeds reduces the efficiency of the module due to the deposition of the dust whereas higher speed winds do a cleaning action. Hygrometer is used here to measure relative humidity and mean humidity are observed in the limits of 3.5 and 6.0. It is observed that mean wind speed varies from 3 m/s to 6 m/s during period of experimentation.

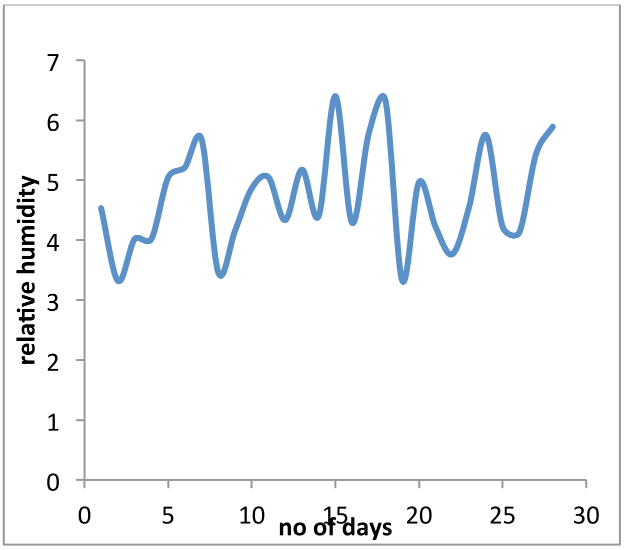

Fig. 5. Relative humidity vs. No of days

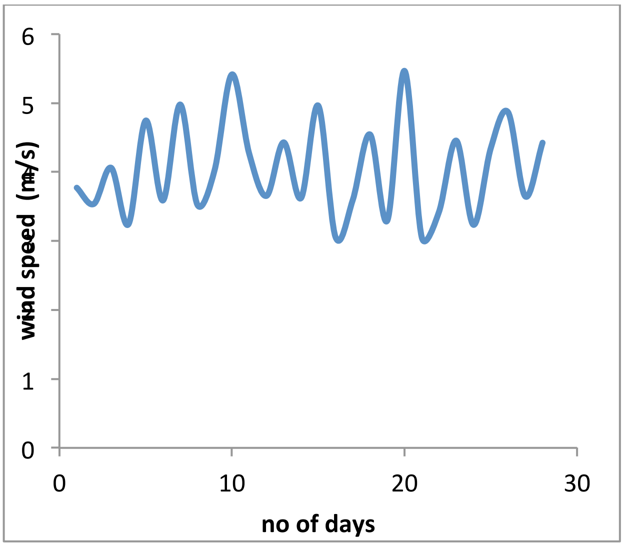

Fig. 6. Wind speed (m/s) vs. No of days

Power is measured from current and voltage readings measured from multimeter attached to module using the formula.

$$p=I*V \qquad (1)$$

Max powers generated by solar cells over experimental duration are 4W and 3.2W, respectively. Mono crystalline silica PV modules generate higher power than poly crystalline PV modules, Power generated from mono and poly PV modules is plotted against the duration of experiment and tilt angles of (0^0, 30^0 and 60^0) in Fig. 7 and Fig. 8. It is evident that 30^0 oriented module generate higher power followed by 0^0 and 60^0. The objective of the study is not related to the optimization of the tilt angles so no efforts are done to find the effective tilt angle β. The maximum powers generated at 30^0 orientation by mono and ploy crystalline solar cells are made up of highest grade silica.

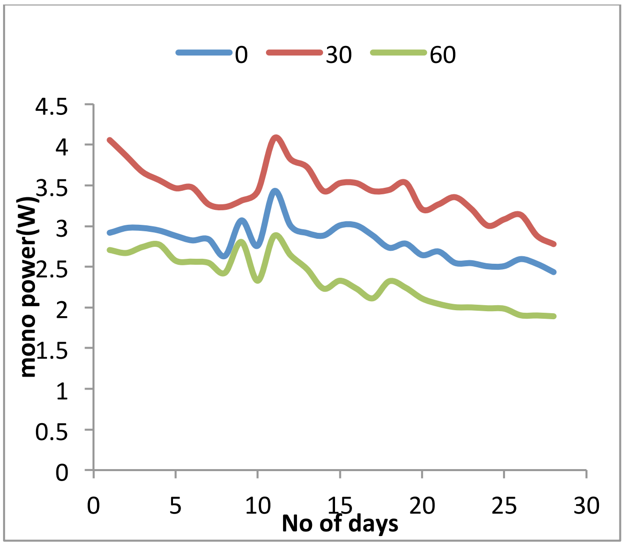

Fig. 7. Mono crystalline silica cells Output power (W) variation with tilt angles (β) and No of days

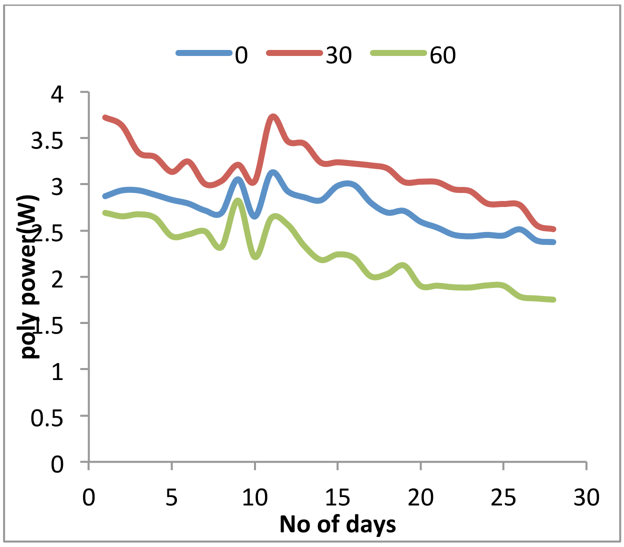

Fig. 8. Poly crystalline silica cells Output power (W) variation with tilt angles (β) and No of days

Efficiencies are calculated from power and area of solar module exposed to radiation using the formula.

$$\eta=(p*100)/(area*solarflux) \qquad (2)$$

Fig. 9 and Fig. 10 describes the efficiencies for mono and poly crystalline PV modules for different inclination angles. Similar to power, the efficiency is maximum at 30^0 orientation followed by 0^0 and 60^0 orientations and also mono crystalline PV modules has higher efficiencies than poly crystalline PV cells. The maximum efficiencies observed at 30^0 inclinations for both types of modules are 21% and 20.2% and the minimum efficiencies registered by 0^0 inclined modules of both types at the end of testing are 11.05% and 10.4%.

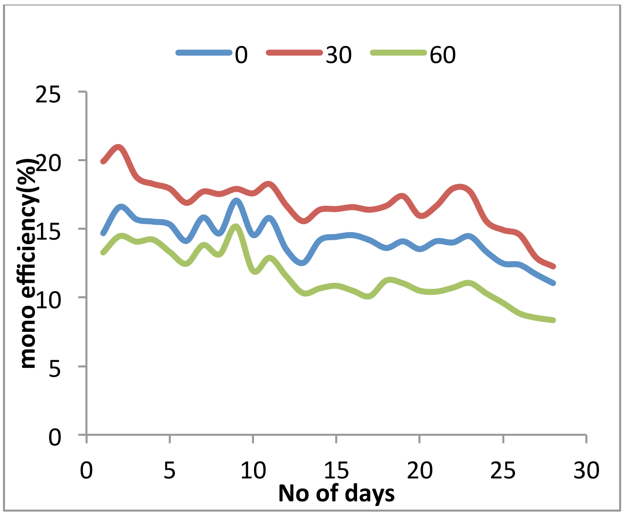

Fig. 9. Mono crystalline silica cells Efficiency (%) variation with tilt angles and No of days

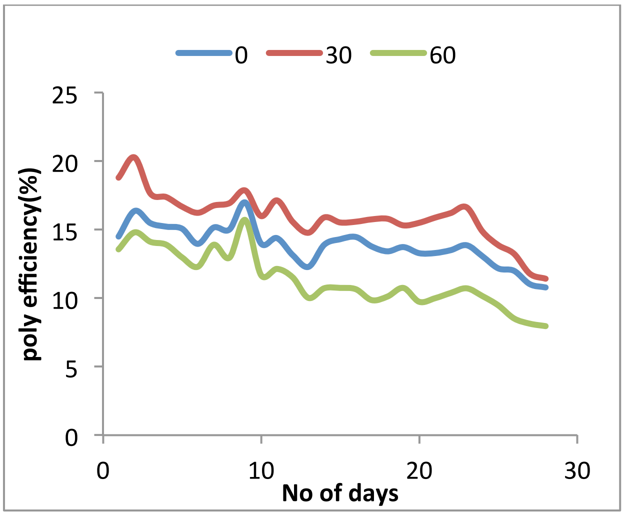

Fig. 10. Poly crystalline silica cells Efficiency (%) variation with tilt angles and No of days

Dust deposition density is measured using digital weighing machine with respect to the initial weight of glass sample. Dust deposited on samples is observed to be forming a layer and microscopic observations revealed that particle size varies from 1µm to 3µm. All samples are undisturbed during experimental duration. Dust accumulation is only through natural causes, natural cleaning process can happen due to heavy wind. From Fig. 11 shows the deposition density on all orientations increases with prolonged exposure and 0^0 plate has more affinity for dust deposition than 30^0 and 60^0 degree plates. The deposition density is measured at intervals of 7 days for a period of 28 days. The steepness of density lines is lowering as the week passes by. Dust deposition has a serious impact on transmittance. Dust deposition density ω varies in a range of 10 g/m^2 to 18 g/m^2.

Similarly, Fig. 12 shows the transmittance dust factor which is measured using Equation (3).

$$Fd=\tau/\tau c \qquad (3)$$

τc is the with transmittance observed for three glasses before the initiation of experiment. While τ values depreciate due to dust deposition that is by prolonged exposure as evident from Fig. 11. Maximum dust factor of about 0.98 registered on day 0 and from Fig. 12 it is observed that 0^0 oriented glass plates have shown minimum transmittance followed by 30^0 and 60^0 plates. 0^0 oriented plate has a dust factor of about 0.7 at the end of study.

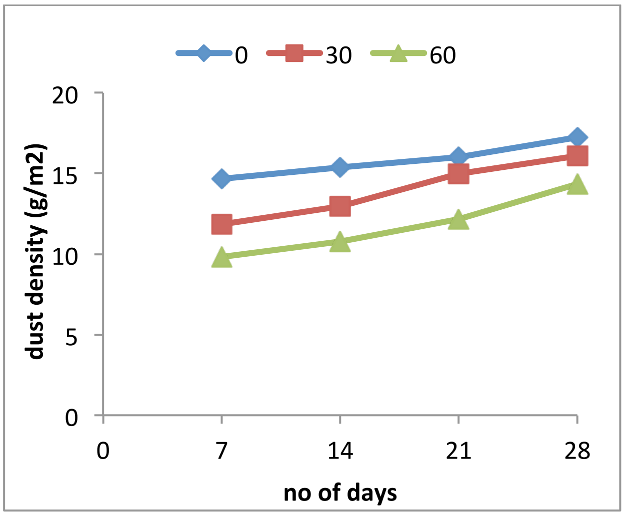

Fig. 11. Dust density variation with No of days for three inclination angles

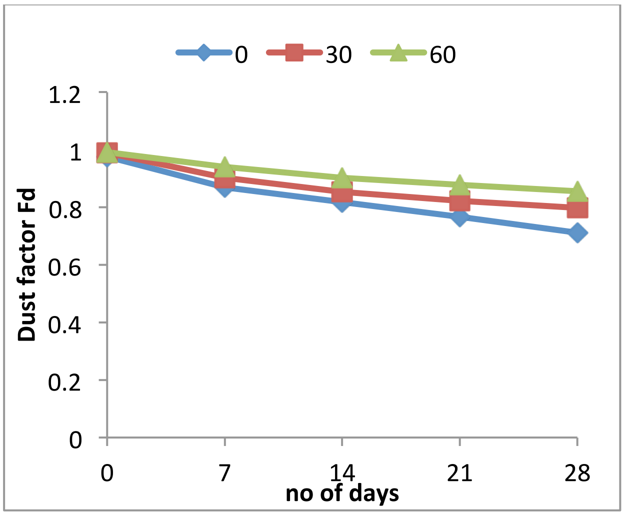

Fig. 12. Transmittance dust factor variation with No of days for three inclination angles

Basic result evident is transmittance reduction percentage also improves with exposure from Fig. 13. Transmittance percentage reduction is calculated by Equation (4).

$$\%\tau \text{ reduction}=(1-\tau/\tau c)*100 \qquad (4)$$

With exposure transmittance reduction percentage is improving. For 0^0 inclined glass plate transmittance reduction percentage increases from 14% to18% in first 7 days while an improvement of 23% to 29% is observed during the last week. Also as tilt angle decreases larger transmittance reduction takes place as observed from Fig. 13.

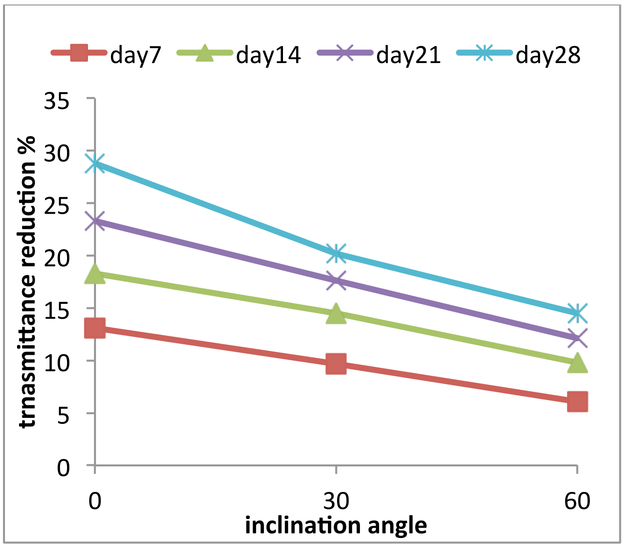

Fig 13. Transmittance reduction % for three inclination angles exposed for period of days

3. Conclusion

Experimentation discuss the performance characteristics of mono and ploy crystalline silica PV modules at 0^0, 30^0 and 60^0 inclination angles at Vellore and effect of dust deposition and orientation angle on transmittance.

1. Vellore experiences good solar irradiation with an average of about 800 W/m^2 on an average from mid-Feb to mid-March. So, there is a good scope for utilisation of solar energy.
2. Power generated from all modules show gradual decline in production with reduction in solar radiation for a particular period.
3. For both mono and poly crystalline modules max power is registered with 30^0 inclination and so max efficiency.
4. Comparative study between mono and poly crystalline PV modules it is observed that mono crystalline modules register considerably superior power and efficiencies.
5. Dust deposition is observed to more on 0^0 oriented plate than 30^0 and 60^0 with density of 18 g/m^2 after 28 days of exposure.
6. Transmittance dust factor as observed lowers mostly for glass inclined at 0 degrees 0.7 Fd is observed for this plate after 28 days of exposure.
7. Reduction in transmittance is greatly affected by dust deposition density and reduction percentage improves with exposure duration and inclination angle increment.

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