GEOMAGNETIC EFFECT ON ELECTROMAGNETIC FIELD STRENGTH OF POWER LINE RADIATION OVER NORTHERN EUROPE OBSERVED ON THE BALLOONS B_{15}-1N AND B_{15}-2N

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Abstract: Observations of the electromagnetic field strength of power line radiation over northern Europe were conducted under the geomagnetically active conditions using the balloons B_{15}–1N on March 20, 1982 and B_{15}–2N on November 23 and 24, 1982. Substorms occurred during the both flights.

A substorm effect on the strength of the electromagnetic field of the power line radiation was investigated at the harmonic frequencies of commercial power line frequency, 50 Hz in the frequency range from 40 Hz to 1 kHz. The strength of the power line radiation at the harmonics of 50 Hz in the frequency range from 200 to 900 Hz enhanced during the substorms. A great increase of strength was observed at 300, 450 and 600 Hz on the balloon B_{15}–1N, and at 300, 450 Hz on B_{15}–2N. However, the strength at 50, 100, and 150 Hz did not enhance more than 3 dB during the substorms. It is concluded that the strength of the power line radiation enhanced at higher harmonics of 50 Hz during a geomagnetic substorm.

1. Introduction

Geomagnetic effect on man-made long conductors has been investigated by many authors (ALBERTSON and VAN BAILEN, 1970; ALBERTSON *et al.*, 1973, 1974; ALBERTSON and THORSON, 1974; ANDERSON *et al.*, 1974; AKASOFU and MERRITT, 1979; CAMPBELL, 1980; AKASOFU and ASPNES, 1982; LANZEROTTI, 1983). It is revealed from these studies that the geomagnetic effect is caused by potential difference between grounded points of conductor system. This potential difference on the earth is induced by a horizontal electric field component of geomagnetic fluctuations, which are the reflection of auroral currents flowing in the ionosphere, with the ohm's law (ALBERTSON and VAN BAILEN, 1970). This effect on conductor systems has caused a severe disturbance in case of a large geomagnetic storm (ALBERTSON and THORSON, 1974; ALBERTSON *et al.*, 1974; ANDERSON *et al.*, 1974). However, a small geomagnetic storm should cause some effect on conductor systems even though the induced current is not so large compared with the severe storm.

It is important to obtain a relationship between the geomagnetic fluctuations and the strength of electromagnetic fields of power line radiation because the mechanism of geomagnetic induction, distortion, and radiation is known only partially. It is also important to know the field strength of the power line radiation at higher harmonic frequencies below the ionosphere since they may trigger VLF emissions in the magnetosphere (HELLIWELL *et al.*, 1975; LUETTE *et al.*, 1977, 1979).

The present paper describes the strength variations of power line radiation during geomagnetic substorms. Since observations of power line radiation were conducted by using balloons, at 32 km altitude, the observed electromagnetic field was not radiated from power lines just below the balloons but from those distributed in a wide area. Therefore, those observations of power line radiation revealed a geomagnetic effect on power lines which are distributed in a wide area.

2. Observations

The instrumentations of the balloons B_{15}-1N and B_{15}-2N were equipped with the same type of sensors and boards except for the gain differences of the receiver (TOMIZAWA and YOSHINO, 1984). The receiver consisted of a horizontal magnetic field detector and a vertical electric field detector. The receiver output is transmitted through a telemetry channel by sequentially switching the outputs of the detectors. The frequency range of these observations was from 40 Hz to 1 kHz.

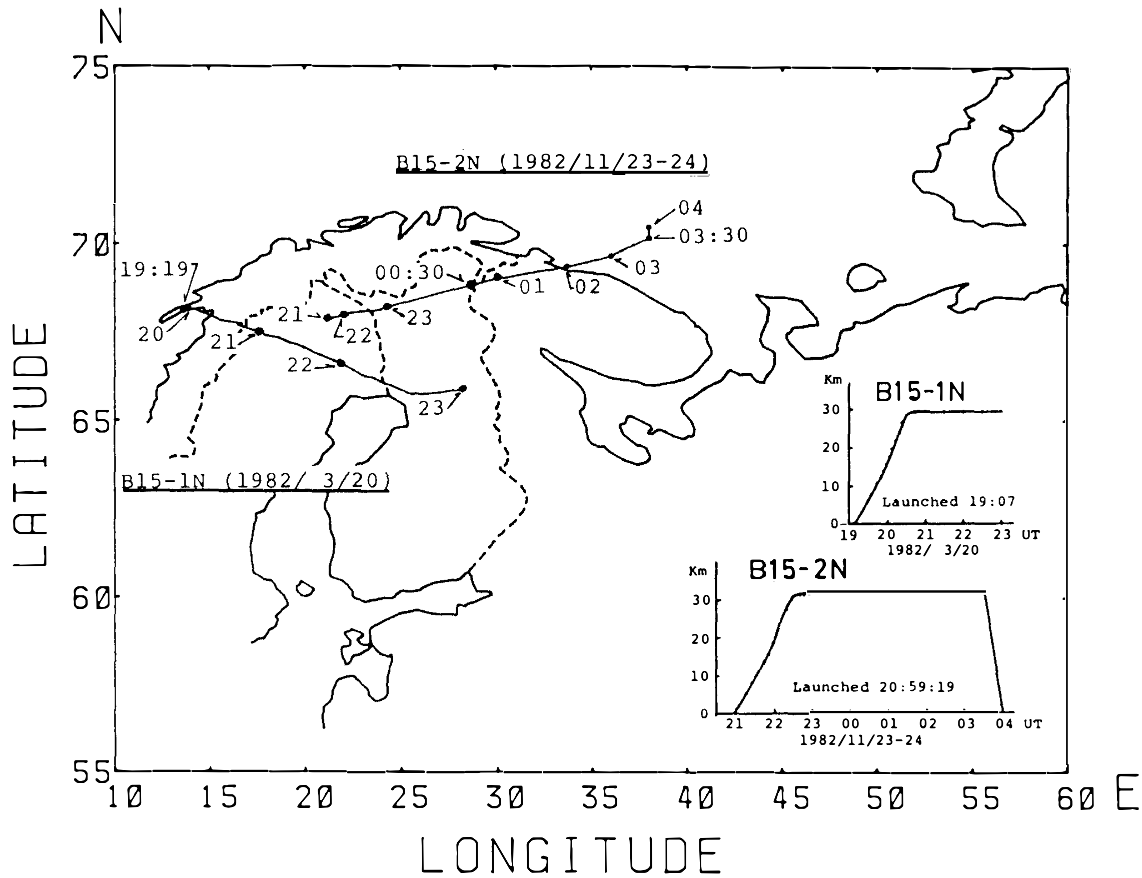

Fig. 1. The flight trajectories of the balloons B_{15}-1N and B_{15}-2N. The balloon B_{15}-1N was launched at 1907 UT on March 20, 1982 from Stamsund, Norway, and the balloon B_{15}-2N was launched at 2059 UT on November 23, 1982 from Esrange, Sweden.

The balloon B_{15}-1N was launched at 1907 UT on March 20, 1982 from Stamsund, Norway, while the balloon B_{15}-2N was launched at 2059 UT on November 23, 1982 from Esrange, Sweden. Their flight trajectories and altitudes are shown in Fig. 1. The balloon B_{15}-1N drifted eastward across Norway and Sweden, and then the payload was cut down in Finland. On the other hand, the balloon B_{15}-2N drifted toward the northeast direction across Sweden, Finland, and USSR, and then the payload was cut down after the balloon entering into the Arctic Sea.

3. Results

3.1. Result of B_{15}-1N observation

The balloon observation was operated under the geomagnetically active condition as shown in Fig. 2a. Time variations of the magnetic field strength of power line radiation observed on the balloon B_{15}-1N are displayed in Fig. 2b. In this figure,

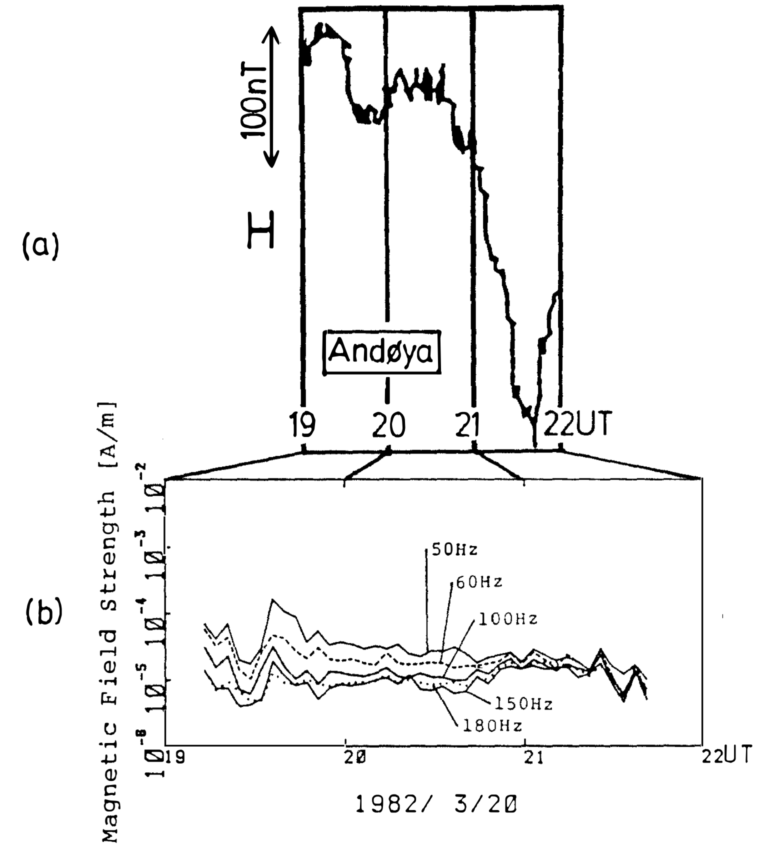

Fig. 2. Strength variations of power line radiations observed by the balloon B_{15}-1N versus geomagnetic field variations.
(a) The horizontal component of the geomagnetic field observed at Andøya, Norway during the flight of the balloon B_{15}-1N. Substorm started at 2040 UT with a negative bay. (b) The magnetic field strength at 50 Hz which is the fundamental frequency of power lines in Europe, and those of harmonics at 100 and 150 Hz. The strengths at 50, 100 and 150 Hz are indicated by the solid lines. The magnetic field strengths at 60 and 180 Hz, which are used as the references of the background noise strength, are indicated by the dashed and the dotted lines, respectively. Strength fluctuations from 1907 to 1920 UT are produced by the vibration of the balloon gondola during the balloon's ascent.

the strength of power line radiation at the fundamental frequency of 50 Hz and those of harmonic frequencies at 100 and 150 Hz are indicated by solid lines. On the other hand, the strengths at 60 and 180 Hz are indicated by the dashed and the dotted lines, respectively. The strengths at 60 and 180 Hz are used to infer the strength of background noise close to the harmonic frequencies of 50 Hz.

In Fig. 2b, the strength of the magnetic field at all observed frequencies was disturbed by the vibration of the gondola from 1907 to 1920 UT. At 1936 UT, the magnetic field strength at 50 Hz has a peak value of 1.6×10^{-4} (A/m) which is much greater than the value at 60 Hz (background noise close to 50 Hz). As the peak value does not correspond with the geomagentic fluctuation, it can be considered that the balloon was flying over the power lines. The balloon was flying over the coast line of Norway at that time where many power lines are extended. After the peak value, the strength at 50 Hz gradually decreases with time till the end of the data without any enhancement even at the substorm onset of 2040 UT. The strength at harmonic frequencies (100 and 150 Hz) is less than that of the background noise through this observation. However, the strength enhancements at 60, 100, 150 and 180 Hz are associated with the substorm. The enhancements at 100 and 150 Hz are attributed to the strength enhancement of the background noise because the strengths at 100 and 150 Hz are comparable to those at 60 and 180 Hz.

Dynamic spectra of the magnetic field strengths in the frequency range from 40 Hz to 1 kHz are as shown in Fig. 3. A spectral peak at 50 Hz is clearly identified till 2013 UT, but, after 2017 UT, the strength at 50 Hz keeps almost the same level as that of the background noise. Spectral peaks at harmonics of 50 Hz are not identified in the dynamic spectra till 2036 UT except for the spectrum at 1954 UT. At 2040 UT, a spectral peak appears at 350 Hz, but, the spectral peak at 350 Hz does not appear after 2044 UT. It seems that the 350 Hz peak appears as transition phenomena of geomagnetic effect on power lines. In place of the spectral peak at 350 Hz, a spectral peak at 600 Hz appears in the spectrum at 2044 UT. The spectral peak greatly increases at 2044 UT, and then it appears in the successive spectra till 2121 UT. As seen in Fig. 3, in addition to the spectral peak at 600 Hz, spectral peaks at 300 and 450 Hz appear in the spectra from 2051 to 2121 UT, but the spectral peaks at 300 and 450 Hz are not clearly identified. It is noticeable that the frequencies of the spectral peaks are not exactly at harmonic frequencies of 50 Hz and that the frequencies sometimes shift downward. The downward shift of the frequencies of the three spectral peaks is correlated with each other, and the amounts of frequency shift from their expected ones can be reduced to the same amount of shift at 50 Hz, dividing the frequency of 300, 450 and 600 Hz by their multiples, 5, 9 and 12, respectively. So the downward frequency shift can be attributed to the frequency shift of the fundamental frequency from 50 Hz. The appearance of these spectral peaks is coincident with an onset of the geomagnetic substorm which started at 2040 UT. Therefore, the geomagnetic substorm not only enhances the power line radiation especially at 300, 450, 600 Hz, but also disturbs the frequency of the commercial power lines.

3.2. *Result of the balloon B_{15}-2N*

The horizontal component of geomagnetic field and ULF magnetic pulsation

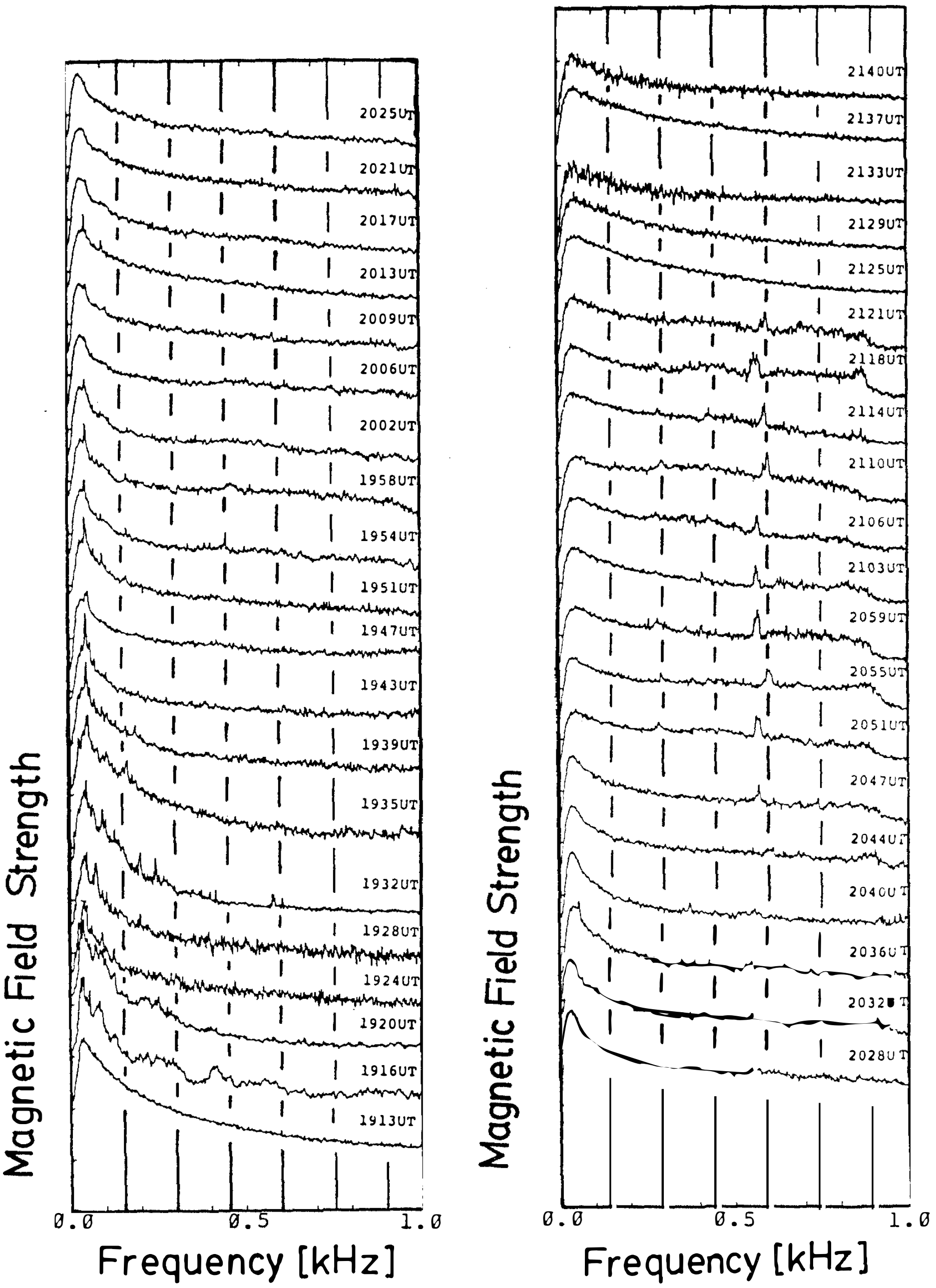

Fig. 3. Magnetic field spectra from 40 Hz to 1 kHz observed on the balloon B_{15}-1N. Time of the spectrum advances from the lower-left to the upper-right. The positions of harmonic frequencies of 150 Hz (150, 300, 450, 600 and 750 Hz) are indicated by the vertical lines.

during the flight of the balloon B_{15}-2N observed at Esrange, Sweden is presented in Fig. 4a. As shown in this figure, a sudden decrease in the horizontal (H) component of the geomagnetic field and a sudden increase of amplitude of magnetic pulsations in the differential H-component indicate that a magnetic substorm occurred at 2051 UT. The substorm decayed after about 30 min.

Magnetic and electric field strength variations are shown in Figs. 4b and 4c, respectively, at 50, 60, 100, 150 and 180 Hz during the flight time of the balloon. The

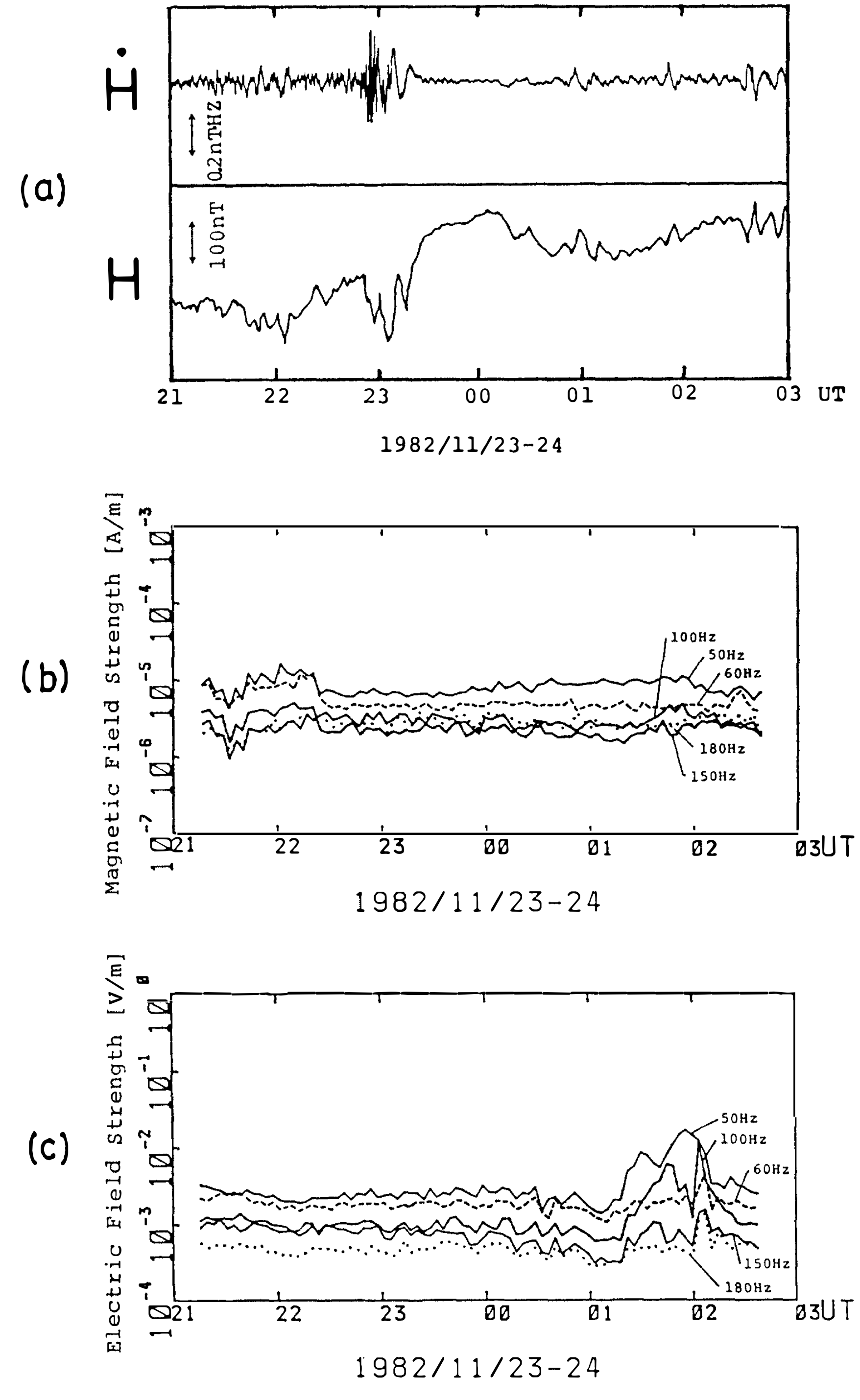

Fig. 4. Strength variations of power line radiations observed on the balloon B_{15}-2N and their relation to geomagnetic field variations.
(a) The horizontal component of geomagnetic field and ULF magnetic pulsation. The magnetic (b) and the electric (c) field strengths at 50, 60, 100, 150 and 180 Hz, are indicated in the same way as Fig. 2b. Strength fluctuation of the magnetic field at all frequencies from 2115 to 2220 UT is produced by the vibration of the balloon gondola while the balloon was ascending.

strengths at 60 and 180 Hz, which are indicated by the dashed and the dotted lines respectively, illustrate background noise level near the frequencies of power line harmonic radiation. The enhancements of the magnetic field strengths at all frequencies from 50 to 180 Hz in the time interval 2115–2220 UT are due to the vibration of the gondola during the ascending time. The electric field strengths, however, did not seem to be disturbed by the vibration of the gondola. This result can be interpreted by a fact that the sensor of the electric field is physically isolated from the gondola.

It is evident that the magnetic and electric field strengths at 50, 60, 100, 150 and 180 Hz did not increase during the geomagnetic substorm from 2250 to 2320 UT as indicated in Figs. 4b and 4c. This result coincides with the result of the B_{15}-1N observation in which magnetic field strengths at 50, 100 and 150 Hz did not enhance during substorm. Furthermore, it is found that the strengths at 50, 100 and 150 Hz increased from 0115 to 0230 UT when the geomagnetic activity was low. The enhancement of the field strength of the electric field component is much higher than that of the magnetic field component. It is therefore suggested that the strength enhancement of power line radiations during this interval is induced by a localized power line system. A wave impedance calculated from values of the fundamental frequency of 50 Hz at 0155 UT is approximately 1300 ohms. This value supports again the existence of a

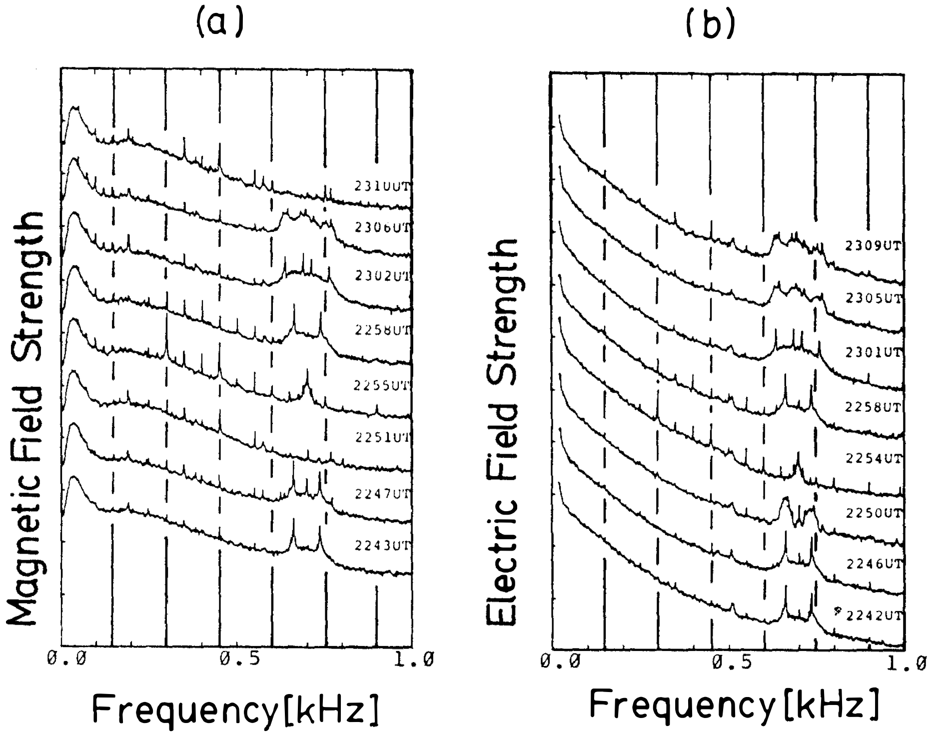

Fig. 5. The magnetic (a) and the electric (b) field spectra from 40 Hz to 1 kHz observed on the balloon B_{15}-2N around the start time of a geomagnetic substorm. Time of the spectrum advances from the bottom to the top. It should be noted that the spectral enhancement from 620 to 800 Hz is caused by the interference from the other instrument on board the balloon B_{15}-2N. The positions of harmonic frequencies of 150 Hz are indicated by the vertical lines.

localized power line since the estimated wave impedance is much higher than that of a propagation mode, *i.e.*, 377 ohms. The higher wave-impedance is also obtained from the balloon experiment near the Japan Islands where numerous power lines are circuited (TOMIZAWA *et al.*, 1983). The strength of the magnetic and the electric fields at 50, 100 and 150 Hz is not affected by the substrom.

Then, the geomagnetic effect on the power line radiation at higher harmonic frequencies is investigated in the frequency range from 40 Hz to 1 kHz during the geomagnetic substorm which started at 2251 UT as shown in Fig. 4a. Amplitude spectra of the magnetic and the electric fields around 2250 UT are displayed successively in Figs. 5a and 5b, respectively. It is evident that spectral peaks at the harmonic frequencies of the power line radiation in the frequency range higher than 200 Hz enhanced at the substorm onset of 2251 UT in the both magnetic and electric fields. The enhancement was particularly remarkable in this spectrum at 2255 UT when the amplitude of the geomagnetic ULF pulsation suddenly increased. At the substorm onset, the strengths of power line harmonics at 300 and 450 Hz greatly increased as shown in Figs. 5a and 5b, while the intensifications of other harmonics were not so much increased in comparison with those of 300 and 450 Hz. The enhancements at 300 and 450 Hz decayed within 5 min concerning to the duration of the enhancement of ULF pulsation as shown in Fig. 4a. The strengths of power line harmonic radiation higher than 200 Hz in the both magnetic and electric fields were enhanced during the geomagnetic substorm.

4. Discussion and Conclusion

The strength at the fundamental frequency of 50 Hz observed on the balloons was not affected during the geomagnetic substorms, although the field strength was controlled by power lines above which the balloons were flying. Also, the field strength at harmonics lower than 200 Hz (100 and 150 Hz) was not affected during the substorms. TOMIZAWA *et al.* (1983) showed that the field strength at the fundamental frequency depends on the amplitude and phase balances of 3-phase power lines. If the balances of 3-phase power lines are kept during substorms, the field strength should be kept constant. As the field strength of the harmonic frequency of 50 Hz less than 200 Hz did not show any enhancement during both substorms observed on the balloons, it is concluded that amplitude and phase balances of power lines are not so severely disturbed as to radiate these harmonic fields less than 200 Hz during substorms with an amplitude in the order of a few hundred nano-Tesla's. In case of a severe geomagnetic storm such as reported by ALBERTSON and THORSON (1974) and ALBERTSON *et al.* (1974), these harmonic frequency fields less than 200 Hz should be enhanced because the amplitude and phase balances of 3-phase power lines will be disturbed by currents which are induced by geomagnetic fluctuations.

The field strength at harmonics higher than 200 Hz was enhanced during the substorms, particularly at 300, 450 and 600 Hz on B_{15}-1N, and at 300, and 450 Hz on B_{15}-2N. Such strength enhancements at 180 Hz (3rd), 360 Hz (6th), 540 Hz (9th) and 720 Hz (12th) were also observed in central Canada at the time of geomagnetic substorm (HAYASHI *et al.*, 1978). As the electric current at the 3rd, 6th, 9th and 12th harmonics of 50 Hz can flow as a neutral current of 3-phase power lines, the strength of magnetic field radiated from a current loop which is produced by a power line and the earth should be intensified at these harmonics. So the field strengths at multiple frequencies of 150 Hz are particularly enhanced. Thus, the field strength observed on the balloons can be related to neutral currents of 3-phase power lines. Therefore, it is interpreted that amplitudes of electric currents at harmonic fields of power line radiation higher than 200 Hz are increased by geomagnetic substorms.

There is no mechanisms in suppression of power line radiation at 150 Hz since the radiation mechanism at 150 Hz is not so different from those at 300, 450 and 600 Hz in this model. Therefore, it is suggested that the harmonic current at 150 Hz is not comparable to the current at 300, 450 and 600 Hz at the time of the both observations; in other words, the induced current on power lines is not so large as to saturate cores of transformers. It is also suggested that strengths of power line harmonic radiation in the VLF frequencies range can be radiated even at weak substorm conditions and they may be related to the effect of power line radiation observed by HELLIWELL *et al.* (1975), LUETTE *et al.* (1977, 1979) and PARK and HELLIWELL (1977).

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