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Qualitative Effect of Solar Eclipse on Power Generation of Solar Power Plant

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ABSTRACT

Solar energy is the energy of the present and future. With the growing demand for power, it is likely that solar energy is going to be the only reliable energy source in the future. This adds to the collective responsibility of solar power plants to deliver power efficiently. As every method of energy conversion has its own limitations, so does this method exhibit its inefficiency to convert solar energy into electrical energy in the presence of cloud cover or in event of eclipses. This paper shall consider the effect of a solar eclipse on the power generation process of a solar power plant and propose a theory for the same. Initially, various types of eclipses shall be discussed for the need of acquaintance and understanding after which the effect of solar eclipse on the stability of the plant shall be understood. This work shall be restricted to qualitative analysis and shall intend to establish a theory of correlation between progression of eclipse and the stall and surge in power generation which shall then be linked to the stability of the power plant. As modern day technology can easily provide details of the next eclipse in line, necessary precautions and safety measures can surely be undertaken to avoid damage to power generation equipment. Towards the end, a procedure shall be proposed to validate the theory.

KEYWORDS: *Solar, Eclipse, Power, Generation, Surge, Solar Cell*

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A. Motion of the Earth

It is a well established fact that at any given instant, the Earth rotates about its own axis causing day and night and revolves around the Sun in the Ecliptic plane causing change of seasons thereby marking every revolution as an Earth year.

The motion of earth around the Sun is a collective result of various factors and forces which include gravitational forces due to presence of nearby planets, the moon and the Sun itself.

It is an astonishing fact that the motion as of today is so well synchronized. The moon revolves around the earth in a period of nearly 28 earth days in a prograde orbit. The Sun appears to rise and set but it is in fact the rotation of the earth that causes this illusion. However, although the moon also appears to rise and set, it actually revolves around the earth in its tidally locked position. Thus to establish the concept of eclipses, the relative motion of these celestial bodies viz. earth, sun and moon needs to be understood.

For better comprehension, an inertial frame of reference with respect to the Sun can shall be considered. Since Newton's Laws are applicable to such frames of reference, concepts of relative circular motion shall also hold true although circular motion is a type of accelerated motion due to change in direction of motion with every instant of time. With the Sun thus fixed, the earth revolves around the Sun in the plane of Ecliptic obeying Kepler's Laws of planetary motion. The Earth rotates about its axis and the moon revolves around it. Following a prograde motion, it can be observed that on a full moon day, the moon rises as soon as the sun sets. Following this, in the bright fortnight, the moon rise gets delayed until the new moon day when the moon does not rise at all. In the following dark fortnight, crescent can be seen following the sun during daylight. Thus considering this relative motion, two events viz. full moon and new moon are necessary for an eclipse. Little consideration will clearly show that an eclipse can occur only on these two days as the chances of occurrence on any other day are absurd.

B. Eclipses

Every self-luminous object radiates light in all directions. However, to record these, presence of an observer is of utmost necessity. The light radiated by a self-luminous object falls on any object and makes it luminous. Thus earth and moon are observable because of the light of the sun as they are non self-luminous celestial bodies. If this light is obstructed, a shadow is formed. Eclipse in itself is a mere shadow at a grander scale.

Thus as indicated earlier, let us consider two scenarios. First is that of a full moon day. On the evening of a full moon day, as soon as the sun sets in the west, the moon appears to rise in the east. This means that the sun, earth and moon are in a straight line and the earth is in between. If accurately aligned, light from the sun falling on the moon, can be obstructed by the earth either partially or totally, an effect of which can be observed by reduced brightness of the moon. This itself is called as a lunar eclipse which shall be elaborated eventually.

The second scenario is that of a new moon day. On this day, the moon is not at all visible as it is in the apparent vicinity of the sun with reference to the sky. Thus on a new moon day, the sun, earth and moon are again in a straight line but this time, the moon is in between. Again, if accurately aligned, the light coming from the sun towards the earth can be obstructed by the moon, causing blackout or reduced daylight. This itself is called as solar eclipse which shall be elaborated in the following section.

Thus eclipse is an obstruction to the light coming from a self luminous object and formation of a celestial shadow on a body receiving the light.

Certain well known terms in the context of an eclipse may now be revived. Umbra is the region of total darkness past the celestial body causing the eclipse enclosed by direct common tangents between the light source and the obstruction. Umbra is more or less a finite region. Penumbra is the region of partial darkness past the celestial body causing the eclipse mostly enclosed but not restricted between the transverse common tangents between the light source and the obstruction. Thus penumbra is comparatively more pervasive than umbra. The magnitude of umbra and penumbra is dictated by the relative linear distances between the sun, earth and moon during the eclipse. If the obstruction is relatively nearer to the light source, a greater umbra can be witnessed.

For both, solar and lunar eclipses, the point of observation shall be the earth. Solar eclipse is that in which the sun is eclipsed by the moon and lunar eclipse is that in which the moon is eclipsed by the earth. Thus the location of the observer is of paramount importance without which the concept shall not hold any gravity.

B.A. Solar Eclipse

Solar eclipse is caused when a shadow of the moon is cast on the earth. It is imperative that a solar eclipse occurs on a new moon day during the day time only. Astronomical effects of the same shall be out of purview of this paper.

B.A.A. Partial Solar Eclipse

Following Figure depicts a schematic arrangement of a Partial Solar Eclipse.

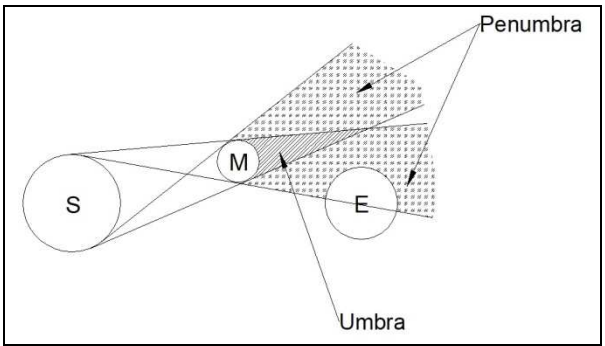

Fig. 1: Partial Solar Eclipse

In this type, the earth partially lies in the penumbra caused by the moon. The location experiencing such an eclipse can witness mild reduction in daylight for a short duration. There may be minor variation in the incoming radiation due to the eclipse which may not have the potential to cause severe damage to the solar power plants. On account of diffraction of light, the observer may not even notice the variations during the eclipse period.

B.A.B. Total Solar Eclipse

Following Figure depicts a schematic arrangement of a Total Solar Eclipse.

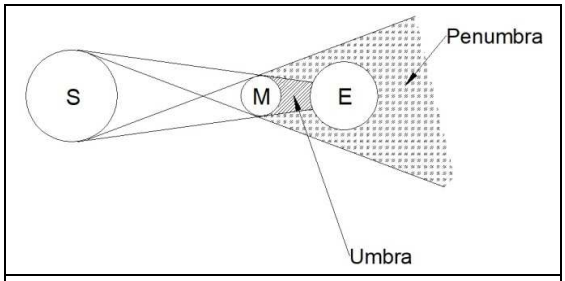

Fig. 2: Total Solar Eclipse

In this type, the earth completely lies in the penumbra caused by the moon and a certain area lies in the umbra depending on the location and time of the eclipse. This type of eclipse has the potential to cause a sudden stall and surge in the radiation levels pre and post the eclipse there bearing the potential to cause severe damage to the solar power plants. The observer can see and experience considerable reduction in daylight and at times a black out as well. The eclipsed sun may be seen as a total or annular eclipse during totality depending on the relative distance of the moon from the sun.

B.B. Lunar Eclipse

Lunar eclipse is caused when a shadow of the earth is cast on the moon. It is imperative that a lunar eclipse occurs on a full moon day during night time only. Astronomical effects of the same shall be out of purview of this paper.

B.B.A. Partial Lunar Eclipse

Following Figure depicts a schematic arrangement of a Partial Lunar Eclipse.

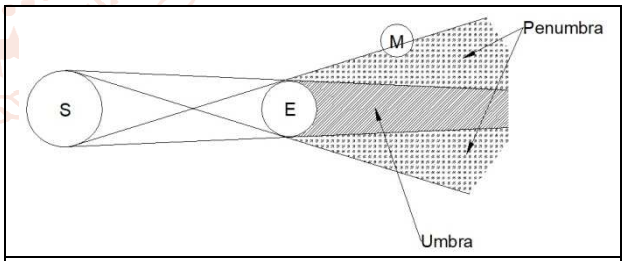

Fig. 3: Partial Lunar Eclipse

In this, the moon partially lies in the penumbra caused by the earth. The observer may not be easily able to see the eclipse to its mild visual effects.

B.B.B. Total Lunar Eclipse

Following Figure depicts a schematic arrangement of a Total Lunar Eclipse.

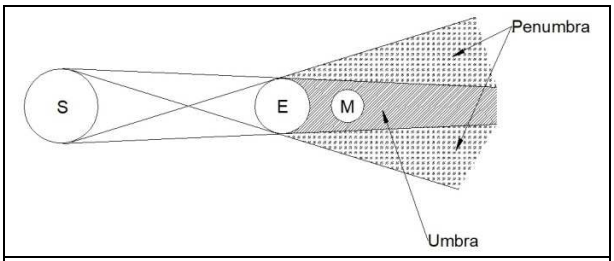

Fig. 4: Total Lunar Eclipse

In this, the moon completely lies in the umbra with the extent solely dependent on the relative distance between the celestial bodies. The moon is completely eclipsed during this period and is feebly visible. Due to diffraction, the moon may appear red during totality of the eclipse. This itself has led to the naming of the totally eclipsed moon as a blood moon.

C. Power Generation in a Solar Cell

A solar power plant comprises of solar panels connected in parallel to generate electrical energy out of the solar radiation incident on them. Every solar panel comprises of a matrix of solar cells which are mainly made up of silicon and perform the basic electronics function of power generation at the right temperature.

Solar energy can be the most clean source of energy as there is zero effect on the environment during the process of energy conversion.

The efficiency of energy conversion of a solar is dependent on various factors, one of which is the reception of radiation. Reception of radiation can be hindered due to dirty surfaces, cloud cover and eclipses. Dirt can be cleaned by periodic maintenance. Cloud cover is not in our control but it is a boon that cloud cover occurs or gets released gradually which gives enough time for the power plant to stabilize.

Eclipses, although occasional, can cause serious damage due to their property of sudden occurrence although precisely predicted. The sheer magnitude of radiation obstructed and then released is sufficient to cause instability in the power grid.

This shall be the central idea of this paper and shall now be discussed.

D. Qualitative effect of solar eclipse on power generation of solar cell

A Total Solar eclipse shall be considered for this study and the time of occurrence shall be during the forenoon as most of the solar eclipses occur during this period.

In a well maintained solar power plant of any size, power generation effectively begins as the sun rises and the solar radiation entering the atmosphere is incident on the solar panels.

With the onset of the total solar eclipse, the moon starts to cover a portion of the sun. At this time, radiation from that covered portion, is blocked and the earth starts to receive partial solar radiation. By this, it can be observed that power generation in the solar power plant starts to gradually decrease.

As the eclipse proceeds towards the totality, more and more radiation is blocked and lesser power is generated. At the totality of the eclipse, almost all the incoming radiation is blocked and the power plant does not effectively generate power.

Further as the moon starts to uncover the sun, the incoming radiation is restored gradually but in addition to this, there is a gush of previously blocked radiation, that rushes to the earth which results in additional load on the solar power plant with every passing instant. As the moon completely uncovers the sun and the eclipse ends, the will be high incoming radiation, greater than a normal day incident on the solar panel almost instantaneously. This can lead to system failure on account of extra power generation resulting into imbalance of the power grid.

E. Effect of Solar Eclipse on performance of Solar Power Plant

The performance of a solar power plant is such that with the progression of the day, power generation goes on increasing and is maximum at local noon time. Thereafter, the power generation reduces and is minimum during the absence of direct solar radiation.

The solar panels are deigned to receive certain maximum rated radiated but in gradual manner. Eclipses can cause a sudden incidence of high radiation which bears the potential to cause mechanical failures due to overheating and over generation of power.

Safety measures like grid stabilizers can be designed to be installed especially during occurrence of eclipses. The plant may be put under partial closure to avoid collateral damage as well. This can be an input towards a sustainable design of a solar power plant and can ensure industrial safety of the equipment and the employees assigned to the same.

F. Proposed procedure for validation of theory

A theory has now been established that compared to a normal day, during a total solar eclipse, there is sudden stall in the incoming radiation onto the solar power plant while during totality, there is a record minimum radiation received after which, as the moon uncovers the sun, there is a sudden surge in the incoming radiation which has the potential to cause instability in the power grid.

Following experimental procedure is proposed to validate this theory.

Step 1 : On the day of a total solar eclipse, start monitoring the power generated by the solar plant from the beginning of the eclipse

Step 2 : During totality, note down the power generated as this is theoretically the lowest of the day of eclipse

Step 3 : Note the power generated as the moon uncovers the sun to get the quantization of the surge in incoming radiation

Step 4 : On the very next day, repeat the procedure at the exact time as that of the eclipse day

Step 5 : Compile the data and compare the same

AS a part of validation, the theory can be said to be true if a noticeable surge is seen in the incoming radiation with certain additional radiation once the eclipse has ended.

Conclusion

Thus it can be concluded that the qualitative effect of solar eclipse on power generation of solar power plant has been discussed and a theory regarding the same has been put forward. It is intended to validate the theory with a proposed procedure to ensure sustainable design of solar power plants.