Influence of Pulsed Power Transmission on Radio Wave Environment in Low Frequency Range

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***Abstract*—Influence of pulsed power transmission on radio wave environment in low frequency range is investigated. The pulsed power transmission is already proposed as one of the basics for smart grid technologies. One of the problems of this scheme is a potential influence on radio wave environment by high frequency components of elctric pulse trains. This paper investigates the influence on the radio wave environment especially in low frequency range where standard time signal waves are broadcasted as the lowest frequency of actual radio wave services.**

Keywords: *Smart grid, Energy packet, Pulsed power network, Radio noise.*

I. Introduction

Pulsed power network is already proposed as one of the basics for smart grid technology[4], [5]. In this network, electric pulses are transmitted on pre-reserved power slots within successive frames synchronized over the network. One of the problems of this scheme is a potential influence on radio wave environment by high frequency components of elctric pulse trains. Concerning the peak intensity in noise power spectrum, the influence does not necessarily exceed the conventional low frequency sine wave electric power transmission[1]. However, the previous work only investigates the noise intensity at very low frequency range up to 400[Hz] with restricted analysis of electromagnetic field around the electric wire.

In this paper, the noise intensity around the wire is analyzed more precisely than the previous work regarding the wave velocity of each Fourier component of elctric pulse trains. Based on this analysis, the influence of the pulsed power transmission on actual radio wave services especially in low frequency range is investigated.

II. Electric field intensity

Based on the electromagnetic field analysis[6], the electric field strength E around a straight wire with sinusoidal electric current is derived as[1]:

$$E_y = \frac{-AR\omega\mu}{2\pi}\int_0^{z_m} \frac{z\sin(\omega z/c)\exp\left(-j(\omega/c)\sqrt{R^2+z^2}\right)}{\left(R^2+z^2\right)^{(3/2)}}dz \quad (1)$$

$$E_z = j\frac{-AR^2\omega\mu}{2\pi}\int_0^{z_m} \frac{\cos(\omega z/c)\exp\left(-j(\omega/c)\sqrt{R^2+z^2}\right)}{\left(R^2+z^2\right)^{(3/2)}}dz \quad (2)$$

$$E_{max} = \sqrt{\sqrt{a^2+b^2}+c} \quad (3)$$

$$\begin{aligned} a &= \frac{E_{yr}^2+E_{zr}^2-E_{yi}^2-E_{zi}^2}{2} \\ b &= E_{yr}E_{yi}+E_{zr}E_{zi} \\ c &= \frac{E_{yr}^2+E_{zr}^2+E_{yi}^2+E_{zi}^2}{2} \end{aligned}$$

where, the wire is assumed to stretch along z-axis from $-z_m$ to z_m in XYZ coordinate system. Through this wire, electric current $A\exp\{j\omega(t-z/c)\}$ flows as the electromagnetic field source. Differing from the previous work[1], current velocity c is considered in this formula. E_y indicates y-component of electric field vector at the evaluation point around the wire. The z-coordinate of the point equals 0 and its distance from the wire equals R. E_x at the evaluation point does not exist because of the field symmetry. E_{max} means the maximum field strength at the evaluation point. z_m is set large enough so as to the integration converges. μ and c are the permeability and light velocity, respectively.

III. Pulse trains in each frame

In pulsed power network, time axis is divided equally into frames synchronized over the network. The duration of each frame is denoted by T[sec]. The frame is subdivided into N equivalent power slots of τ[sec] length ($\tau = T/N$) where

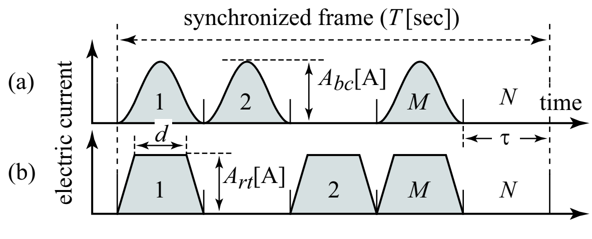

Fig. 1. Pulse trains adopted for noise spectrum evaluation.

[1]Among the components of the electric field, only radio wave component is picked out and other ones: electromagnetic induction field and electrostatic field are omitted.

electric pulses are transmitted at pre-reserved positions [5]. This frame structure and the shape of pulse trains are indicated by Fig. 1. In the figure, (a) shows M pulses located randomly in N power slots. Each pulse shape is one cycle of biased cosine wave assuming that the pulse width equals τ. The peak amplitude of this biased cosine wave (or BC wave) $I_{bc}(t)$ is expressed byA_{bc}. If number M increases of this series of BC waves, its spectrum gradually converges on that of a pure sine wave except for the direct-current component. In contrast, (b) shows M rectangle waves (or RT waves$I_{rt}(t)$) located randomly over N power slots. The amplitude of each RT wave and its upper side width is expressed byA_{rt} ad d, respectively.

IV. Noise spectrum evaluation

Differing from the previous work[1] where noise spectrum of very low frequency up to 400[Hz] is investigated, that of low frequency range around 40[kHz] is investigated here where standard time signal waves are broadcasted as the lowest radio wave service.

At this low frequency range, the maximum electric field strength E_{max} is derived by Eq. (3). In Fig. 1, the duration T of each frame and number N of power slots are set to 1[sec] and 100, respectively[2]. Three cases of pulse trains are adopted for the calculation: BC wave with 99 pulses, that with 50 pulses, and RT wave with 99 pulses. The pulse shapes of former two cases and the last case are indicated by (a) and (b) in Fig. 1, respectively. Upper side width d of RT wave is set to 6[msec].

In each case, the pulse train is Fourier-transformed into the fundamental wave and its harmonics. The electric field strength E_{max} of each Fourier component is calculated by Eq. (3). The distance R of the evaluation point from the wire is set to 3[m] according to the *weak radio signal tolerance* in Japanese radio low.

Pulse amplitudes A_{bc} and A_{rt} are adjusted to bring equivalent *root mean square* I_{rms} of the current $I_{bc}(t)$ and $I_{rt}(t)$ to that of the pure sine wave. I_{rms} indicates the effective current of power transmission. For example, if I_{rms} is set to 1[A], the amplitude of the sine wave, BC wave, and RT wave become 1.414[A], 1.633[A], and 1.168[A], respectively.

[2]From these values, the frequency of electric pulse repetition bacomes 100[Hz]. This frequency is reasonable from the view point of reuseableness of exsistiong power systems designed for 50 or 60[Hz].

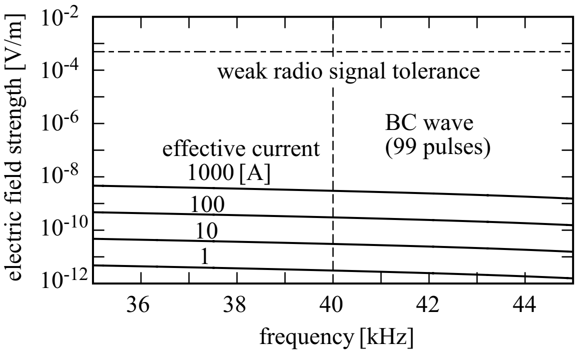

Fig. 2. Noise spectrum of pulse train (a) at low frequency range.

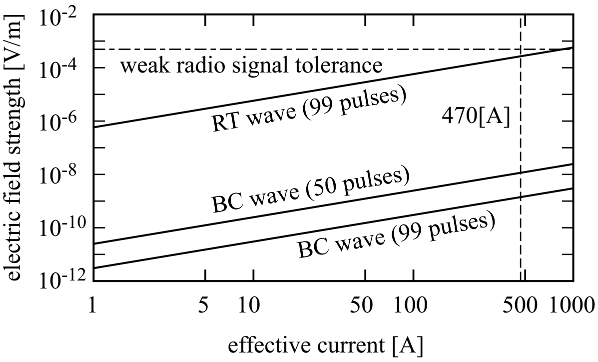

Fig. 3. Noise intensity of pulse trains at 40[kHz].

First, the noise spectrum of BC wave with 99 pulses is shown in Fig. 2. The horizontal axis represents the frequency around 40[kHz] and this center frequency is indicated by dashed line. The virtical axis represents the electric field strength E_{max}[V/m]. Four values of effective current: from 1 to 1000[A] are adoped as the parameter[3]. In comparison with the weak radio signal tolerance indicated by dot-dash line, the influence of radio noise by this case of pulse train on other radio services at low frequency range may not be noticeable.

As this figure shows, the noise intensity gradualy decreases in low frequency range. Therefore, concerning the radio noise influence on actual radio wave service: standard time signal waves, the influence at 40[kHz], the lowest frequency of the service is essential.

Fig. 3 shows the radio noise intensity at this critical frequency 40[kHz] by three cases of the pulse train. Horizotal axis represents the effective current. The virtical axis represents the same as Fig. 2. The maximum available current 470[A] of overhead distribution line is indicated by dashed line.

This figure shows two points. First, the influence by RT wave becomes noticeable at 40[kHz] or higher frequency in comparison with the weak radio signal tolerance. Second, because of the pulse shape designed to supress the higher frequency components, BC wave has less influence on other radio wave services regardless of the number of pulses in each frame.

References

[1] H. Sugiyama, "Influence of Packetized Electric Power Transmission on Radio Wave Environm," *IEEE 2017 ICCE-TW*, June. 2017.

[2] R. Abe, H. Taoka, and D. McQuilkin, "Digial Grid: Communicative Electrical Grids of the Future," *IEEE Trans. Smart Grid*, Vol.2, No.2, pp. 399-410, 2011.

[3] T. Takuno, M. Koyama, and T. Hikihara, "In-Home Power Distribution Systems by Circuit Switching and Power Packet Dispatching," *SmartGridComm*, pp. 427-430, Oct. 2010.

[4] H. Sugiyama, "Direct Relayed Power Packet Network with Decentralized Control for Reliable and Low Loss Electrical Power Distribution," *GCCE2013*, pp. 32-36, Oct. 2013.

[5] H. Sugiyama, "Pulsed Power Network Based On Decentralized Intelligence For Reliable And Lowloss Electrical Power Distribution," *JAISCR*, Vol.5, No.2, pp. 97-108, 2015.

[6] J. C. Slater, N. H. Frank, "Electromagnetism," Dover Publications, 1969.

[3]Considering the maximum available current 470[A] of overhead distribution line, these parameter values are adopted.