Impact of Electromagnetic Field on the Conversion Efficiency of Solar PV Panel

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Abstract — *99Electromagnetic interference (EMI) from High Voltage (HV) transmission lines and nearby solar Photovoltaic (PV) has been a subject of significant research for decades. Solar PV's installation area is a major bottleneck in solar power generation development. Solar PV panels are placed below HV lines using Right of Way (RoW) principles and protected by a safety margin of RoW. In solar PV panels that are situated under HV power lines, due to electromagnetic interference, conversion efficiency is increased. Interference from electromagnetic waves on solar PV panels has no detrimental effects. This paper aims to evaluate and validate the positive effect of the electromagnetic interference produced by HV transmission lines on the efficiency of the solar PV system.*

Keywords— *High voltage transmission line, Electromagnetic interference, Solar PV panel, Installation area and Conversion efficiency.*

INTRODUCTION

Nowadays, the electromagnetic interference caused by high-voltage lines on nearby objects is a very significant phenomenon. HV lines generate a considerable amount of electric and magnetic stress that causes electromagnetic interference [17]. In all directions, HV transmission lines are surrounded by electromagnetic fields. The electric field at higher voltages is strong regardless of distance from the line. It continues to live even when the transmission line does not carry any current. According to electromagnetic theory, the strength of the electromagnetic field is proportional to the amount of electrical current traveling through the transmission line. Magnetic fields are measured by measuring the current flowing in a transmission line [8, 9]. Modern generation systems have utilized a variety of resources to generate electricity. On-grid PV systems are becoming popular with distributed generation applications as well as effectively utilizing the power of solar arrays. Grid-connected solar power schemes are typically located near high-voltage transmission lines, which produce electromagnetic waves that influence PV power generation [1] [2]. Scientific society faces an eminent challenge in developing new ideas to improve the efficiency of distributed generation [3].

EXCITE OF EXTRA MINORITY CARRIERS

The conversion efficiency of silicon (Si) PV solar cell under HV lines attains better efficiency by the generation of excess charge carriers. Stimulation of additional minority carriers in solar PV cells is done through the following processes.

Impact Ionization

A PV cell when subjected to an external electric field stimulates band–trap ionization of charge carriers. The output current and conversion efficiency of PV cells are based on the band-trap collision ionization incident and generation–recombination method. An impact ionization mechanism is a process in which a charge carrier with high kinetic power bumps with a second charge carrier moving its kinetic power to the latter thereby rising to a higher energy level [4, 14]. This process increases the number of charge carriers in the solar cell.

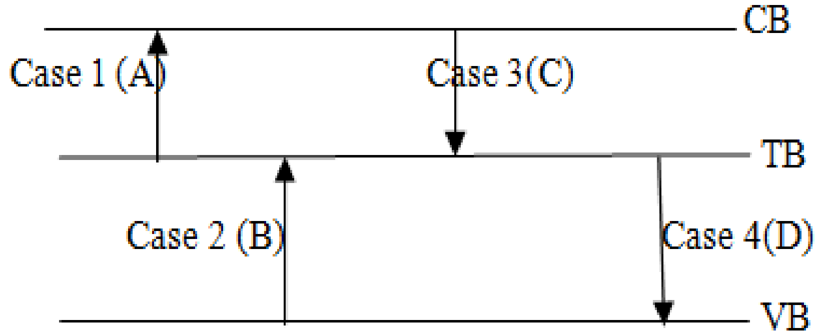

Figure 1. The transition of charge carriers

The Trap Band (TB) levels receive an electron from the Valence Band (VB) and emit an electron towards the Conduction Band (CB) in Figure 1 (case 2 & case 1 respectively). Cases 1and 2 are focused on in this model because those cases permit generating additional free charge carriers. The TB levels receive an electron from the CB (case 3 in Figure 1) or losses an electron towards the VB (case 4 in Figure 1). Cases 3 and 4 are recombination processes. The rate of recombination is one of the important solar cell efficiency limiting parameters. The process of recombination of carriers is opposite to that of the generation of carriers [5]. The recombination of generated carriers is not desirable in solar cell operation. The rate of the band–trap recombination for indirect band gap material is lower. This recombination process (case 3 and 4) is not very significant in Si-based solar cells.

Hot Carrier Solar Cell

The hot carrier cell is a solar energy converter that utilizes the excess thermal energy of photo-excited carriers to generate electric power. When an external electric field is applied to the solar PV cell, it excites the electron as kinetic energy. The kinetic energy of the electron is represented in terms of the thermal energy of electrons. The excited electron has higher thermal energy, which is referred to as a hot electron [12]. The hot electrons lose their energy by collision with lattice, by emitting phonons till their energy level equals the conduction band edge energy level. This process of hot electrons losing their energy and coming to the conduction band edge is known as the thermalization process [15].

The indirect band gap semiconductor (Si) requires two particles (a photon and a phonon) to excite an electron from the VB to the CB. For indirect band gap semiconductors, the value of the absorption coefficient varies from high to low. High value of absorption coefficient is possible only at high photon energy, at which electrons are excited directly from the VB to the CB [13]. Low value of absorption probability is due to the requirement of a photon and a phonon for absorption to occur. Phonon is a quantum of vibrating mechanical energy. For indirect band gap semiconductor material (Si solar cell), additional phonons are needed to reach the high conversion efficiency of the solar cell. These phonons are emitted by the hot electrons [16].

EXPERIMENTAL RESULT

A polycrystalline PV module made by Oswal Electrical Company utilizes to provide experimental verifications. The electrical characteristics of the PV module under the standard test conditions (STC), which refer to solar irradiance (G) of 1029 W/m^2, module temperature 36^0 C, and air mass of 1.5, are reported in Table 1.

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Table 1. Electrical characteristics of the PV module

Maximum power (P_{max})	20 Wp
Voltage at maximum power (V_{mp})	17.0 V
Current at maximum power (I_{mp})	1.18 A
Open circuit voltage (V_{oc})	21.0 V
Short circuit current (I_{sc})	1.19 A
Output power tolerance	+3%
Maximum system voltage	1000 V

This testing is done in the 230 / 110 kV Arasur Substation, Coimbatore, Tamilnadu, India. The electrical setup (shown in Figure 2) is assembled to measure the open-circuit voltage (V_{oc}) and short circuit current (I_{sc}) using a multimeter. The line voltage and line current of 230kV HV transmission lines are 230kV and 100A respectively. The electromagnetic field of the HV line is measured by the Electromagnetic Radiation Tester.

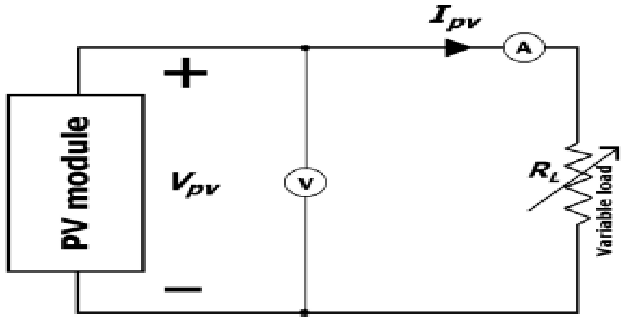

Figure 2. Electrical setup for measuring the open-circuit voltage and short circuit current of the PV module

Two tests are performed under conditions that solar irradiance and the PV module temperature were measured at, respectively, 1029 W/m^2 and 36^0 C. In the first test, the solar panel is placed where without the effect of the HV transmission line, and then the open-circuit voltage and short circuit current of the PV module is measured. The values are tabulated in Table 2.

The photo-current density (J_{ph}), output power (P_{max}) , and conversion efficiency (η) of the PV module is calculated by the following formulas.

$$FF = \frac{v_{oc} - \ln(v_{oc} + 0.72)}{v_{oc} + 1} \quad (1)$$

$$v_{oc} = \frac{V_{oc}}{(\frac{kT}{q})} \quad (2)$$

$$\eta = \frac{P_{max}}{P_{in}} \quad (3)$$

$$P_{in} = G A_c \quad (4)$$

$$P_{max} = V_{oc} I_{sc} FF \quad (5)$$

A_c – area of collector
k - Boltzman's constant
T - Cell's temperature
P_{in} - Input power

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Table 2. The experimental values obtained without electromagnetic interference from HV lines

V_{oc} (V)	I_{sc} (A)	P_{max} (W)	η (%)
18.02	0.91	16.21	12.96

Figure 3. PV module located below the 230kV transmission line.

Table 3. The experimental values obtained with electromagnetic interference from HV line

D (m)	EF (V/m)	MF (μT)	V_{oc} (V)	I_{sc} (A)	P_{max} (W)	η (%)
22	393	1.99	18.01	1.02	18.17	14.52
20	451	3.05	18.05	1.04	18.56	14.83
16	516	6.52	18.18	1.05	18.88	15.09
12	561	6.70	18.55	1.06	19.45	15.54
8	633	7.39	18.78	1.07	19.88	15.89

In the second test, the solar panel is placed under the HV transmission lines (shown in Figure 3). The strength of the electric and magnetic fields (EF & MF) produced by the 230 kV HV power transmission line measured point by point at a different distance (D) from the transmission with corresponding open-circuit and short circuit current of the PV module are summarized in Table 3.

DISCUSSION

According to Indian electricity rules, RoW offer the minimum ground clearance of transmission lines is given in Table 4. as per Gujarat Energy Transmission Corporation limited (GETCO) standards.

Table 4. Permissible miminum ground clearance from transmission lines

Transmission Lines Range (kV)	**Ground Clearance (m)**
66	6.1
132	6.1
220	7.0
400	8.8

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In the Arasur substation, the ground level clearance of the 230kV transmission line is 22 m from the ground. Solar PV panels were placed 22 m away from high-voltage lines for the first reading, and the experiment ended at an 8 m distance due to the RoW. (shown in table 4).

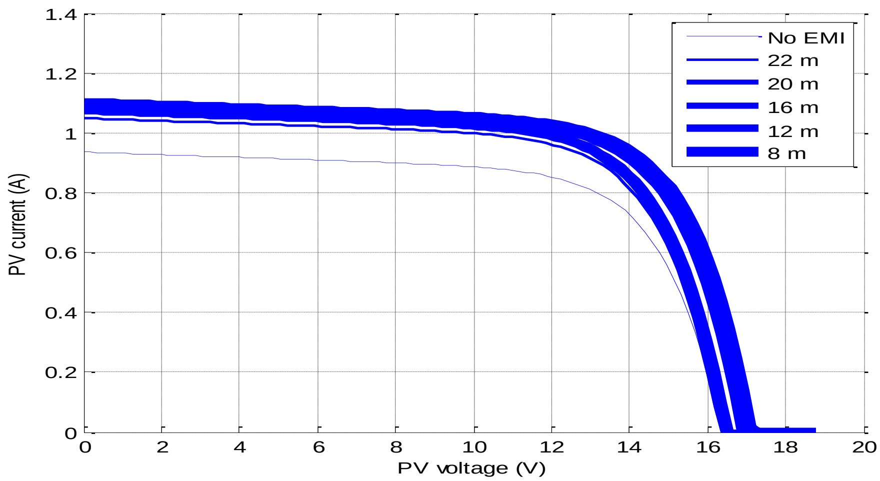

Figure 4. I – V characteristic of solar PV panel with and without EMI due to 230 kV HV transmission lines

The I-V characteristic curves of solar panels under 230 kV HV transmission lines are shown in Figure 4. From table 3, when the clearance distance from HV lines decreases, the electric field increases. In close proximity to the HV lines, EMI is high, while away from the transmission, EMI is reduced. In spite of the higher electric field, solar PV panels have only slightly higher conversion efficiency (Ref. Table 3). In the inference form of the I-V graph, the operating characteristics of solar PV panels with HV lines are better than those without electromagnetic interference.

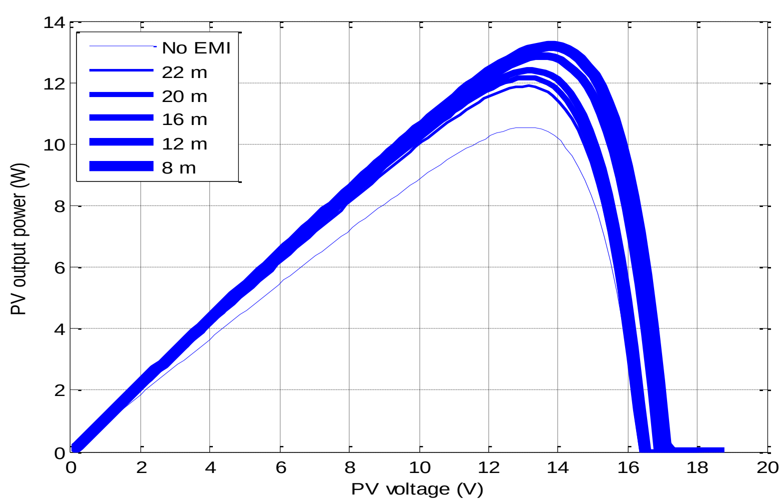

Figure 5. P – V characteristic of solar PV panel with and without EMI due to 230 kV HV transmission lines

The P-V characteristic curves of solar panels under 230 kV HV transmission lines are shown in Figure 5. The experimental curves demonstrate that the photo-current density, photo-voltage, and output power of solar PV panels are increasing the function of the transmission line power of radiation. In comparison to solar PV panels with and without EMI, the PV panel under the HV lines offers the highest power output.

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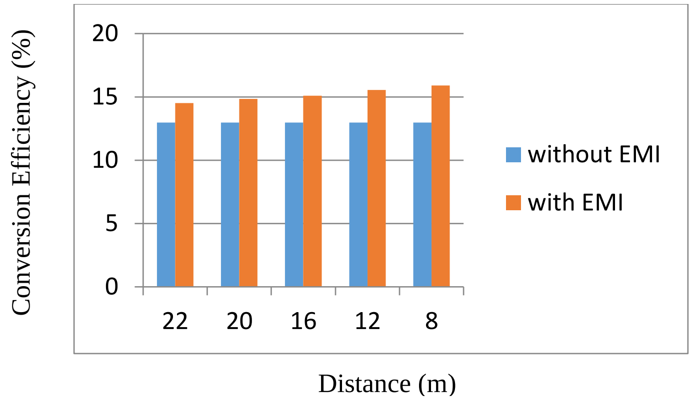

Figure 6. Conversion efficiency of solar PV panel with and without EMI due to 230 kV HV transmission lines

In Figure 6, the calculated conversion efficiency versus the electric field intensity generated by the HV transmission line is presented as a curve and shows high conversion efficiency for solar PV panels placed under HV transmission. Ultimately, the conversion efficiency value of the PV module under the HV transmission lines (15.89% for 8 m) has been increased by nearly 3% compared to the conversion efficiency value of the PV module without the effect of the HV transmission line (12.96%).

Magnetic field associated with an EMI causes some problems in the performance of electrical or electronic devices [6, 7]. Magnetic field values lower than 1 milli Telsa (mT) do not affect conversion process of silicon solar cells. On the other hand, magnetic field values higher than 1 mT have an ominous effect on solar cell recombination parameters [10, 11]. Under a 230 kV HV line, the strength of magnetic field (ref. table 3) is in order of micro Tesla (μT) and such a magnetic field of lower strength has no adverse effect on conversion efficiency of solar PV cells. The conversion efficiency of Si PV solar cell under HV lines is increased due to the generation of excess charge carriers. As a result, these positive disturbances are translated into a way of increasing the conversion efficiency of solar PV panels. This translation process is proved by the impact ionization and hot carrier theories. This is also validated through the testing of solar PV panels under HV transmission lines.

CONCLUSION

A mathematical model and theoretical explanation of electromagnetic radiation's influence on silicon solar cells is presented. Testing of the solar panel under 230 kV transmission lines validated an experimental investigation on the effect of the electromagnetic field generated by the transmission lines on the power generation of a Si PV panel. A direct result of the electromagnetic field is the improved efficiency of the PV module due to impact ionization and hot carrier cells. An interpretation of I-V and P-V characteristic curves is given; solar PV panels under the HV lines promote a better conversion process of solar cells. Presented results suggest that solar PV panels need not be located very close to HV transmission lines because only a very small value variation in conversion efficiency occurs when panels are located at different heights. This is also a risk to the panels. In comparison to solar PV panels with no EMI influence, solar PV panels with EMI influence show approximately 3% of increased efficiency. The solar PV panels mounted at ground level below the HV transmission lines are very efficient and harmless for the solar cell operation and this turns out to be a good solution for the solar PV system installation area issue.

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