

# Impact Analysis of Sun Radiation Activity on Ionospheric Plasma In Terms Of Poynting Flux and Joule Heating

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**ABSTRACT:** Solar radiation emitted by the sun may affect the ionosphere electrons in the atmosphere which will disturb the radio frequencies travelling through atmosphere. Along with this UV (ultraviolet), radiation emitted from Sun affects other factors in the atmosphere. Ionosphere layer generally contains electrons and neutral species which are affected by UV rays emitted from the sun. The region where electron and species contain in ionosphere is known as ionospheric plasma .when ultraviolet rays from the sun hit ionospheric plasma region it leads to certain changes in the atmosphere. In this research we examined the impact of solar radiation on the ionospheric plasma in the atmosphere. Ionospheric plasma in atmosphere contains numerous numbers of electrons which are defined as charged particles and also it contains certain species components. UV rays from the sun reach ionospheric plasma it leads to certain effects on plasma region of the ionosphere which leads to joule heating effect and change in flux. The impact caused by UV rays on the ionospheric plasma in the atmosphere is analysed and its corresponding effects are theoretically explained.

**KEYWORDS:** Ionosphere, Joule Heating, Flux, UV rays, Plasma region, Electrons.

## I. INTRODUCTION

The atmosphere–ionosphere system describes Earth's whole atmosphere extending from the lower atmosphere to the higher regions of the shelter deck region (1000 km) [1]. In the upper portion of the atmosphere-ionosphere system ( $z > 70$  km) enhances the amount of ionization, mainly by solar ultraviolet (UV) and extreme ultra- violet (EUV) radiation, this will generate moderately ionized plasma surroundings on the atmosphere, the ionosphere, that coincides with the thermosphere is called as the warmest neutral atmospheric area [1]. Overall, the structure of the atmosphere–ionosphere system is influenced by internal and external processes, such as, by internal part waves from below [2-8] and magnetospheric, star and geomagnetic processes from on top of [9 – 12]. In atmosphere due to two- way coupling magnetic fields are generated by interaction of plasma and neutral particles in the atmospheric region. During this context, “two-way” doesn't indicate upward–downward directions within the atmosphere; particularly it indicates that neutral region influences on plasma processes likewise as plasma will drive neutral dynamics, calculating the latitude of thermosphere Ionosphere (TI). Such plasma-neutral interactions cause resistance heating of the neutral atmosphere by Joule heating that considerably influences the structure of the higher atmosphere [13].

Consideration of energy flow is a very important fact of magnetosphere-ionosphere coupling. Neglecting particle precipitation, the magnetic attraction energy dissipation within the region takes place as Joule heating, whereas the transport of energy between the region and magnetic field are often inferred from the Poynting flux (or Poynting vector) [12]. Ultraviolet (UV rays emitted by Sun) light from the sun hits atoms in Earth's higher atmosphere. The UV energy emitted from sun knocks associate degree lepton off the atom, going away a neutral associate degree and particle. This kind of ionized gas is named plasma. In contrast to alternative gases, it will conduct an electrical charge and is stricken by magnetic fields. Every layer plays a very important role in riveting a number of the sun's radiation.

# International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 8, August 2016

Ionospheric plasma has a double-refractive index and usually has weak conduction in each direction, season and local time. Attributable to these, the ionospheric parameters like dielectric constant, conductivity and the refractive index profile in each and every direction will be completely different and it has complicated structure (which contains both real and imaginary part). The field propagation in diagonal region of the ionospheric plasma performs conduction, conductivities of the field in atmospheric region. Tensor field in the direction of propagation can be measured by using the plasma region of the atmosphere. Thus, this attenuation result of ionospheric plasma is obtained from the imaginary part of a complex number of the propagation constant. In this research examined the impact of solar radiation on the ionospheric plasma in the atmosphere. Ionospheric plasma in atmosphere contains numerous numbers of electrons which are defined as charged particles and also it contains certain species components. UV rays from the sun reach ionospheric plasma; it leads to certain effects on plasma region of the ionosphere which leads to joule heating effect and change in flux. The impact caused by UV rays on the ionospheric plasma in the atmosphere is analysed and its corresponding effects are theoretically explained. The paper is organized as in section I provides overview and description of study. In section II provides Joules heating and Poynting Flux of ionospheric plasma. In section III provides the detail about Joule's heating impact on ionosphere. In section IV provides discussion about ionospheric electrostatic variables considered for this research. Finally in section V provided with conclusion of this research paper.

## II. JOULE'S HEATING AND POYNTING FLUX

Joule heating in ionospheric plasma region is stated as region where ionized gas produces certain motion. In joule heating region electrical and magnetic fields are orthogonal for the magnetic field force. Normally in the ionospheric region of 100 to 200 km joule heating is at the rate of  $10^{-5} \text{erg cm}^{-3} \text{sec}^{-1}$  in the atmospheric region of earth atmosphere. The pressure gradient on the ionospheric plasma region is at the rate of  $10^{-19} \text{dyne cm}^{-2}$  for the atmospheric region above 150km which follows geomagnetic disturbance. For evaluating the impact of Joule's heating in Ionospheric plasma region equations have been derived for theoretical analysis. Joule's heating in Ionospheric plasma region is evaluated using rectangular co-ordinate system in order to calculate electric and magnetic field in the Ionospheric plasma region of the atmosphere. While calculating Joule's heating in Ionosphere electric, magnetic field has been considered in three directions. The electric field orientation in Ionospheric plasma region in rectangular co-ordinate system is stated as  $E_S(E_{Sx}, E_{Sy}, 0)$ , orthogonal magnetic field in ionosphere is given as  $H(0, 0, H)$  and mechanical force exists in the Ionospheric region of atmosphere is given as  $F(F, 0, 0)$ . In upper atmospheric region of the ionospheric plasma region, fields are assumed to be uniform with induced velocity of the ionospheric plasma region  $v(v_x, v_y, 0)$ . Through the above mentioned rectangular coordinate system will produce ionospheric current density and it is induced in the ionospheric plasma region of the upper atmosphere, given in terms of  $j(j_x, j_y, 0)$  as follows, Joule heating rate can be expressed by using this following equation (1),

$$q_j = j_{\perp} \cdot E'_{\perp} = \sigma_p E_{\perp}^2 = \sigma_p (E_{\perp} + \mu_n \times B)^2 \quad (1)$$

Where,

$j_{\perp}$  = current density perpendicular to the local magnetic field line;

$E'_{\perp}$  = perpendicular electric field in the neutral reference frame

$\sigma_p$  = local Pedersen conductivity

$E_{\perp}$  = perpendicular electric field in the inertial reference frame

$\mu_n$  = neutral wind (wind speed in the atmosphere is related to the earth surface)

B = Earth's magnetic field

Based on the measure of the current density and conductivity with height the joules heating rate can be expressed in equation (2) and (3),

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(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 8, August 2016

$$q_j = j_{\perp} \cdot E'_{\perp} = \frac{j_{\perp}^2}{\sigma_c} \quad (2)$$

$$Q_j = \int_{90}^{zupper} \frac{j(z)_{\perp}^2}{\sigma(z)_c} dz \quad (3)$$

Where, Q = joule's heating; considering particular region (Z) in the ionosphere their limits will be 90 and Zupper and integrating them to find the joule heating effect.

$\sigma_c$  = cowling conductivity

$$\sigma_c = \sigma_p + \frac{\sigma_H^2}{\sigma_p} \quad (4)$$

$\sigma_p$  = local Pedersen conductivity

$\sigma_H$  = hall conductivity

The presence of cowling conductivity will be due to the fact of magnitude of the current density perpendicular to the local magnetic field line  $|j_{\perp}|$  can be expressed in the following equation (5), (6) and (7)

$$|j_{\perp}| = (\sigma_p^2 + \sigma_H^2)^{1/2} |E'_{\perp}| \quad (5)$$

$$|j_{\perp}| = \left[ \sigma_p \left( \sigma_p + \frac{\sigma_H^2}{\sigma_p} \right) \right]^{1/2} |E'_{\perp}| \quad (6)$$

$$|j_{\perp}| = (\sigma_p \sigma_c)^{1/2} |E'_{\perp}| \quad (7)$$

Joule heating effect and Poynting flux are the major parameter in the upper atmosphere has substantial influence on the Ionospheric plasma region. Joule heating rate can be calculated by the eqn (2) and (3). Poynting flux denotes the directional energy flux density (the rate of energy transfer per unit area) of an electromagnetic field. Poynting flux density calculation in the atmosphere delivers the amount of energy dissipated in the electromagnetic field of the atmospheric body. Poynting flux in the ionospheric plasma region defines the divergence performance in the ionospheric plasma region.

### III. JOULE'S HEATING IMPACT IN IONOSPHERIC PLASMA

The total energy of the whole atmosphere under adiabatic motion is conserved. From an energetic point of view, various terms in the momentum and thermal energy equations represent conversions of energy from one form to another [23]. Often, a simplification of the equations of motion for a specific problem requires that the energy conversion relations still hold. To demonstrate the energy consistency of the system, charged particles will induce alteration in kinetic energy density by the influence of ion drag.

$$\left[ \rho_n \frac{D_n}{Dt} \left( \frac{1}{2} u_n^2 \right) \right]_{I-D} = u_n \cdot (J \times B) = -J_{\perp} \cdot (u_n \times B) \quad (8)$$

Where  $\mu_n$  = neutral wind,

I denote identity function and D denotes determinant function

For a system that includes currents and electromagnetic fields, energy conservation is described by Poynting's theorem [15],

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$$\frac{\partial W}{\partial t} + \nabla \cdot S = -J \cdot E \approx -J_{\perp} \cdot E_{\perp} \quad (9)$$

Where W is the electromagnetic energy density

and  $S = (E \times B) / \mu_0$  is the Poynting vector that represents the electromagnetic energy flux density with  $\mu_0$  being the permeability of free space. The term on the right-hand side of Eq. (9) represents the conversion of electromagnetic energy into mechanical energy, which consists of both thermal and kinetic energies for the atmosphere. Likewise, the electromagnetic energy cannot be fully converted into kinetic energy without producing Joule heating in the thermosphere. From this below equation (10) and (11) Joule's heating impact in ionospheric plasma depends on the local Pedersen conductivity and hall conductivity.

$$J_{\perp} \cdot E_{\perp} = \sigma_p |E_{\perp}|^2 - \sigma_p u_n \cdot (E_{\perp} \times B) + \sigma_H (u_n \times b) \cdot (E_{\perp} \times B) \quad (10)$$

$$J_{\perp} \cdot (u_n \cdot B) = \sigma_p |u_n \times B|^2 - \sigma_p u_n \cdot (E_{\perp} \times B) - \sigma_H (u_n \times b) \cdot (E_{\perp} \times B) \quad (11)$$

Where B is the magnetic flux

The above equation (10) and (11) mathematically states the conversion between electromagnetic energy and the thermal energy of the system. While examining the conversion between the electrical and thermal energy mechanical energy in the system also considered for analysis. The below equation (12) provides the conversion of electric energy between the thermal and kinetic energy in the atmospheric plasma region.

$$Q_J = Q_{J1} + Q_{J2} \equiv \sigma_p |E_{\perp}|^2 + \left\{ \sigma_p |u_n \times B|^2 - 2\sigma_p u_n \cdot (E_{\perp} \times B) \right\} \quad (12)$$

Where,

$Q_J$  = total joule heating impact

$Q_{J1}$  = joule heating rate excluding neutral wind

$Q_{J2}$  = joule heating rate including neutral wind

In upper thermosphere region of the atmosphere faces problems due to the speed of air in ionosphere related to the earth's surface. Hence wind speed in the upper region is very difficult to determine so the derivation eliminates wind speed in our proposed analysis.

## IV. IONOSPHERIC ELECTROSTATICS

For simplicity, we have a tendency to assume Cartesian geometrical co-ordinates (x North, y East, z down) and vertical background magnetic flux to form ionospheric ohms law The height-integrated ionospheric Ohm's law is

$$J = \sum_p E + \sum_H \hat{e}_z \times E \quad (13)$$

Where,  $\sum_H$  and  $\sum_P$  are the height-integrated Hall and Pedersen conductance and  $\hat{e}_z$  is a downward unit vector. We have a tendency to neglect neutral wind effects in ionospheric region, therefore, there's no energy resource within the ionospheric plasma region. During this study of impact analysis of sun radiation activity on ionospheric plasma in terms of poynting flux and joule heat has a tendency to limit our discussion to quasi-static phenomena(neglecting neutral wind) and its corresponding field equation is stated as  $E = -\nabla \phi$ . Where,  $\phi$  = electric flux density.

$$J_p = J_p^{cf} + J_p^{df} = \sum_p E \quad (14)$$

$$J_H = J_H^{cf} + J_H^{df} = \sum_H \sum_H \hat{e}_z \times E \quad (15)$$

The curl-free and divergence-free parts satisfy

$$\left( \nabla \times J^{cf} \right)_z = 0, \nabla \cdot J^{df} = 0 \quad (16)$$

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(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 8, August 2016

Based on Hall and Pedersen currents on an individual basis, the magnetic field in the plasma region is defined in terms of pointing flux outlined as  $s = \frac{(E \times B)}{\mu_0}$ . An equivalent internal energy flow within the magnetosphere-ionosphere

system is obtained by neglecting the non-divergent contribution from the Earth's main magnetic flux; therefore, we have a tendency to think about solely the perturbation Poynting flux.

$$S_p = \frac{(E \times \delta B)}{\mu_0} \quad (17)$$

Here  $\delta B$  is the perturbation magnetic flux caused by the ionospheric and field-aligned currents (we neglect the contribution from the distant magnetospheric currents). As we have a tendency to neglect the neutral wind, there's no generator within the region and energy should be equipped from the magnetic flux by the field-aligned element of  $S_p$ .

The amount of magnetic energy dissipated within the static region of the upper atmospheric region of the atmosphere where Ionospheric plasma is originated is defined through following equation (18).

$$E \cdot J = \sum_p |E|^2 \geq 0 \quad (18)$$

From the analysis it is observed that Joule heating has been originated in the upper atmosphere through the collision between the charged and neutral particles in the Ionospheric plasma region of the atmosphere. Any potential electric field denotes that the normal element of Poynting flux integrated over a surface limited by an equipotential curve is dissipated in the ionospheric surface. Based on the magnetic flux theorem there is an off chance to neglect the potential drops in the upper Ionospheric region of the atmosphere with magnetic flux which is written as follows in below equation (19)

$$\int_D E \cdot J da = \int_{D'} S_p \cdot \hat{e}_z da \quad (19)$$

Where D is any ionospheric area limited by an equipotential curve. While using spherical coordinate's  $\partial D$  and D is the area plotted to a higher altitude along the magnetic field. As a special case this theorem grips the whole ionosphere. But here we are assuming Cartesian geometry so we have to assume that E, J and dB disappear rapidly at infinity.

## V. CONCLUSION

In this paper, we derived a mathematical model for the Joule heating term by using the thermal energy equations for the dynamic region and the impacts of ionospheric plasma. Where each and every electrical parameters are parameterized as functions of the electron flow rate and neutral wind. The electron flow rate expressions conjointly dependent and calculated by using magnetic flux, the Pedersen and Hall conductivities, and also the quantitative relation of the electrons accelerator frequency to the ion-neutral collision frequency. But it is not possible to provide neutral wind approach because neutral wind is the flow of wind speed in the ionosphere region according to the earth's surface. There is no electric source available to provide wind speed in ionosphere so it is impossible to predict the neutral wind speed and this parameter is neglected in our research. Our derivation expressly shows 2 different kinds of approximations in parallel: approaches gross formulation in terms of electro dynamic force and resistance unit dissipation by Eqn. (3) and (16), respectively, and approach, a parameterized particle drag and Joule heating in terms of bulk rate distinction by Eqn. (6) and (17), respectively. The electric field and current density in ionospheric region was defined by set of expressions in section 2 and section 3. Specifically it's shown that Joule heating linearly depends on Pedersen conduction and hall conduction it is regularly positive. In real time, when energy is converted from one form to another form some of the energy will be converted as joule heating effect. If the neutral wind coincides with the majority electron flow rate, the result will drag the majority electron flow rate and Joule heating rate vanishes.

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