EFFECTS OF PULSE NOISE PROPAGATION IN ELECTRICAL SYSTEM

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Abstract: Switching processes cause pulse voltage in electrical system. Travelling wave technique can be used for calculation of pulses. Capacitor switching generates pulses with amplitude up to double value of nominal amplitude Um. Overvoltage is less then 3Um. Reflections of pulses in cables can give pulse amplitude up to 4Um on far load. But overvoltage can be more than 7Um on this load. The level of pulse voltage can be higher than immunity level of equipment. It is important to take into account propagation effects for overvoltage protection of electronic apparatus.

Key words: Pulse noise, overvoltage, propagation, cable, electrical system.

1. Introduction

Pulse noise in electrical system is dangerous for electronic equipment. Short time voltage and current change induce voltage inside equipment. It can lead to its malfunction. Transient overvoltage can damage semiconductor devices in power secondary supply units. Immunity standards set requirements for surge testing of equipment. Test level is based on average environment. But the level of pulse voltage can be higher in some cases.

2. Calculation model

Shipboard electrical system has radial structure with generators and loads connected through main and local switchboards (fig.1).

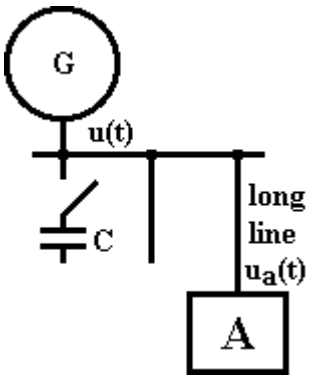

Fig. 1. Electrical circuit of system part.

Length of cables can be up to some hundreds meters. Minimum rise time of switching transients is less than 10 ns. Propagation delay in cables is more than rise time. It means that calculation model has to take into account propagation effects. Full equivalent circuit includes many long lines and loads with wave parameters. But this circuit is not convenient for calculation. Simplified circuit gives possibility to calculate microsecond transients u(t) at switchboard when some load is switched [1, 2]. The circuit (fig. 2) can be used for estimation of pulse voltage, generated by switching of capacitor C. Parameters R, Cs, L, Rs simulate wave effects of the whole electrical system. Generators, cables between generators and main switchboard determine inductance L and resistance Rs. More powerful generators have lower L and Rs parameters. Inductance L is about 10^0 – 10^1 uH and resistance Rs is less than 100 mOhm. Wave resistances of cables, loads, generators determines parameter R. Resistance R is lower for higher number of cables, connected to main switchboard. Capacitance Cs is used for calculation of low capacitance switching. Resistance R is about 10^0 – 10^1 Ohm and Cs is less than 10 nF. E is sine voltage source with Um amplitude.

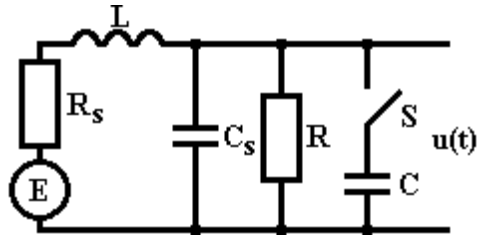

Fig. 2. Equivalent circuit for pulse voltage calculation in electrical mains.

Voltage u(t) caused by switching of charged capacitor is changing in accordance with the following equation:

$$u(t) = E - (E - Uc)\cdot\frac{C}{C+Cs}\cdot\exp(-\frac{t}{\tau})\times \\ \times(\cos(\omega\cdot t) + \frac{1}{2\omega}\cdot(\frac{Rs}{L} - \frac{1}{RC})\cdot\sin(\omega\cdot t)) \quad (1)$$

E is the moment voltage in mains just before the switching, Uc is the voltage on capacitor before the switching.

The graph of voltage change in time domain (fig.3) is calculated on the base of equation (1) for L=10uH, C=1 uF, E=Um, Uc=-Um, where Um is the nominal amplitude of sine voltage in electrical system.

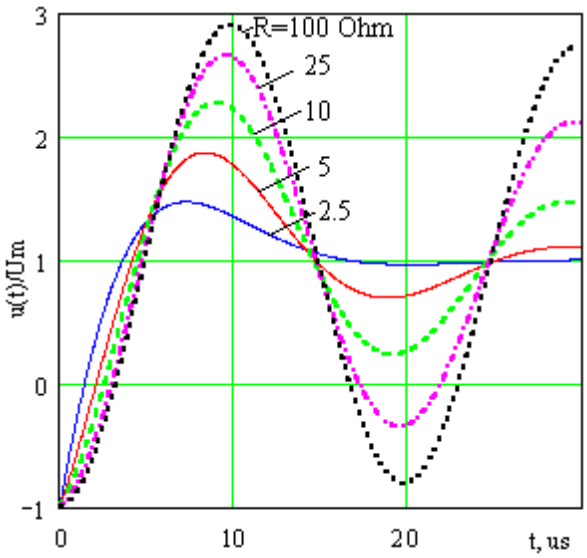

Fig. 3. Voltage variation in microsecond scale due to switching on of 1 uF charged capacitor.

3. Pulse amplitude and overvoltage

Amplitude of pulse voltage Up (maximum difference between u(t) and E) is the following:

$$Up = |E - Uc| \cdot \frac{C}{Cs + C} \qquad (2)$$

The value of E and Uc are in the following limits: -Um<E<Um; -Um<Uc<Um.

Maximum pulse amplitude is equal to 2Um, when E=-Uc=Um and C>>Cs.

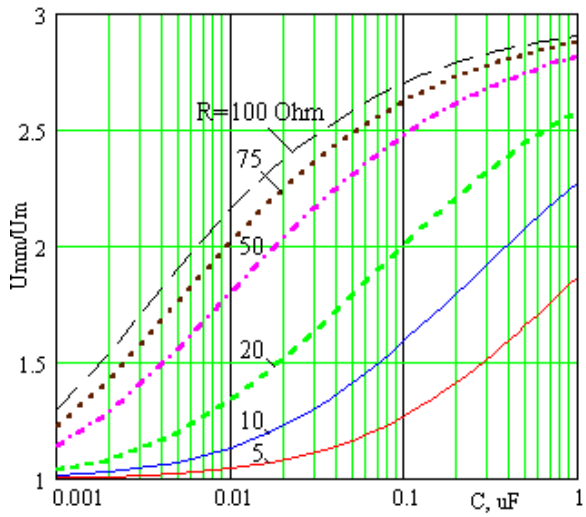

Fig. 4. Overvoltage due to switching on of charged capacitor C for different capacitance and R parameter.

Transients can give overvoltage up to 3 Um. The value of overvoltage depends on capacitance C and R parameters (fig. 4, 5).

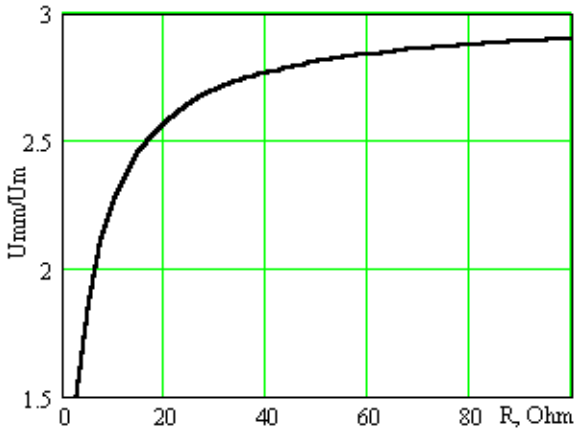

Fig. 5. Overvoltage due to switching on of 1 uF charged capacitor for different R parameter.

4. Propagation effects

Pulse voltage on far load $u_a(t)$ are calculated with travelling wave technique (fig. 6, 7).

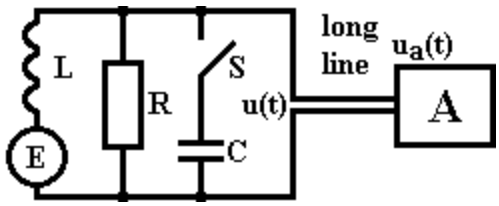

Fig. 6. Equivalent circuit for pulse voltage calculation on far load (apparatus).

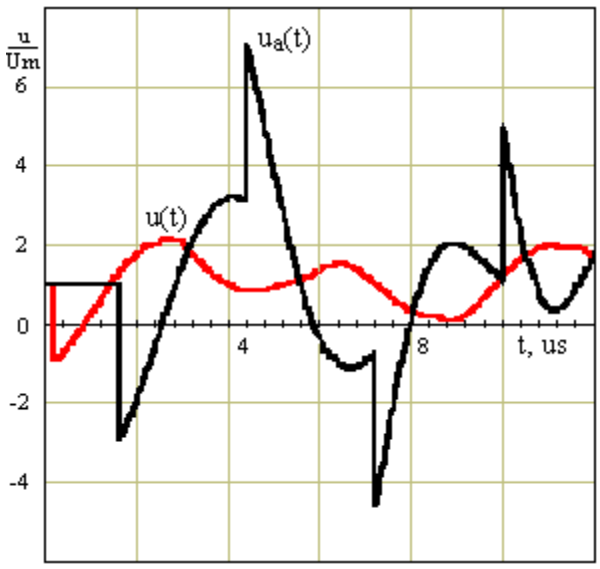

Fig. 7. Voltage variation in electrical mains u(t) and on high resistance load $u_a(t)$ for 280 m cable due to swiching on of charged 0.08 uF capacitor.

The first step in $u_a(t)$ graph corresponds to the coming of the first pulse voltage wave to high resistance load. The second plus step means the coming of the second wave after reflection from the load and the capacitor. The next wave has the same polarity as the next semicycle of previous wave if double propagation time in cable is about half of oscillation period (fig. 6). The addition of the first and the second waves gives overvoltage about 7Um. The voltage graph in fig. 8 is calculated for shorter propagation time. The voltage achieves the maximum for many waves composition.

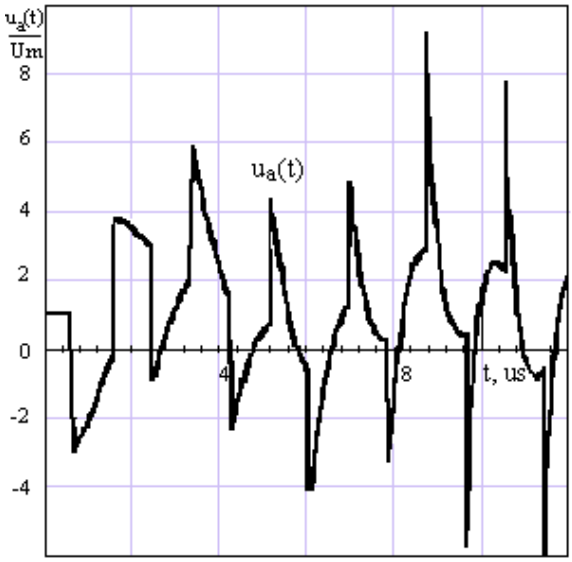

Fig. 8. Voltage variation $u_a(t)$ for 90 m cable due to swiching on of charged 0.08 uF capacitor.

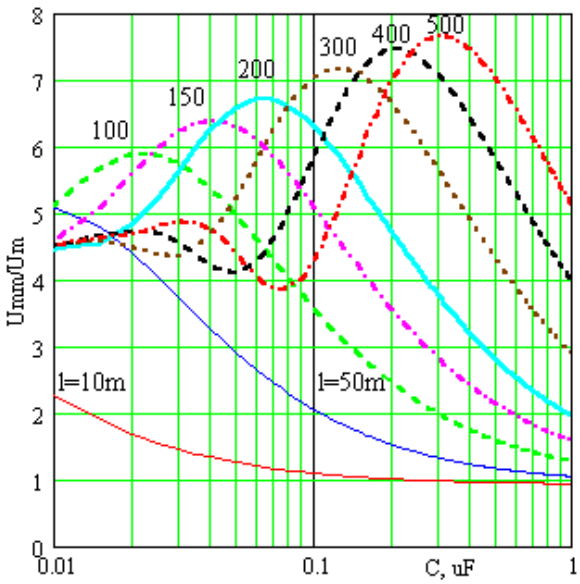

Fig. 9. Second wave overvoltage on high resistance load for different length of cable and capacitance of charged switching capacitor.

5. Maximum voltage on electronic apparatus

The step of voltage on far load (apparatus) can be 4Um if load resistance Ra is much more than wave resistance Z of the cable (long line).

Overvoltage depends on length of cable l and capacitance C of switching capacitance (fig. 9, 10). The graphs are calculated for L=10 uH, R=50 Ohm, Z=50 Ohm.

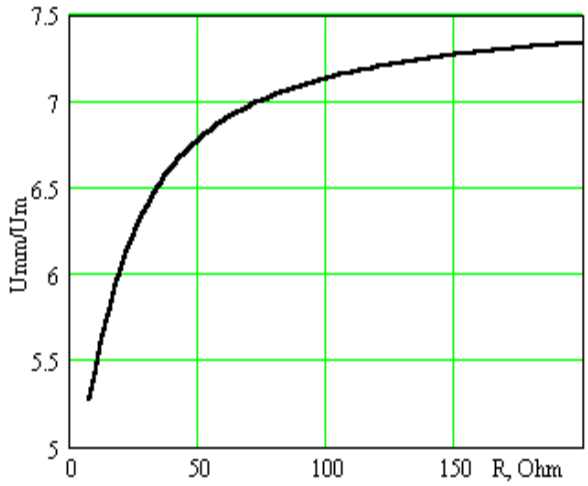

Fig. 10. Second wave overvoltage on high resistance load for 0.08 uF charged switching capacitor, 280 m length of cable and different R parameter.

Theoretical maximum of overvoltage for the second coming of wave is 9Um. Addition of many waves can give even higher overvoltage (fig. 8). But every reflection and propagation in cable give attenuation of every next wave. Practical maximum is less than 7.5Um.

6. Conclusion

Amplitude of pulse voltage can be up to 4Um on far load. Multiple reflections of pulses in cables can give overvoltage more than 7Um on this load. The level of pulse voltage and overvoltage can be higher than immunity level of equipment. It is important to take into account propagation effects for overvoltage protection of electronic apparatus.

References

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[2] A.A. Worshevsky, “Digital simulation of pulse noise in electrical system in time domain”, in Proceedings of International Symposium on EMC, Beijing, 1992, p.140-142.