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EFFECT OF IONOSPHERIC INDUCED DEPOLARIZATION ON SATELLITE SOLAR POWER STATION

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Abstract—The paper presents the ionospheric effect on the power transmitted by satellite solar power station. Consequently, the Faraday rotation and losses due to ionospheric layer are calculated at 2.45 GHz frequency. It is observed that the fluctuation in the Faraday rotation in day time is found to be the maximum as compared to the night hours and. Loss due to depolarization is found to have the maximum value at noon hours for all the seasons (summer, winter and spring) however, the loss is the highest for summer season as compared to winter and spring season. This is logically correct because the ionization is the highest in summer in comparison to winter which gives rise to maximum electron content and maximum depolarization.

1. INTRODUCTION

Ionosphere covering Earth surface from nearly 90 km to 1500 km altitude gives a significant depolarization like other constituents of atmosphere. The most important ionospheric parameter is electron density N. The behavior of ions and electrons in ionosphere is largely governed by earth's magnetic field, which may be approximated by a dipole, inclined at 12° to the earth axis. An analysis on the theory of energy flux and polarization changes of a radio wave with two magnetic components undergoing self demodulation in the ionosphere [1]. Deterministic were typically validated by performing comparison between real and simulated E-field envelope distribution [2]. Theoretical analysis of non linear interaction of intense electromagnetic wave and plasma waves In ionosphere and numerical

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estimation of SSPS microwave impact on ionospheric environment were also discussed [3, 4].

Radio waves propagating in the ionosphere set the charged particles into oscillations causing them to radiate secondary wavelets in all directions. During oscillation, the charge may collide with neutral particles in the air. The regular oscillations are interrupted and the energy has to be fed in from the main wave. So the wave become weaker or is absorbed as it progresses [3]. The paper presents the study of ionospheric effect on the microwaves propagating from satellite solar power station. The analysis of ionospheric induced depolarization on the performance of satellite solar power station is presented in the paper. The data of electron density available from ISRO Ahmedabad for satellite communication link between Arvi earth station and any geostationary satellite is utilized [5]. In this analysis the geostationary satellite is INSAT-2A.

2. BASIC PRINCIPLE OF SATELLITE SOLAR POWER STATION

Glaser proposed the classic satellite solar power station in 1968 [6]. Satellite solar power station is concept for placing a gigantic satellite as an electric power plant in the geostationary orbit. The satellite mainly consist of three segments; viz (a) Solar energy collector to convert solar energy in to D.C. electricity. (b) D.C. to microwave converter. (c) A large antenna array to beam down microwave power to ground.

Research on delivering energy from space to earth started at the Institute of space of Astronautical science [ISAS] in 1981 and there has been an annual space energy symposium at ISAS since then. As part of working of this group "Solar power satellite" Strawman project was conceptualized [2].

The proposed system locates the power generator on a satellite, which is located on geosynchronous orbit. Solar power will be converted to dc power and it will again converted to microwave power by cross-field devices, which may be transmitted to earth. The frequency of microwave transmission is 2.45 GHz. This power will be received at Earth by receiving antenna called Rectenna. In the present endeavor the ionospheric effect on such transmitted power is investigated the details of which are given in the following sections.

3. IONOSPHERIC EQUATIONS

The mean ionospheric height h_m is taken as 400 km. If the electron density in plasma varies with distance and if B_0 is not constant i.e., the magnetic field is changing in plasma in the direction of wave propagating them.

$$\text{Tilt angle } \Omega = \frac{|e|^3}{2cm^2\varepsilon_0\omega^2} \int B \cos\theta N ds \tag{1}$$

where

e = charge of electron
c = velocity of light
m = mass of electron
ε_0 = permittivity in vacuum
ω = angular frequency of electromagnetic wave

Equation (1) when applied in the case where electromagnetic wave travels in ionosphere, under the influence of earth's magnetic field the Equation (1) is transformed as

$$\Omega = \frac{e^3}{8\pi^2 m^2 \varepsilon_0 f^2} \int_0^{h_t} B \cos\theta N \operatorname{cosec}(\delta+\beta) dh \tag{2}$$

Where h_t is the height up to which ionosphere exist. δ and β are defined as total separation angle and elevation of rays at earth station. dh is elemental increase in altitude perpendicular to earth surface. δ, β, dh and ds are shown in Figure 1 where a ray from satellite is traveling toward earth station through ionosphere. Putting the values of e, m, ε_0 in Equation (2) one gets

$$\Omega = \frac{2.365 \times 10^4}{f^2} \int_0^{h_t} B \cos\theta N(h) \operatorname{cosec}(\delta+\beta) dh \tag{3}$$

For any ray T traveling from geostationary satellite to any fixed earth station, β is constant but δ varies from point to point throughout the ray path. Hence to get the integration of Equation (3) one has to know B, θ, δ and N as a function of h i.e., altitude of any point on ray path.

Defining function $\Psi(h, T)$ as

$$\Psi(h, T) = B \cos\theta \operatorname{cosec}(\delta+\beta)$$

Equation (3) becomes

$$\Omega = \frac{2.365 \times 10^4}{f^2} \int_0^{h_t} \Psi(h, T) N(h) dh \tag{4}$$

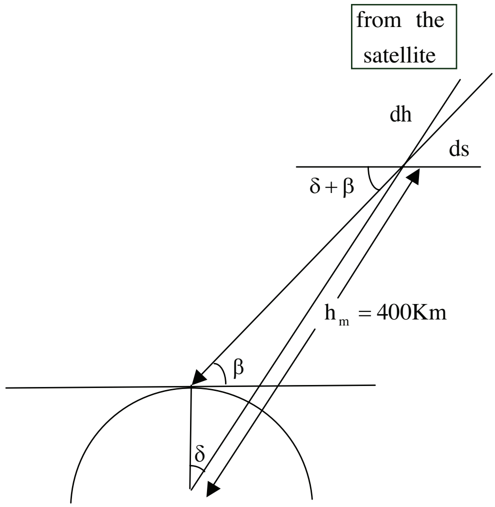

Figure 1. Microwave propagation from satellite to Earths Ground Station.

Mean ionospheric height is normally assumed to be around 340 km to 400 km, which is near the Centroid of electron concentration distribution. Thus if we calculate at this mean ionospheric height h_m, then $\Psi(h, T)$ can be assumed constant having the value $\Psi(h_m, T)$ throughout the ray path. It means that if ionospheric height h_m is taken as 400 km then Equation (4) becomes

$$\Omega = \frac{2.365 \times 10^4}{f^2} \Psi(400, T) \int_0^{h_t} N(h)dh \tag{5}$$

in which the value of $\Psi(400, T)$ is given as

$$\Psi(400, T) = 1.06 \times 10^{-5}\,\mathrm{web/m^2} \tag{6}$$

The data of electron content is calculated using Simpson's 3/8 rule. Results for electron content $\int_0^{h_t} N(h)dh$ in various seasons i.e., summer, winter and spring were calculated the data thus obtained are shown as function of time in Fig. 2.

Faraday rotation at 2.45 GHz frequency were calculated using Equations (5), (6) and Figure 1. The data thus obtained for various seasons i.e., summer, winter and spring are shown as function of time in Fig. 3.

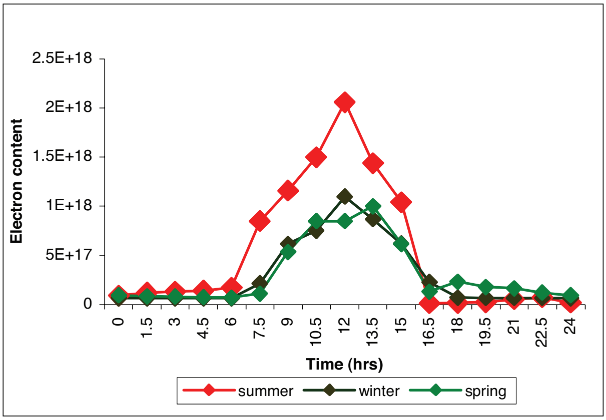

Figure 2. Electron content for various seasons.

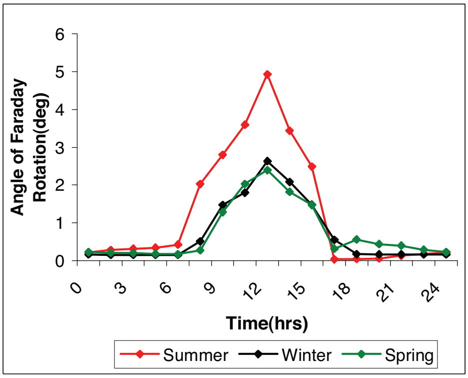

Figure 3. Faraday rotation at 2.45 GHz frequency for various seasons.

4. DEPOLARIZATION LOSS

In order to estimate loss due to depolarization in ionosphere, let us consider E, as incident field. After passing through ionosphere, the polarization plane of incident wave changes. If the medium produces the depolarization of an angle Ω, then the effective values of electric field after passing through the medium will be $E_1 \cos\Omega$, parallel to incident field vector. Therefore the loss due to depolarization (L_d) in the ionosphere can be given by

$$L_d = \frac{E_1^2 - E_1^2 \cos^2 \Omega}{\eta_0}$$

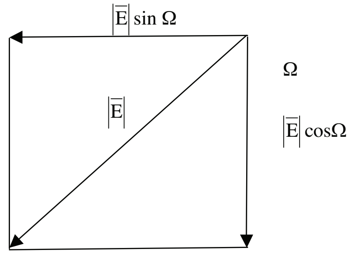

Figure 4. Depolarization due to ionosphere in the incident wave plane.

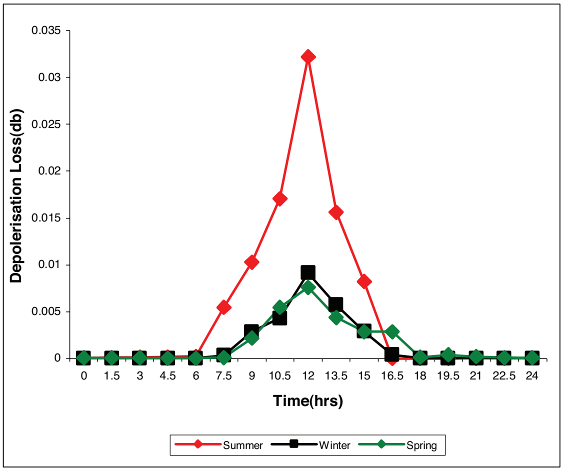

Figure 5. Depolarization Loss for various seasons.

where η_0 = Intrinsic impedance of free space medium.

The depolarization loss, in *db*, can be given by

$$\begin{aligned} L_d &= 10 \log \text{ (transmitted/received power)} \\ &= 10 \log \frac{E_1^2/\eta_0}{E_1^2 \cos^2 \Omega/\eta_0} \\ &= 20 \log \sec \Omega db \end{aligned}$$

Loss due to ionosphere-induced depolarization $L_d(db)$ for satellite solar power station in various seasons i.e., summer, winter and spring are shown in Figure 5.

5. DISCUSSION ON RESULTS

From Table 1 and Fig. 2 it is observed that

1. Electron content is maximum at 1200 Hrs for all the seasons. This may be attributed due to the fact that maximum radiation occurs at around 1200 Hrs causing maximum ionization in the ionosphere. The electron content is higher for summer season as compared to winter and spring seasons.
2. Electron content is found to be very small in the morning from 0000 Hrs to 0600 Hrs. Similar patterns are observed from 1650 Hrs onwards. This is because of the fact that radiation available from the sun is found to be minimum both in the morning and evening Hrs for all the seasons.

From Fig. 3 and Fig. 4, it is found that

1. Angle of Faraday rotation is the highest for summer as compared to winter and spring season. This is attributed to the fact that in summer, maximum ionization takes place due to maximum radiation available from the direct rays coming from the sun.
2. The Faraday rotation is found to have the maximum value around mid day (noon) hours. This is because of the fact that the maximum radiation is available from the sun during this period. Actually, during noon hours, sun rays will be available almost vertically as compared to the rays in the morning and evening periods when they will be available at some slant angle. As this slant angle decreases with hours from morning to noon hours, the effective ionization is bound to increase. The case is otherwise, for the rays from noon to evening hours, because in this period of time, the effective radiation available will be decreasing with increasing hours.
3. The fluctuation in the Faraday rotation in day time is found to be the maximum as compared to the night hours. This is because, in day time, the ionization in the layer changes significantly from morning to noon hours and from noon to evening hours due to large variation in the radiation intensity available in the day hours. In night hours, there is no ionization variation due to sun rays as the sun rays are absent during this duration. However, there will be some variation in the ionization due to temperature variation in the night hours.
4. Loss due to depolarization is found to have the maximum value at noon hours for all the seasons (summer, winter and spring) however, the loss is the highest for summer season as compared

to winter and spring season. This is logically correct because the ionization is the highest in summer in comparison to winter which gives rise to maximum electron content and maximum depolarization.

5. The losses are found to be minimum in the morning and night hours because of low ionization in the ionospheric layer and hence low Faraday rotation.
6. Loss increases almost linearly in the morning hours (0600 Hrs to 1200 Hrs) while it decreases in the evening hours (1200 Hrs to 1800 Hrs). This is because of change in ionization with changing hours. The ionization increases from morning to noon as the radiation intensity increases from morning to noon because of change in the incident angle of the sun rays. The ionization intensity decrease from noon to evening hours because of decreasing illumination intensity.
7. The variation in the depolarization loss is maximum in day hours from 0600 Hrs to 1800 Hrs. This is because of the fact that, the illumination intensity varies to a great extent from morning to noon hours and noon to evening hours giving rise to a large variation in the electron content and thus Faraday rotation.

6. CONCLUSION

It may, therefore, be concluded that the propagation of electromagnetic waves through ionospheric layer is considerably affected. The depolarization of waves ultimately results into significant loss in the electromagnetic energy.

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