Time Transfer Scheme in Power Line based on Narrow Electric Pulse

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***Summary*—We demonstrated a time transfer scheme in power line based on narrow electric pulse. With this scheme, we have transmitted a narrow pulse of 100 ns across a 50-meter power line. The preliminary experimental result shows that the time deviation of the transmission link is 20.9 ps at 0.1-ms averaging time and down to 1.2 ps at ~1s averaging time. The deviation of the time difference and the quality of transmission implies the technique shown in this paper has potential to be directly used in the high-precision time synchronization across power line in a medium and short distance transmission.**

Keywords*—*power line; time transfer; narrow pulse

I. INTRODUCTION

Time transfer technique is important in scientific research, which is widely used in communication, satellite navigation, and fault detection [1, 2]. The precision of time transfer directly restricts the performance of the system in these fields.

Time transfer methods are various, such as fiber-based link, satellite, and free-space optical link [3,4]. The fiber-optic method needs to set up an extra fiber channel, and the satellite-based system will loss satellite signals in some special scenes. The free-space optical method needs to deploy extra lasers. Compared with the transmission link mentioned above, power lines are widely distributed and inexpensive. The time transfer scheme based on power line does not require extra channel deployment, and can be applied in a wider range of scenarios. It is a powerful supplement to the existing time transfer methods. However, the bandwidth of power lines limits the precise of the time transfer [5, 6].

In this paper, we propose a time transfer scheme in power line based on narrow electric pulse, and built a preliminary experiment and simulation to show its performance.

II. METHODS/RESULTS

We assume that time difference between site A and site B is Δt. We need to realize time transfer between A and B. Ignoring the technical details, as shown in the Fig.1, at site A, there are two parts, pulse generation and pulse detection. The device at site B is exactly the same as that at site A.

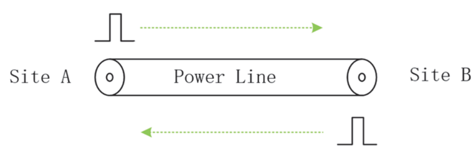

Fig. 1. Brief schematic diagram of time synchronization scheme in power line.

As shown in Fig. 2, site A sends pulse at a certain time (time 0), and it arrives site B after a time delay, where the delay has three parts, the sending delay τ_{TA}, path delay τ_{AB} and the receiving delay τ_{RB}. Site B sends pulse when the clock time of site B is (0+T), and it arrives site A after another time delay. Similarly, the delay has three parts, the sending delay τ_{TB}, the path delay τ_{BA}, and the receiving delay τ_{RA}. At Site A, the pulse from B is detected, and the pulse from A is also detected at Site B. In addition, T_{AB} is the time difference between the signal sent by Site A and the signal received, and T_{BA} is the time difference between the signal sent by Site B and the signal received.

Considering the relations of above mentioned time intervals in Fig. 2, we can write follow equations:

$$\tau_{TA} + \tau_{AB} + \tau_{RB} + T_{BA} + \tau_{TB} + \tau_{BA} + \tau_{RA} = T_{AB} \quad (1)$$

$$T + \Delta t = \tau_{TA} + \tau_{AB} + \tau_{RB} + T_{BA} \quad (2)$$

Since the two - way transmission pulse channel is almost the same, we have,

$$\tau_{AB} = \tau_{BA} \quad (3)$$

Based on Eq. (1) ~ Eq. (3), the time difference between site A and site B can be calculated by:

$$\Delta t = \frac{\tau_{TA} - \tau_{TB} + \tau_{RB} - \tau_{RA} + T_{AB} + T_{BA}}{2} - T \quad (4)$$

where T_{AB} and T_{BA} can be measured by time interval counter (TIC). τ_{AB} and τ_{BA} are identical as the two-way links are reciprocal. τ_{TA}、τ_{TB}、τ_{RA} and τ_{RB} could be calibrated by high-precision counter. Finally, Δt can be calculated to determine the real time difference between site A and B.

According to the theory [7~9], the power line in the system in this paper can be regarded as a uniform lossy transmission line. the general solution of uniform lossy transmission line of a single frequency electromagnetic wave in time domain form is:

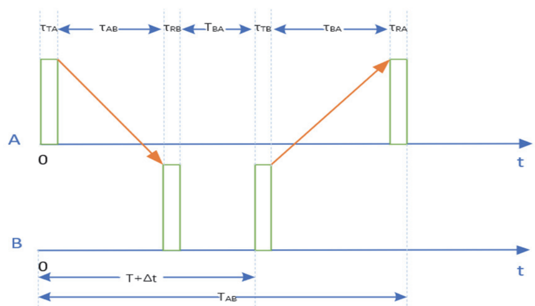

Fig. 2. Two-way time synchronization scheme

$$V(z,t) = V^{+}e^{-\alpha z}\cos(\omega t - \beta z + \theta^{+}) + V^{-}e^{\alpha z}\cos(\omega t + \beta z + \theta^{-}) \quad (5)$$

$$I(z,t) = \frac{V^+}{Z_C} e^{-\alpha z} \cos(\omega t - \beta z + \theta^+ - \theta_{Z_C}) - \frac{V^-}{Z_C} e^{\alpha z} \cos(\omega t + \beta z + \theta^- - \theta_{Z_C}) \quad (6)$$

Where α is the attenuation constant, β is the phase constant, and the phase velocity propagated along the transmission line is v=ω/β. The phase velocity of electromagnetic waves with different frequency components is different. Therefore, the pulse waveform at the receiving end is broadened and attenuated eventually.

The key assumption in our two-way time transfer scheme is Eq. (3). The forward and backward channel can be regarded as identical. However, there is a time interval T between two pulses. We built an experiment to test the time fluctuation to prove the correctness of the scheme.

The experimental device is shown in Fig.3. We used a common household two core power line which is 50m. We used a signal generator as a pulse source to generate a narrow pulse (width:100 ns amplitude: 5v), and used TIC and oscilloscope to record the interval.

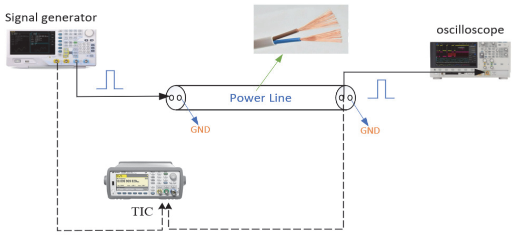

Fig.3. Schematic diagram of pulse transmission experiment.

To estimate the performance of our power line time transfer, we recorded a group of experimental data sustaining about 20 seconds using TIC and a group of waveform data. We analyzed experimental results according to these data from two different aspects: time fluctuation and time deviation. Fig. 4 shows the preliminary results of time fluctuations and time deviation of our power line one-way time transfer scheme.

From Fig.4 (a) we can form a qualitative cognition about timing fluctuation of our experiment. We calculated the time deviation from the data of Fig. 4(a), which is shown in Fig. 4(b) We can see that the time deviation of the transmission link is 20.9 ps at 0.1-ms averaging time and down to 1.2 ps at ~1 s averaging time. That proves our power line time transfer scheme is effective.

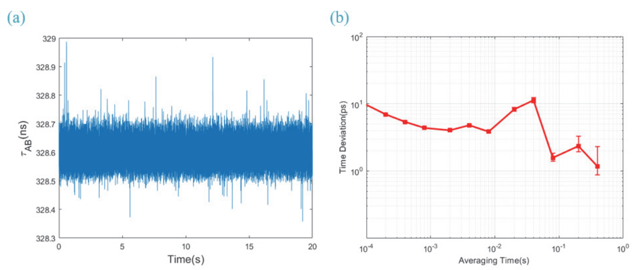

Fig.4. Time interval measurements. (a) Time fluctuation; (b) Time deviation

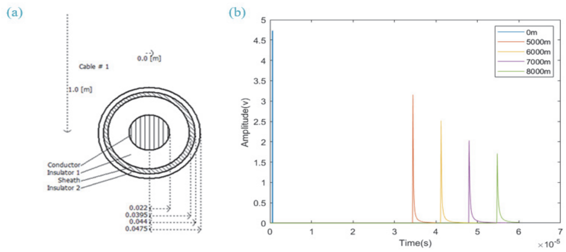

Fig.5. Pulse tranmission simulation. (a) Cable parameter; (b) Waveform

Last, we used PSCAD/EMTDC for simulation which is shown in Fig. 5. The simulation environment is similar to the actual environment which is shown in Fig.3. we can find that the pulse waveform was attenuated and broadened over thousands of meters transmission distances which is consistent with the theory.

III. Conclusions and Future Work

We have demonstrated a novel two-way time transfer scheme for power lines based on narrow electric pulses. In the time transfer experiment, the preliminary results show that the calculated time deviation over the 50-m power line transmission link is 20.9 ps at 0.1-ms averaging time and down to 1.2 ps at ~1 s averaging time, which means the this scheme has potential to be directly used in the high-precision time synchronization. We also have used PSCAD/EMTDC to simulate on over thousands of meters transmission distances. The results indicate that this scheme also has potential to synchronize time at the kilometer level or longer.

Due to material limitations, we have verified the one-way fluctuation effect of power line transmission only, but did not build a real two-way time transfer system. Besides, branch and coupling fluctuations in the power line network should also be considered. In the future work, we will design time code, consider the multi-branch case and longer distance, and build a real two-way time transfer system on the actual power line network.

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