A Time Stretch Supply Method to Reduce the Power Line Loss

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***Abstract*–For a cable based sensor network, power line loss restricts the cable length and cable copper diameter. In this paper, we propose a time stretch method to reduce the power line loss for a sensor network. A sensor network usually works in burst mode, when it works a high current consumption is required, while in idle state it need a little power energy. This method uses a super capacitor to collect and store the energy in idle time for each Sensor Unit (SU), so when it changes to active state the SU can use the local power to work, and would not absorb high current from the cable. Since the power line loss is proportional to the square of the current, the lower current can reduce the line loss significantly. The results shows that this method can reduce the line loss to less than 10%. This method can be used to extend the length of the sensor network cable, or make it possible to use much finer cable copper core.**

Index Terms—power line loss, charge efficiency, sensor network

I. INTRODUCTION

POWER line loss is the energy waste in a cable when electronic power is distributed from one place to another place. Power line loss leads to low efficiency for power distribution, especially when the distance is long. The problem of power line loss is usually studied in industry, such as the power transmission from a power station. For sensor networks, power line loss is also an important factor of the performance. Sensor networks can be used to monitor the environment for a building, a huge equipment or an experimental field. As shown in Fig.1, a cable based sensor network is used to monitor the lake. The sensor network is composed by one Center Control Unit (CCU) and plenty of Sensor Units (SU). All the SUs is connected with a cable to the CCU, the cable can be used to distributed the power from the CCU to the SUs and also can be used to collect the acquired data from the SUs to the CCU.

For the application in Fig.1, the sensor network is usually powered by battery, so it is important to reduce the power requirement of the system for a better lifetime. Reducing the power line loss is an efficient method for lower power consumption. The general ways to reduce the power line loss is to use higher transfer voltage or coarser cable. But high voltage makes it unsafe, and coarser cable makes it uneconomical. This paper shows a new method to reduce the power line loss for the sensor network.

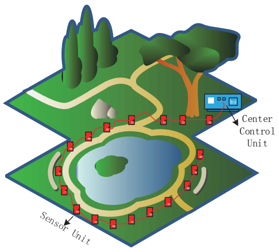

Figure. 1. An application of sensor network

II. POWER LINE LOSS ANALYSIS

The power distribution model of Fig.1 is shown in Fig.2. A 48V DC power module installed in CCU is used to provide power to SUs along with a power line. The SUs are assume to be a constant power unit, which means they can work under wide range voltage while the power requirement is almost the same.

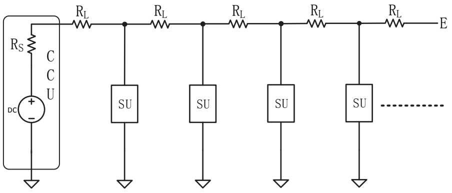

Figure. 2. Power line model of Fig.1. R_S is the internal resistance of the power of CCU. R_L is the power line resistance.

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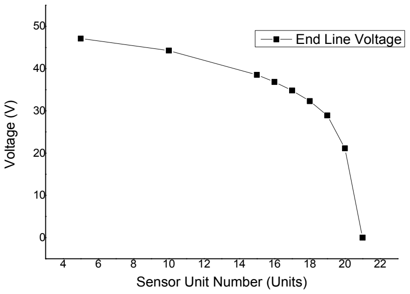


Figure. 3. Power line loss simulation. CCU DC voltage is 48V, R_S is zero, R_L is 4.21 Ω (the resistance of a 50 meter long AWG 24 wire) and the power consumption of each SU is 0.2W. The total output current of the CCU with 20 SU connected is 0.14A.

Fig.3 shows that the power line loss is much more seriously than we think. The power line voltage drops quickly when the SU number increases. When the SU number is 20, the voltage drops from 48V to 21.13V; when the SU number is 21, the voltage drops suddenly to zero. That means in Fig.1, it cannot support more than 20 SUs. And also it can be noticed that when 20 SUs are connected, the output power of CCU is 48V×0.14A=6.72W, the total power of SUs is 0.2W×20=4W. The power efficiency is as low as 4W/6.72W=59.5%.

The power loss follows ohm's law, $P=I^2\times R$. So, increasing the line voltage or increasing the diameter of the power cable can both work. But as mentioned above, these two method make the system dangerous or expensive.

III. STRETCH THE WORK TIME TO LOWER THE AVERAGE CURRENT

The ohm's law tells us the power loss is most related with the magnitude of current. A sensor network always works in burst mode, which means the SUs sometimes are triggered to collect the data when an event is received, and most of the time they keep in idle state. The power requirement of an SU in active state and in idle state varies greatly. And also the time in active state and in idle state varies greatly. A typical power consumption diagram is shown in Fig.4.

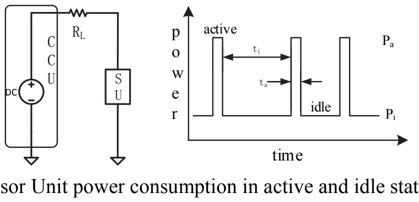


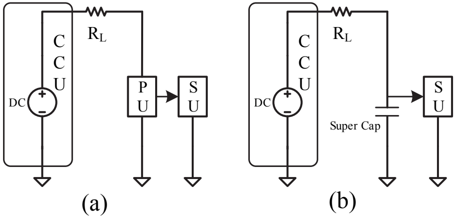
Figure. 4. Sensor Unit power consumption in active and idle state. P_a and t_a is the power requirement and time in active state; P_i and t_i is the power requirement and time in idle state.

For convenience, let's assume $P_a=\alpha P_i$ and $t_i=\alpha t_a$. So the power loss in one period is:

$$\mathrm{P}_{loss}=\left(\frac{P_a}{U_{ccu}}\right)^2 R_L t_a+\left(\frac{P_i}{U_{ccu}}\right)^2 R_L t_i=\left(\frac{\alpha P_i}{U_{ccu}}\right)^2 R_L \frac{t_i}{\alpha}+\left(\frac{P_i}{U_{ccu}}\right)^2 R_L t_i=(\alpha+1)\left(\frac{P_i}{U_{ccu}}\right)^2 R_L t_i$$

To reduce the average current, Fig.4 can be modified as shown in Fig.5 (a). A Power Unit (PU) is added to each SU. The PU can be charged the whole time of period, and when SU change to active state, the PU can be used to provide the high working current instead of CCU. Since the PU can be charged the whole period, the average current drops dramatically which leads to lesser power line loss. The power loss in this method can be calculated with:

$$P_{loss'}=\left(\frac{P_{average}}{U_{ccu}}\right)^2 R_l(t_a+t_i)=\left(\frac{\frac{P_a t_a+P_i t_i}{t_a+t_i}}{U_{ccu}}\right)^2 R_l(t_a+t_i)=\frac{4\alpha}{\alpha+1}\left(\frac{P_i}{U_{ccu}}\right)^2 R_l t_i$$



(a) (b)

Figure. 5. Time stretch to reduce the average power supply current.

It is obviously that $(\alpha+1)\geq\frac{4\alpha}{\alpha+1}$, so $P_{loss}\geq P_{loss'}$. $\frac{P_{loss'}}{P_{loss}}=\frac{4\alpha}{(\alpha+1)^2}$, the relationship of the proportion versus α is shown in Fig.6. When α increases, the power line loss reduces to less than 10% of the original level.

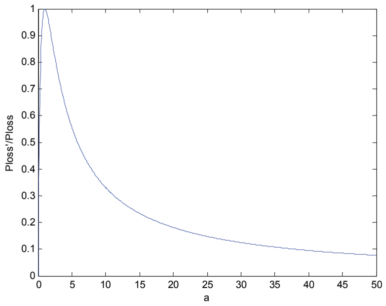


Figure. 6. The relationship between reduced power loss proportion versus α.

IV. DISCUSSION

The PU can be realized by super capacitor as shown in Fig.5 (b). A super capacitors have more than 99% energy efficiency, while its behavior is like a normal capacitor. When a capacitor is charged to U_c, the total energy it can hold is $0.5CU_c^2$. Reference to Fig.5 (b), when the capacitor is charged to U_c, the output power from CCU is:

$$\mathrm{P}_{ccu}=\int_0^{\infty} U_c i(t)dt=U_c\int_0^{\infty} C\frac{dV_c}{dt}dt=CU_c\int_0^{U_c} dV_c=CU_c^2$$

So only 50% of the power is charged into the capacitor, 50% of the power is wasted in R_l. The efficiency is even worse than the discussion in Section II.

There are many papers to discuss how to improve the charge efficiency for the RC circuit in Fig.5 (b). To change U_{ccu} from a constant voltage type to a linear increasing type (like in Fig.7) is a simple and effective method to increase the charge efficiency.

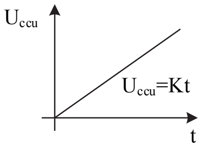


Figure. 7. Linear increasing source voltage

We define $U_{ccu} = Kt, \tau = R_l C$. So when t>0,

$$U_c = K\left(t - \tau + \tau e^{-t/\tau}\right)$$

$$i = C\frac{dU_c}{dt} = KC\left(1 - e^{-t/\tau}\right) \qquad \text{(Equ.1)}$$

The energy stored in the capacitor is:

$$\omega_c = 0.5CU_c^2 = 0.5CK^2\left(t - \tau + \tau e^{-t/\tau}\right)^2$$

The total output energy from the CCU is:

$$\omega_{ccu} = \int_0^t U_{ccu} i dt = K^2C\int_0^t t\,(1 - e^{-t/\tau})dt = K^2C(0.5t^2 + \tau(t+\tau)e^{-t/\tau} - \tau^2)$$

So the charge efficiency is:

$$\varepsilon = \frac{\omega_c}{\omega_{ccu}} = \frac{0.5\left(t - \tau + \tau e^{-t/\tau}\right)^2}{0.5t^2 + \tau(t+\tau)e^{-t/\tau} - \tau^2}$$

Let's make an assumption that $t = m\tau$ then:

$$\varepsilon = \frac{0.5\tau^2(m-1+e^{-m})^2}{0.5(m\tau)^2+\tau^2(m+1)e^{-m}-\tau^2} = \frac{0.5(m-1+e^{-m})^2}{0.5m^2+(m+1)e^{-m}-1} \qquad \text{(Equ.2)}$$

From the above equation we can see that the charge efficiency ε has nothing to do with K and τ. In Fig.7, it can be seen that when charge time is more than 4τ (m>4), the charge efficiency is high enough for use.

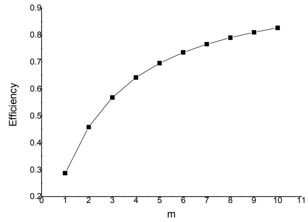


Figure. 7. Charge efficiency versus charge time (m)

The reason why when m is small the efficiency is low, is because that when m is small the voltage of the capacitor is low

V. CONCLUSION

In this paper, a time stretch method to reduce the power line loss is discussed. It uses the burst work mode characteristic of a sensor network to reduce the peak current when the SU works. Not only the work time, but he idle time is utilized to collect and store energy from cable to local super capacitor. This is called time stretch. The result shows when the ratio of idle time and active time is big enough, the power line loss can be reduced to less than 10%.

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