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The effect of electromagnetic wave on photovoltaic array performance

By

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Abstract:

This paper studies the effect of electromagnetic waves (EMW) on PV system performance. It discusses the effect of EMW radiated from radio repeater antenna on I-V characteristic curve of PV module. This paper represents the designing of radio repeater station depending on the minimum value of EMW reached the PV module surface. The parameters which are calculated are the antenna tower height (H), the distance (D) between PV module and antenna tower, the operating frequency (f), and finally the antenna length (L). The I-V characteristic curve of PV module is calculated at the designed parameters. XFDTD Recomm® is used to calculate the specific absorption rate (SAR) value at the PV module surface.

Keywords:

Renewable energy Radio repeater, Photovoltaic, Specific absorption rate, Electromagnetic waves.

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1. Introduction:

Repeater are digital radio signal amplifiers, which increase the connection reliability of mobile telephones within radio cells and raise the accessibility level throughout the network. They receive the conversations, which have been converted to digital data, by radio, it process this data and transmit it to a base station, also by radio. In rural areas and in mountainous regions, repeaters often have to install and operate at sites remote from the public electricity grid the power supply for repeater should be reliable and free of maintenance [1, 2]. Remote telecommunication systems present a special energy supply challenge, requiring reliable, unattended power system operation in locations where grid power is not available [3]. Specific Absorption Rate (SAR) is a dosimetric quantity and is defined as the rate at which RF energy is absorbed per unit mass of biological tissue [4]. This paper examines the effect of electromagnetic wave emitted from the antenna of radio repeater station. The specific absorption rate on PV module has been calculated. The PV module performance has been calculated before the electromagnetic wave effect and after the electromagnetic wave effect.

2 Specific Absorption Rate

Specific Absorption Rate (SAR) is a measure of the amount of radio wave energy absorbed by the body during mobile phone use.
SAR was calculated from the measured electric field strength E and the properties of object using Eq. 1 [5].

$$SAR = \frac{\sigma \left| E^{2} \right|}{\rho} \tag{1}$$

3. PV Mathematical Model

This section introduces the mathematical model of the PV system; this model represents the equation of the generated current of PV array. The electrical modeling of suggested PV system is represented in the following equations.
The operating equation of current – voltage characteristics of PV array under illumination effect is expressed by Eq. (1) [6, 7 and 8]

$$I_G = N_p I_{lg} - N_p I_o \left(\exp\left(\frac{qv}{akT_p N_s} \right) - 1 \right) \quad (2)$$

Light generated current is given as

$$I_{lg} = \frac{G}{Gr}\left[Isc + m(Tc - Tr)\right] \quad (3)$$

Where reverse saturation current of PV cell is represented by

$$I_o = cT_p^3 \exp\left({-qEgo}/{bkT_p} \right) \quad (4)$$

Cell temperature can be calculated by using the following equation [9]

$$T_C = T_{air} + 0.03\ G \quad (5)$$

4. The FDTD Stability Requirements

In order to obtain sufficient spatial resolution within the computational domain to reduce the numerical dispersion, the Yee's cell size should be small enough so that Δx, Δy, and Δz are typically 1/10 to 1/20 of the minimum wave length [10].

5. The Radio Repeater Design

In this section four parameters are used which affected SAR values on PV module surface. The aim of this design is to obtain minimum SAR value at PV module surface.

5.1. The Effect of Antenna Tower Hieght (H) Variation on SAR Value

All radio systems require towers to hold the antennas that transimit and recive radio energy, as the tower height is increased, the caverage area is increased also for a given antenna. Also in generally, as the capacity of radio systems is increased, more towers are required to attain necessary reliable area coverage .
In this case tower height (H) has changing in range of 15, 17, and 20, and the different parameters have a constant values: D = 4 m, f = 900 MHz, and L = λ as shown in table 1.

Using XFDTD Rcomm® program to calculate SAR values in each case of variable H and SAR values are calculated with the mobile communication station power range from 0 to 100 W, are in this range [11].
Figure 1 presents the relation between SAR value and output power at different values of antenna height. It is found that as power is increased SAR value is also increased. Thus, SAR values are inversely proportional with the antenna tower hieght because the electromagnetic wave radiation has a negligable value on the PV module surface .
Figure 2 shows the electric field distrbution at the best value of deffirent parameters obtaiend which are H = 20 m, D = 4 m, f= 900 MHz, and L = λ.

5.2. The Choice of Distance(D) between PV Module and Antenna Tower

This section illustates the ability to determine the distance between antenna tower and PV module (D). The range of varying D is 2 m, and 4 m at H = 15 m, f= 900 MHz, and L = λ as summarized in table 1. It is found that SAR values are inversely proportional with the distance (D) as depicted in Fig. 3.
Figure 4 presents the distrbuition of electric field from the antenna, it is found that, the PV module at H = 15 m, D = 4 m, f= 900 MHz, and L = λ is far from these radiation.

5.3. The Choice of The Operating Frequency (f) of The Station

The SAR values are calculated at H = 20 m, D = 4 m, L = λ, and frequency f is varying in the range of 450 MHz to 900 MHz. The choice of this range is based on the mobile communication used this range.
Figure 5 illustrates the relation between SAR values with power at different values of operating frequency. It is clear that, SAR value decreases as operating frequency increase.
Figure 6 shows the complex electric field magnitude of electromagnetic wave radiation emitted of the antenna with the presence of PV module. These calculation are calculated using H = 20 m, D = 4 m, f= 900 MHz, and L = λ.

5.4. The Effect of Varying Antenna Length (L) on SAR Value

Antennas (or aerial) are a device that either converts electrical energy into an electromagnetic wave, or extracts energy from a passing wave and converts it to electrical form. Perhaps surprisingly, antenna engineers don’t distinguish between the two cases – it turns out that an antenna’s characteristics are exactly the same whether you transmit or receive [12]. In this section the effect of varying antenna length (L) on SAR value has been calculated. Antenna length L is changed to different values and kept the other parameters constant. As summarized in table. 1.

Figure 7 shows that as antenna length increase the value of SAR value decrease. It is found that SAR values reaches to a very small value at L = 3λ.
The complex electric field distribution at H=15 m, D=4 m, F= 900 MHz, and L=3λ is seen in Fig. 8. The PV module is far from the domain of the radiation so there is no effect on the PV performance.

6. The Optimum Design of Radio Repeater Station

The optimum design of photovoltaic radio repeater station is at the antenna tower height (H) =20 m, the distance (D) between PV module and antenna tower = 4 m, the operating frequency (f) = 900 MHz, and finally the antenna length (L) = 3λ. These values give minimum SAR values at PV module surface. It is clear that the values of SAR are very small at all values of the design parameters, which means electromagnetic wave radiation emitted from the radio repeater antenna doesn't reach PV module surface.

7. The Effect of Electromagnetic Wave Radiation on PV Module Performance

The effect of electromagnetic wave on current – voltage charactristic curves are studied at the optimum design. Using the previous calculated of SAR values to obtain the value of temperature which can be arise when using PV array near a radiating source.
The relation between the temperature and the SAR value is given in Eq. (6) [13].
As the value of SAR increase the temperature increase. The value of temperature obtained are very small. From Eq. 5 cell temperature can be calculated, and the value of SAR which is used at the maximum power = 100 W. The current – voltage curves are then calculated, as depicted in Fig. 9. it clears that the tow curves without the electromagnetic wave radiation effect and that with its effects, have no difference between them which are coincide together.

$$SAR=\rho \frac{\partial T}{\partial t} \qquad (6)$$

Figure (1): *The effect of changing antenna tower height (H) on SAR values.*

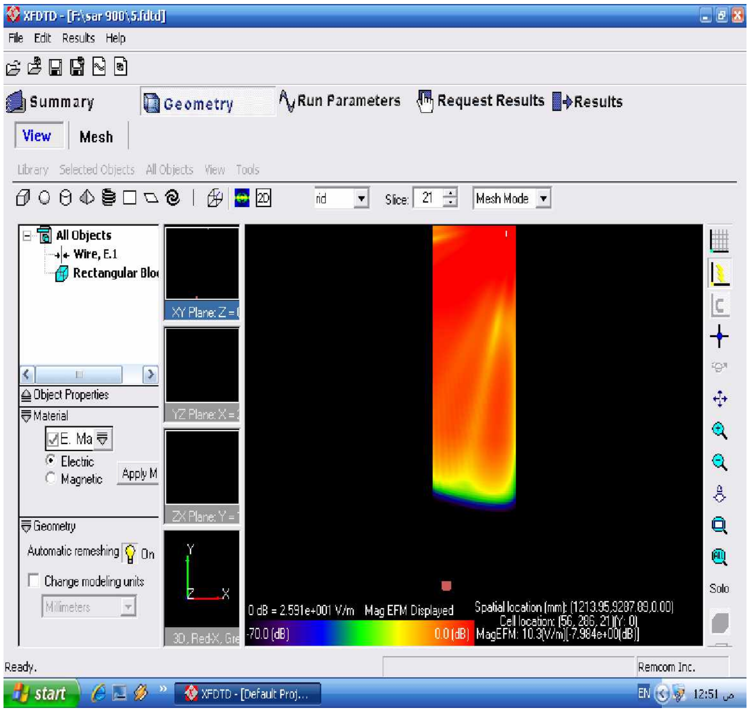

Figure (2): *The effect of varying antenna tower height on SAR value*
H = 20 m, D = 4 m, f= 900 MHz, and L = λ.

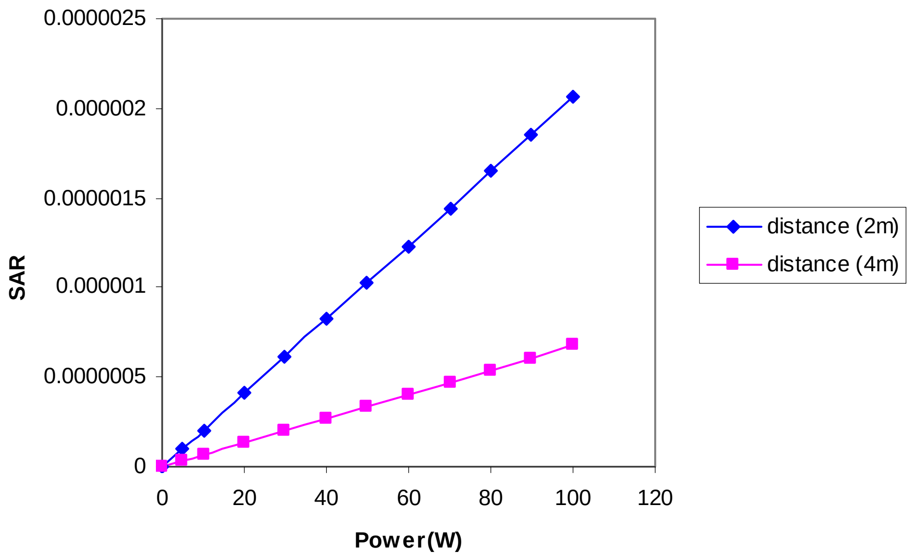

Figure (3): *The effect of changing distance between PV module and antenna tower on SAR value.*

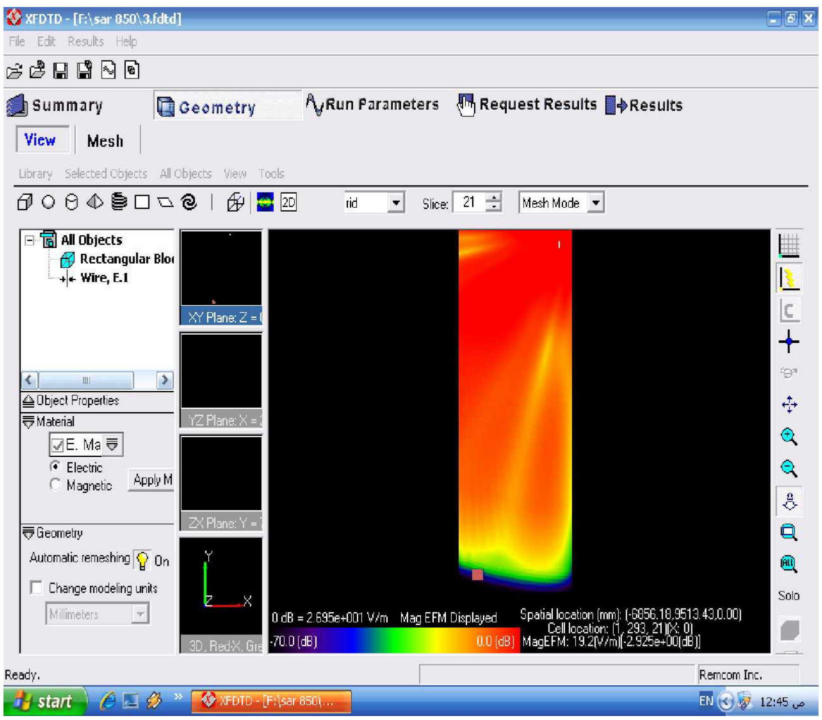

Figure (4): *The complex electric field magnitude at H = 15 m, D = 4 m, f= 900 MHz, and L = λ.*

Figure (5): *The effect of changing operating frequency on SAR value.*

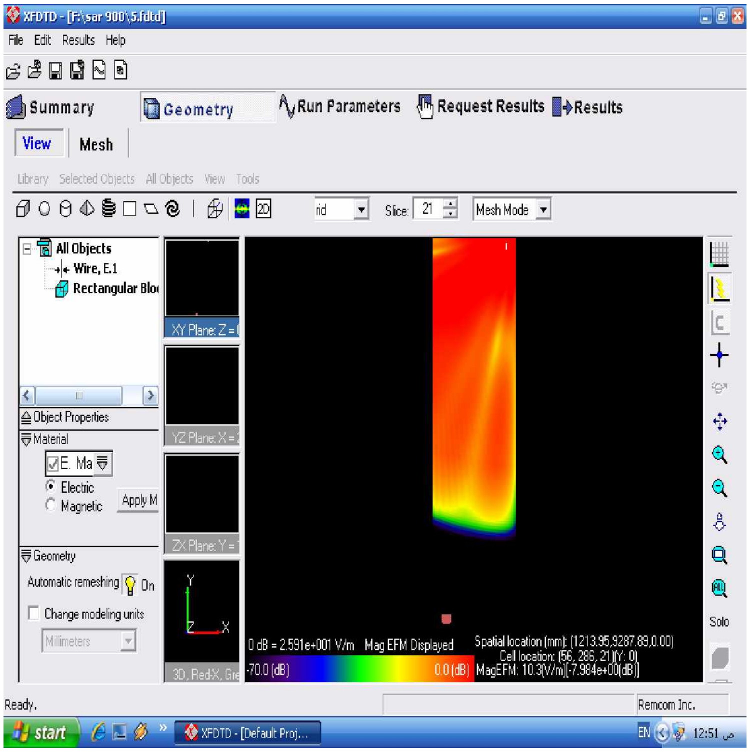

Figure (6): *The complex electric field magnitude at*
H = 20 m, D = 4 m, f= 900 MHz, and L = λ.

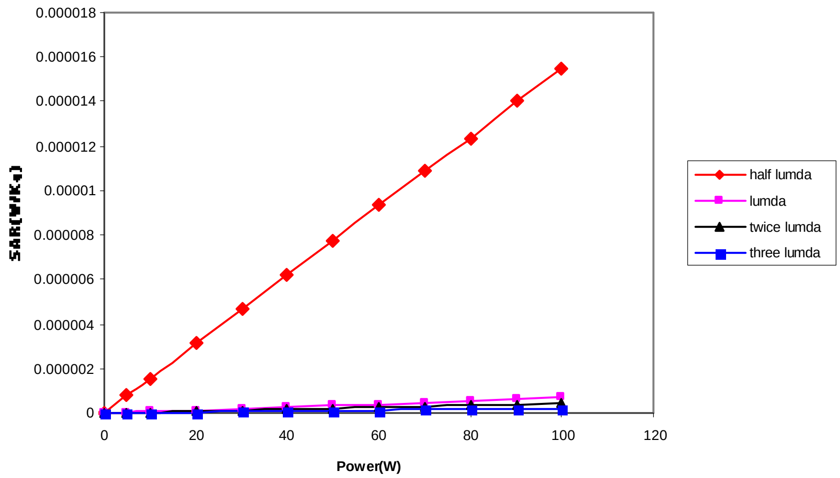

Figure (7): *The effect of changing antenna length on SAR value.*

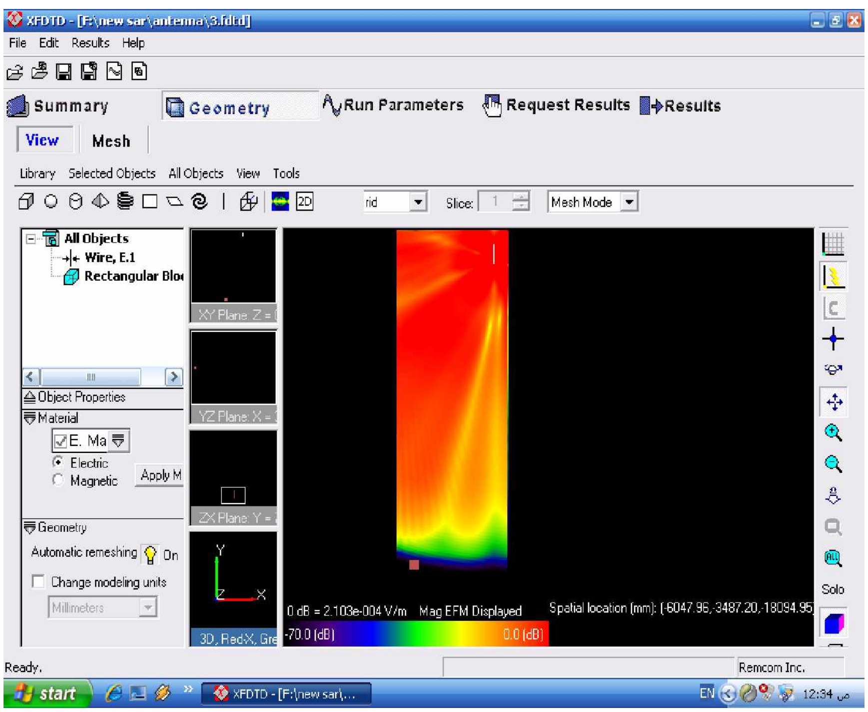

Figure (8): *The complex electric field magnitude at H = 15 m, D = 4 m, f= 900 MHz, and L = 3λ.*

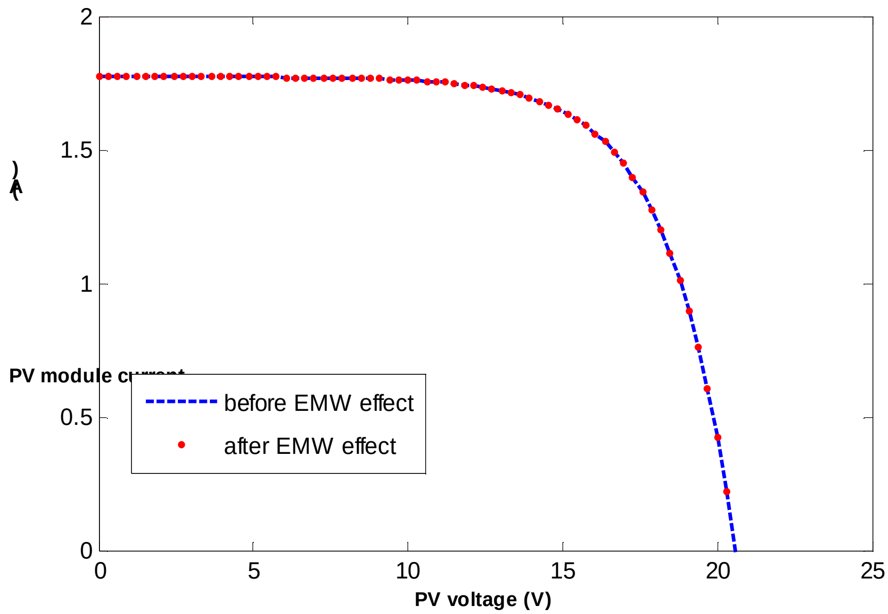

Figure (9): *I-V characteristic curve of PV module before and after electromagnetic radiation.*

Table (1): *The required parameters for the different cases.*

Cases	H (m)	D (m)	L	F (MHz)
Changing of operating frequency	20	4	λ	450, 800, 900
Changing distance	15	2,4	λ	900
Changing height	15, 17, 20	4	λ	900
Changing antenna length	15	4	λ/2, λ,2 λ 3λ	900

6. Conclusions:

This paper studies the effect of electromagnetic wave radiation on PV module. FDTD is used to calculate the effect of SAR value.

It is concluded that the study of electromagnetic wave radiation effect on PV module, it is found that there is no effect of electromagnetic wave radiation emitted from radio repeater station on PV module I-V characteristic curve, and there is no degradation in

PV module performance. So it is safety to use PV system as a power source of radio repeater station in remote area.
The results shows the optimal design of radio repeater is, distance between antenna tower and PV module (D) = 4 m, the antenna length
(L) = 3λ, the operating frequency (f) = 900 MHz, and finally the antenna tower height (H) =20 m. These values give minimum SAR value.

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Nomenclatures:

SAR… Specific Absorption Rate W/Kg.
E… Electric field strength V/m.
σ… Material conductivity S/m.
ρ… material density Kg/m^3
I_G … output current of PVarray, A.
V… output voltage of PV array, V.
N_S… number of series strings.
N_P… number of parallel strings.
I_L… light generated current, A.
I_O… revese saturation current at operating temperature,(A).
I_{SC}… short circuit current at 28°c and $1000w/m^2$.
a, b.. ideality factors(=1.92).
T_r… reference temperature(=301° k).
T_P… cell temperature(°k).
T_C… cell temperature(°c).
K… Boltezman's constant($=1.38\times10^{-23}$).
G… cell illumination,w/m^2.
G_r… reference illumination($=1000w/m^2$).
E_{go}… band gab for silicon solar cell(=1.16ev).
m… short circuit current temperature coefficient(=0.0017A/°c).
q… electron charge($=1.602\times10^{-19}$ column).
T_a… air temperature.