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Interdependence of Factors Affecting Intensity of Incident Solar Radiation during Solar Eclipse

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ABSTRACT

Solar eclipses are one of those rare yet predictable events which bear the potential to render impacts on the functioning of a solar power plant. Solar radiation being the input to a solar power plant, plays a vital role in the quality of power generated. However, this input radiation is useful only when the intensity is adequate enough to generate power. The intensity of solar radiation depends on various key factors but in context of a solar eclipse, there are certain additional factors that need necessary consideration without which the analysis can be incomplete and unintelligible. This paper shall at first introduce all such qualitative factors on which the intensity of solar radiation depends during any regular day and thereafter extend the study to a day with a solar eclipse. The qualitative interdependence of all these factors shall then be discussed with a view point of establishing a basis for the derivation of a relation between the same. In reality there are numerous factors affecting the incident radiation but the factors considered for this study shall be broadly restricted to location or latitude, time of the day or relative altitude of the sun and moon, time of the year or sidereal position of the earth, cloud cover, apparent diameter of the celestial bodies on the day of eclipse, magnitude and obscuration of the eclipse.

KEYWORDS: *Solar, Eclipse, Power, Generation, Fluctuation, Interdependence*

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A. INTRODUCTION

Solar Radiation in the true sense is the source of life. One can hardly imagine life on earth in the absence of solar radiation. From organic matter to synthetic materials, everything depends on solar radiation for energy. It is solar energy alone that aids many other non conventional sources of power generation.

Energy is necessity of the day. Every equipment needs energy to function. Earlier this role was played by mechanical energy which had led to hefty machines. Over the years, mechanical energy is replaced by electrical energy and generation of optimum electrical energy is what is the area of focus in modern times. Particularly in solar power plants, the goal is to harness maximum energy from the incoming radiation.

Solar power plants are generally designed to suit the location based on various factors. During the early hours of morning, the power generation is quite feeble. As the day progresses, the intensity of solar radiation goes on increasing and so does the power generation. After reaching a peak value, from the noon time to the evening, the intensity of solar radiation as well as power generation wanes. During night time, the power generation is minimum as although not visible, solar radiation does exist in the atmosphere. One cannot feel it as radiation has the property of not heating the intervening medium but the very fact that temperatures do no exponentially fall below freezing point as soon as the sun sets, establishes a premise that there is radiation in some or the quantity at all times.

In order to generate optimum power, the solar power plant should receive optimum solar radiation. This depends on various factors which shall be discussed in the subsequent sections.

B. Factors affecting intensity of incident solar radiation on a solar power plant on a regular day

Regular day shall be considered as that on which there is no eclipse. There are various factors that govern the power generation of a solar power plant.

First comes the location or latitude of the observation. As an established fact, an observer is necessary while conducting an experiment without which the data is deemed to be devoid of meaning. Similarly while evaluating the effects of intensity of solar radiation, it is essential that the exact location of the observer is known. This can be done by knowing the coordinates indicating the latitude and the longitude. Longitude does not affect the understanding of this experiment as far as the latitude remains constant. However, for a given longitude, the variation in latitude can add to the difference. It is known that the earth revolves around the sun in the ecliptic plane with an axial tilt of 23.5°. On various latitudes of observation, this can lead to varies observations. At the equator, the day length is constant throughout the year. As the observer moves from the equator towards the poles, the day length varies wherein, during one half of the year it is greater than that in the other. Thus ideally, the location that can chosen to set up a solar power plant is anywhere nearer to the equator so that consistently throughout the year, power generation can be carried out with optimum stability.

Next is the time of the day. This can be related to the altitude of the sun as observed from a given location. Altitude of the moon needs to be considered on the day of an eclipse. As the day progresses, the altitude of the sun goes on increasing to reach a maximum at the noon time. With this, power generation also goes on increasing. Additionally, it can be observed that as the day progresses from noon to the evening, the overall intensity of incoming radiation goes on decreasing. This sets the premise that the optimum time for power generation is around the noon.

Next is the time of the year or sidereal position of the earth. Sidereal year is the time taken by the earth to revolve around the sun once with respect to fixed stars in which the sun returns to the same position with respect to the fixed stars after travelling around the ecliptic as observed by the observer. The orbit of earth is not circular but is elliptical in shape. This leads to existence of a perihelion and aphelion. During perihelion, the earth is nearest to the sun and during aphelion the earth is farthest from the sun. Following Kepler's laws of planetary motion, and laying emphasis on the second law which states, "A line segment joining the planet and the sun sweeps equal areas in equal intervals of time", at perihelion, the earth revolves faster as compared to aphelion. By this, at the larger scale, the intensity of incoming solar radiation does not fluctuate much disregarding the occurrence of seasons.

Next is cloud cover. Cloud cover is a factor which can be a boon or a bane. Boon in event of eclipse and bane on a regular day without an eclipse. While the individual effects of various types of clouds shall be out of purview of this paper, it can be said that cloud cover collectively hinders power generation by reflecting, absorbing and scattering solar radiation.

C. Factors affecting intensity of incident solar radiation on a solar power plant on an eclipse day

While carrying out any scientific investigation, an observer plays a vital role in the success of the analysis. Factors discussed in this section are highly observer specific and do require sufficient knowledge and competence to carry out observations.

In this, first is the relative apparent diameter of celestial bodies taking part in the eclipse. Depending on the relative positions, the extent of an eclipse is determined which can be either partial or annular or total.

Magnitude of an eclipse is defined as the fraction of the diameter of disc of eclipsed body that is covered by the eclipsing body. Greater the magnitude, greater will be the totality of the eclipse. Magnitude is measures purely as a diameter and may not provide data regarding the area under eclipse unless calculated.

In order to determine the area of eclipsed body, another term called obscuration is often used. Obscuration is defined as the fraction of area of the eclipsed body obscured or blocked by the eclipsing body.

D. Significance of study of interdependence of various factors

Any experiment is bound to have a result which may be favourable or otherwise depending on the process undertaken. While studying the intensity of incoming solar radiation on the day of an eclipse, it is necessary to know the interdependence of various factors that govern the experiment in total.

Knowledge of interdependence of factors leads to complete comprehension of the experimental aspects. Following sections consider interdependence of various factors and their effect on the power generation of a solar power plant.

E. Interdependence of factors affecting intensity of incident solar radiation

To begin with, let the location of the observer be defined. This can be done by defining the coordinates of observation. As stated in a previous section, latitude plays a vital role in determining the quantum of solar radiation received by the earth. As the location is now fixed, a model can be generated to study the variation in incoming solar radiation with the latitude. By this knowledge, one can figure out the variation in radiation with respect to the latitude. At a given latitude, as the altitude of the sun increases, there is an equivalent increase in the incoming solar radiation until the maxima is reached. The motion of moon is such that it also traverses a defined path in the sky depending on the phase and its location in orbit. The sidereal position of the earth is important when it comes to higher latitudes because at these, daylight varies as there is a change in the sidereal position. In the northern hemisphere, during the summer solstice, length of the day is longest while it is shortest on the same day in the southern hemisphere. This shows that although it may be the same time of the year indicating the same sidereal position, the latitude governs incoming radiation. Latitude and cloud cover are interdependent too. Based on the location and local seasons, there is a variation in the cloud cover. This can also be attributed to the vegetation and climate over a specified period of time. as stated earlier, the location of observer is as important as the experiment itself, apparent diameter of the celestial bodies is highly dependent on the latitude of observation. While occurrence of solar eclipse at the polar region might be a very rare event, at equatorial latitudes, it can be a much frequent occurrence depending on the lunar nodes attained by the moon. Magnitude and obscuration of the eclipse are a part of the observer's illusion of the eclipse for a particular latitude. Thus latitude does govern a major part of the observations and affects the incoming solar radiation in a manner to ensure location specific data evaluation.

Earth revolves around the Sun and the moon revolves around the earth. This results into a spectacular relative motion of celestial bodies as observed from the earth. This leads to an illusion of rising and setting of the sun and the moon. The Sun traverses a defined path everyday with a slight change such that an oscillatory motion in the position of the sun can be observed in a sidereal year. Since the moon revolves around the earth, it too traces a defined path everyday and the same can be predicted by simple mathematical modeling. Eclipses can occur only when these paths of the Sun and Moon intersect at a point and he two are visible at that point at the time of observation. Since the Sun is 8 light minutes away from the earth and the moon is one light second away from the earth, all that we see as an eclipse is the past but since it is been observed then, it is considered is considered to occur at that point of time. This sets up a premise that the apparent position and diameters of the celestial bodies can lead to obscuration of the Sun during an eclipse, magnitude of which can be measured by simple mathematical analysis or by observation and simulation. In addition to all these, cloud cover can lead to blocking of radiation although there might be an eclipse occurring due to relative altitude of the sun and the moon.

Coming to the sidereal position of the earth, it is a well established fact that always one hemisphere of the earth faces the sun for half of the sidereal year and for the remaining half the other hemisphere faces the sun. This is purely due to the inclination of the axis of the earth's rotation to the ecliptic plane. There are two locations in the earth's orbit around the sun that can be of greater interest viz. perihelion and aphelion. At the perihelion, the hemisphere facing the sun registers largest incoming radiation due to lesser proximity and availability due to lesser absorption. Thereafter at the perihelion, the hemisphere facing the sun registers least incoming radiation compared to the perihelion. This signifies that sidereal position governs intensity of incoming radiation. It is the sidereal position of axial tilt with respect to the ecliptic plane that causes occurrence of seasons. Thus depending on the seasons there can be variation in the cloud cover. Magnitude and obscuration of eclipse may be different at perihelion and aphelion due to change in the apparent diameter of the sun with the moon having the same apparent diameter. At the perihelion or aphelion of both, the earth and moon, occurrence of an annular solar eclipse is greater. At the aphelion of earth and perihelion of the moon, apparent diameter of the moon is greater than that of the sun and if the altitude paths intersect, there can be a total solar eclipse. At the perihelion of the earth and aphelion of the moon, occurrence of an annular solar eclipse is greater. In addition to this considering the curvature of the earth, at certain locations, a hybrid eclipse can also be witnessed. In a hybrid eclipse, although a given location may observe an annular eclipse, a place nearer to that depending on elevation and earth's curvature, may observe a total solar eclipse.

On any day, the most deterring factor that can wane the power generation of a solar power plant is the cloud cover. Thus while selecting the location, conditions similar to that of airport need to be considered. A place with minimum average cloud cover and mild breeze is optimum for a solar power plant. Clouds absorb part of the incident radiation and transmit the remaining radiation which leads to generation of lesser power. There are methods like amplification in effect to compensate the loss of power due to cloud cover, but non occurrence can be most beneficial

The magnitude of a solar eclipse is an apparent measure of the amount of diameter of the body being eclipsed. In order to determine the quantum of incident radiation, another term called obscuration can be employed. This term can provide a clearer picture of the effect of eclipse on the incident solar radiation.

Conclusion

Thus by evaluating the interdependence of factors affecting intensity of incident solar radiation during solar eclipse, it can be concluded that intensity of incoming radiation is directly proportional to relative altitude of the sun and the moon, sidereal position of the earth and is inversely proportional to the latitude of observation, cloud cover, relative apparent diameter of the celestial bodies taking part in the eclipse, magnitude and obscuration of the eclipse. This basic data can be useful to derive a relation between the factors so as to set up a model to optimize the power generation of a solar power plant in event of an eclipse

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