The Rated Voltage Determination of DC Building Power Supply System Considering Human Beings Safety

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Abstract. Generally two-level voltages are adopted for DC building power supply system. From the point of view of human beings safety, only the lower level voltage which may be contacted barehanded is discussed in this paper based on the related safety thresholds of human beings current effect. For several voltage levels below 100V recommended by IEC, the body current and current density of human electric shock under device normal work condition, as well as effect of unidirectional single impulse currents of short durations are calculated and analyzed respectively. Finally, DC 60V is recommended as the lower level rating voltage through the comprehensive consideration of technical condition and cost of safety criteria.

1. Introduction
With the development of power electronics technology, control technology and DC-load products [1-3], the DC supply has regained advantages and extensively applied in many fields such as communication system, urban rail system, ships and aircraft [4-6], which makes it possible to apply DC supply technology in general fields, especially intelligent building. Considering the extensive application of electronic interfaces such as rectifier or converter in many electronic devices in buildings for power supply, theoretically, using DC directly can skip the step of current conversion and is more energy-efficient. Therefore, DC supply is now being developed as a direction of intelligent building power supply.

Similar to AC supply, DC supply should also be coordinated with multilevel distribution network by making power system planning and design appropriately; therefore it is necessary to determine the voltage level in DC supply for buildings [7]. Generally, there are two voltage levels in DC supply system for buildings [8], including the higher voltage level (for devices with high-power load) and the lower voltage level (for devices with low-power level load used for IT, communications and personal use). Most of the current studies focus on the higher voltage level, the literature [9] in references proposed that 400 VDC is quite efficient as the voltage level for the power supply system of building data center; and the literature [10] introduced that 380 VDC, adopted by CEPS for building power supply, performs well in real life. Few literatures have mentioned about the selection of lower voltage level for building power supply, therefore, it is urgent to carry out the relevant studies [11].

Since the lower voltage level is designed for the devices used frequently by people in buildings, safety is the critical determinant in defining the specific voltage value. In the lower voltage supply system, the higher the voltage is, the higher the cost-effectiveness is, but meanwhile, the safety risk
will be also higher. Therefore, the voltage value for lower voltage level is expected to be safe without using any protective devices, technologically feasible and economically reasonable.

The thresholds relative to the effects of DC on human body has been obtained from the basic studies at home and abroad. Based on these thresholds as criteria, this paper technologically conducted the comprehensive analysis, calculation and safety evaluation on several voltage values (≤ 100V) recommended by IEC, including 1) when people contact the electrical conductor at normal operation, the magnitude of current flowing through human body; 2) when people contact the electrical conductor at normal operation, the density of current flowing through human body; 3) the possible effects on human body when people connect the power port with capacitor discharge just after the device disconnected from the power. Considering the cost-effectiveness as the major factor, in combination with technological and other economic factors, this paper proposed an appropriate voltage level. The analysis methods and conclusion utilized in this paper provided references for defining the voltage level for the DC supply system of buildings in our country.

2. Effects of DC on human body

2.1. Basic concepts

Relevant studies indicated that it is the current rather than the voltage should be blamed for the injuries on human body caused by the electric shock accidents. The thresholds relative to the effects of DC on human body include: perception thresholds, the minimal value of the current that can cause any feeling; the reaction thresholds, the minimal value of the current that can cause unconscious muscle contraction; shake-off threshold, the minimal value of the current that people can shake off the electrical conductor when feeling current flows through his/her body; threshold of ventricular fibrillation, the minimal value of the current that can cause ventricular fibrillation; in addition, human skin may turn red, burned or even carbonized when current density exceeds certain value, see Figure 1. Compared to men, the perception threshold and shake-off threshold of women and children is lower. When current exceeds certain amps, the electricity field intensity is very high, or in the case of other effects such as electroporation. The effects of low voltage DC on human body will not involve the effects of high current and high electricity field intensity.

Different with AC, in terms of perception threshold, people can only feel the current when connecting or disconnecting with the electricity conductor, and when the current flows through his/her body, they will not have such feeling. The perception threshold of DC measured in studies is about 2mA \(^{[17]}\). Different with AC, there is no definite shake-off threshold for DC, which can only cause muscle pain and spasm-like contraction when connecting or disconnecting with the electricity conductor. The ratio of root - mean - square (r.m.s) values between DC and the equivalence AC with the same probability in inducing ventricular fibrillation is 3.75. In terms of the DC application, the electric shock accidents caused less frequently by DC than AC, because it is easier to shake off from the DC conductor, and when the duration of electric shock is higher than cardiac cycle (about 800ms), the ventricular fibrillation threshold of DC is far higher than that of AC. In the case of safety, DC supply for buildings is superior to AC.

Current may flows through human body via different paths. The estimated relative risk of ventricular fibrillation is represented by heart current factor (F) and calculated by the formula as below:

\[
F = \frac{I_{ref}}{I_s}
\]  

(1)

Of which, \(I_{ref}\) refers to the body current from left hand to feet, \(I_s\) refers to the body current from different paths, see the F values from different paths in Table 1.

The possibility of hand to hand current (225mA) causes the same ventricular fibrillation as left hand to fee current (90mA). Table 1 shows that under the same current, the electric shock caused by the path from chest to hand is the most dangerous but unlikely to happen, while by the path from left
hand to feet is less dangerous but more likely to happen. Therefore, it should focus on the path from left hand to feet.

![Figure 1](image)

**Fig. 1** Dependence of the alteration of human skin condition on current density and current duration

**Tab. 1** The heart current factor for different current paths

| Current paths                                      | Heart current factor, F |
|----------------------------------------------------|-------------------------|
| From left hand to left foot, right foot or feet     | 1,0                     |
| From left hand to right hand                       | 0,4                     |
| From right hand to left foot, right foot or feet    | 0,8                     |
| From back to right hand                            | 0,3                     |
| From chest to right hand                           | 1,3                     |
| From chest to left hand                            | 1,5                     |
| From buttoc to left hand, right hand or hands       | 0,7                     |
| From left foot to right foot                       | 0,04                    |

Note: Heart current factor is only regarded as the rough estimation for the relative risk of ventricular fibrillation caused by various current paths.

2.2. Factors influencing human body

In the case of electric shock, when the time function of shock is definite, the body impedance is the determinant of current. The factors influencing body impedance (for DC, i.e., the resistance) include: environment conditions, contact voltage, power frequency, parts and area of electric shock, etc., all of which vary with each individual. The environment conditions herein include dry environment, water-wet environment and salt-wet environment. The normal activity areas in buildings belong to dry environment. In the case that other conditions are identical, body impedance decreases with the increase of contact voltage, see Figure 2. In the case that other conditions are identical, body impedance decreases with the increase of frequency, and there is no discussion about frequency in DC. In the event of electric shock, different parts through which the current flows may have different impedance. If the impedance from one hand to one foot is 100%, then it can calculated roughly according to the body impedance figure IEC-60749-1[13]: the impedance from one hand to the other hand is about 95% and from hands to feet is about 50%. See Figure 2 for the influence tendency of contact area on body impedance, of which, curve 1 to 5 represents different contact parts, and see Table 2 for the size of contact area, different areas represent several typical situations of electric shock. It is known that the expected impedance value of children is higher than adults, but the order of
magnitude is the same. The impedance which limits the peak current during the moment when people contact voltage (about tens of milliseconds) is the initial resistance, at this moment, the capacitor of human body is not charged; therefore the resistance of skin doesn’t help. However, the initial impedance is almost the same as the resistance of internal body, therefore the initial resistance is lower than the total body resistance, and equivalent to the resistance when skin is completely broken.

**Tab. 2** The explanation of Fig.2

| Curve No. | Effective contact area mm² | Mimic typical situations                          |
|-----------|-----------------------------|--------------------------------------------------|
| 1         | About 8,200                 | Large contact area                               |
| 2         | About 1,250                 | Ring-shaped conductor packed appropriately with insulation tape |
| 3         | 100                         | Rectangle conductor packed appropriately with insulation tape |
| 4         | 10                          | Electrode on insulation cylinder                 |
| 5         | 1                           | Smaller electrode on insulation cylinder          |

![Fig.2](image)

**Fig.2** Dependence of the body resistance on the contact surface area

3. **Calculation and safety evaluation on effects of current on human body under different voltage**

3.1. *Analysis on values of current flowing through human body*

The current values determine the risk level, so it is required to calculate the corresponding current value when judging whether a specific voltage value is safe for human body. When selecting the voltage level for power supply system of buildings in China, it is preferred to apply the voltage levels recommended by IEC. The voltage levels for current below 100 V recommended by IEC-60038 include 6V, 12V, 24V, 36V, 48V, 60V, 72V and 96V [17]. The higher the voltage is, the lower the cable loss is. When delivering current with the same power, the thinner the cable is, the higher the cost-effectiveness is. However, the higher the voltage is, the higher the risk is. Therefore, we expect to
find a voltage which can ensure human safety and meanwhile is technologically feasible and economically reasonable.

Figure 3 shows the relationship among the physiological effects of DC (current path is vertically upward, i.e., from feet to left hand) on human body, current value and current duration. See Table 3 for the meaning of each district in this figure, from which it is seen that, if located at the left side of curve b, there is generally no harmful electrical physiological effect.

Fig.3 Conventional time/current zones of effects DC current on persons for a longitudinal upward current path

| District name | District scope | Physiological effect |
|---------------|---------------|----------------------|
| DC-1          | Line a at 2mA  | When people connect or disconnect conductor, or fast-changing current flows through his/her body, people may feel slightly tingling. |
| DC-2          | 2mA to fold line b | Actually, when people connect or disconnect conductor, or fast-changing current flows through his/her body, people may suffer unconscious muscle contraction, but generally no harmful electrical physiological effect. |
| DC-3          | Fold line b to curve c1 | Generally, it is not expected to cause any organ injury. With the increase of current magnitude and time, it is likely to cause unconscious cardiac muscle reaction and reversible pulse conduction disorder |
| DC-4          | Above curve c1 | It is possible to cause pathophysiological effects, such as cardiac arrest, respiratory arrest, and burns or other destruction of cells. The probability of ventricular fibrillation increases with the magnitude and duration of the current. |
| DC-4.1        | c1–c2          | The probability of ventricular fibrillation increases to about 5%. |
| DC-4.2        | c2–c3          | The probability of ventricular fibrillation increases to about 50%. |
| DC-4.3        | Above curve c3 | The probability of ventricular fibrillation increases to above 50%. |

GB/T13870.1 indicates that in dry conditions, the current path of large contact surface is from hand to hand, the voltage is 25V, 50V and 75V, and the body resistance value is 100V, see Table 4. Considering the difference of body resistance between the current paths form left hand to feet and from hand to hand, the former is about 75%±95%±0.79 times of the latter, by this conversion, the total body resistance of the former can be calculated., see the part of conversion values in Table 5. By fitting interpolation, the corresponding resistance of DC values 24V, 36V, 48V, 60V and 72V can be
calculated, see Table 5. When calculating the DC values of the current path from left hand to feet (at 24V, 36V, 48V, 60V and 72V), if the DC value is located at the left side of DC-2 in Figure 3, then it is safe for human; if the current shock duration is longer than 2 seconds (in the most demanding condition for current limits), then the corresponding limit value is 25mA, therefore, if the calculated current value is \( \leq 25\text{mA} \), then it can be judged as “very safe”, see Table 6.

**Tab.4**  Body resistance for a direct current path hand to hand, for large contact surface area in dry conditions

| Contact voltage (V) | Total body current if no more than three percentages (%) as below, will be less than the following values (mA) |
|---------------------|------------------------------------------------------------------------------------------------|
|                     | 5% of the measured object | 5% of the measured object | 5% of the measured object |
| 25                  | 2100                       | 3875                       | 7275                       |
| 50                  | 1600                       | 2900                       | 5325                       |
| 75                  | 1275                       | 2275                       | 4100                       |
| 100                 | 1100                       | 1900                       | 3350                       |

Note: The data should be rounded to the integral multiple of 25Ω.

**Tab.5**  Body resistance for a direct current path of both hands to both feet, for large contact surface area in dry conditions

| Acquisition method | Contact voltage (V) | Total body resistance RT (&) no more than three percentages (%) as below |
|--------------------|---------------------|------------------------------------------------------------------------|
| Conversion values  |                      | 5% of the measured object | 50% of the measured object | 95% of the measured object |
| 25                 | 1675                | 3075                       | 5750                       |
| 50                 | 1275                | 2300                       | 4225                       |
| 75                 | 1000                | 1800                       | 3250                       |
| 100                | 875                 | 1500                       | 2650                       |
| Fitting interpolation calculation value | 24 | 1675 | 3075 | 5750 |
|                    | 36                  | 1475                       | 2700                       | 5050                       |
|                    | 48                  | 1350                       | 2475                       | 4550                       |
|                    | 60                  | 1225                       | 2225                       | 4075                       |
|                    | 72                  | 1100                       | 2975                       | 3575                       |

Note: The data should be rounded to the integral multiple of 25Ω.

**Tab.6**  The current for a direct current path of left hand to both feet

| Contact voltage (V) | Total body current if no more than three percentages (%) as below, will be less than the following values (mA) | Safety evaluation |
|--------------------|------------------------------------------------------------------------------------------------|-------------------|
|                    | 5% of the measured object | 50% of the measured object | 95% of the measured object | Whether less than 25mA |
| 24                 | 15                       | 8                           | 4                           | Very safe               |
| 36                 | 24                       | 13                          | 7                           | Very safe               |
| 48                 | 36                       | 19                          | 11                          | Safe for 50% people     |
| 60                 | 49                       | 27                          | 15                          | 50% people are likely to enter DC3 |
| 72                 | 65                       | 24                          | 20                          | Most people are likely to enter DC3 |

Note: Current values are rounded to integers.
Since the DC is easier to shake off, if the current shock duration is 1 second, then the corresponding comparative limit value is 50mA (see Figure 3), then current values $\leq 60V$ are very safe for human body.

Considering the body resistance from hands to feet is only $50%/75%=0.67$ times of the body resistance from left hand to feet, if people get an electric shock in the former way, the current value is higher, see Table 7 for the calculated values. Similarly, if the current shock duration is 1 second, then current values $\leq 48V$ are very safe for human body (since 53MA is close to 50mA, therefore, 48V is a threshold).

**Tab.7 The current for a direct current path of both hands to both feet**

| Contact voltage (V) | Total body current if no more than three percentages (%) as below, will be less than the following values (mA) | Safety evaluation |
|----------------------|-------------------------------------------------------------------------------------------------|-------------------|
|                      | 5% of the measured object | 50% of the measured object | 95% of the measured object | Whether less than 25mA |
| 24                   | 22 | 12 | 6 | Very safe |
| 36                   | 37 | 20 | 11 | Safe for most groups |
| 48                   | 53 | 29 | 16 | 50% people are likely to enter DC3 |
| 60                   | 73 | 40 | 22 | Most people are likely to enter DC3 |
| 72                   | 98 | 36 | 30 | Most people are likely to enter DC3 |

Note: Current values are rounded to integers.

The above values are calculated when only considering human body resistance, if also taking the resistance of shoes into account, and then these values are much lower than the real amount. Hand contact with different electric potential is one of the most common electric shocks. The IEC-TR-60479-5, the technical report of IEC, indicates that the threshold that may not cause slight injury on human body by long-time holding different electric potential via current path from hand to hand is also 25mA$^{[14]}$, see Table 8 for the current values of current path from hand to hand under different voltage, and by calculating these values, we can make corresponding evaluation on safety.

**Tab.8 The current for a direct current path of hand to hand**

| Contact voltage (V) | Total body current if no more than three percentages (%) as below, will be less than the following values (mA) | Safety evaluation |
|----------------------|-------------------------------------------------------------------------------------------------|-------------------|
|                      | 5% of the measured object | 50% of the measured object | 95% of the measured object | Whether less than 25mA |
| 24                   | 22 | 13 | 7 | Very safe |
| 36                   | 17 | 9  | 5 | Very safe |
| 48                   | 30 | 17 | 9 | Safe for most groups |
| 60                   | 47 | 26 | 15 | Safe for 50% people |
| 72                   | 65 | 38 | 21 | Most people are likely to enter DC3 |

The technical report IEC-TR-60479-5 also indicates that the long-time charged threshold of ventricular fibrillation for current path from hand to hand is 350mA, while the long-time charged threshold of ventricular fibrillation for current path from hand to foot is 140mA (when foot is the positive electrode and hand is the negative electrode with upward current) or 280mA (when hand is
the positive electrode and foot is the negative electrode with downward current); the current values calculated in the aforementioned situations are not higher than these thresholds, therefore, it is concluded that in the DC supply system with voltage \( \leq 72\text{V} \), in the event of electric shock, it is impossible to cause such serious injury as ventricular fibrillation.

The above values are calculated on the basis of large contact area in the case of electric shock, but if such area is small, then body resistance will increase rapidly, see Figure 2, the current flows through human body will decrease, and thus reducing the possibility of serious injury caused by body current.

3.2. Analysis of surface current density of human body

According to the parameters in Table 2 and Figure 2, the current density of skin at different contact area and DC (36V, 48V, 60V and 72V) can be calculated, see the results in Table 9.

| Contact area \((\text{mm}^2)\) | Voltage (V) | Current density |
|-----------------------------|-------------|----------------|
|                            | 36          | 1              |
|                            | 1250        | 1              |
|                            | 100         | 2              |
|                            | 10          | 2              |
|                            | 1           | 7              |
|                            | 48          | 2              |
|                            | 1           | 2              |
|                            | 2           | 10             |
|                            | 60          | 2              |
|                            | 1           | 3              |
|                            | 3           | 12             |
|                            | 10          | 4              |
|                            | 1           | 14             |

Note: the current values are rounded to integers.

Compared to Figure 1, if the duration of electric shock is shorter than 3~4 seconds, then all of the above voltage values may not cause injury on skin; if the duration of electric shock is much longer, for example, longer than 10~20 seconds, and the contact area is 1\(\text{mm}^2\), then voltage of 36V may make skin turn red, but as long as the contact area is larger than 10 \(\text{mm}^2\), voltages \( \leq 72\text{V} \) is unlikely to cause injury on skin.

3.3. Analysis of short-time unidirectional current pulse effects

When the DC supply is in parallel with large capacitance and very short discharge time, it should also consider the short-time unidirectional current pulse effects, this refers to the specific situation that the pulse duration is 0.1ms~10ms\([15,16]\), the analysis for the situation that the pulse duration is longer than 10ms is expounded in section 2.1, and there is no definite study results about the situation that the pulse duration is shorter than 0.1ms, but it is definite that the shorter the pulse duration is, the higher the threshold which may cause injury on human body is higher.

Figure 4 shows the probability of ventricular fibrillation via the current path from left hand to feet. The probability of ventricular fibrillation in district below C1 (at left side) is 0; such probability between C1 and C2 is 5%; between C2 and C3 is 50%; and above C2 (at the right side) is > 50%. All current values can be only located at the left side of C1 due to the existence of body resistance, therefore, it is unlikely to cause ventricular fibrillation for capacitor discharge.

Rapid capacitor discharge caused by body contact may lead to short-time unidirectional current pulse effects, including the effect of perception and pain except for the above mentioned ventricular fibrillation. The pain threshold is associated with capacitance and charge voltage, and can be expressed by the discharge time integral of the square of electric current (known as specific fibrillating energy); its approximate values can be calculated by multiplying 3 times of time constant with discharge peak current. In the case of electric shock via current path from hand to foot with large contact area, the pain threshold is \( 50\times10^{-6}~\text{to}~100\times10^{-6}\text{A}^2\text{s} \).
If people hold the electrode which is just unplugged, and there is capacitance discharge current flows through human body, then the initial body resistance $R_0=750 \Omega$ (50% of the subject’s body resistance), then approximate DC values at 24V, 36V, 48V, 60V and 72V can be calculated; if the resistance of discharge circuit is very small, calculated values of the possibility of feeling painful when contacting the power discharge port is shown in Table 10. Such calculated values may lower than the real amount because other resistances of discharge circuit are not considered. The results show that when contacting the discharge current of DC power port, if the voltage of DC power is lower than 60V, it is unlikely to cause the sense of pain.

| DC voltage (V) | Peak current (A) | $I^2*0.01s (A^2S)$ | Pain     |
|---------------|------------------|-------------------|---------|
| 24            | 0.032            | 10                | No      |
| 36            | 0.048            | 23                | No      |
| 48            | 0.064            | 40                | No      |
| 60            | 0.08             | 60                | Not possible |
| 72            | 0.096            | 92                | Possible|

4. Influence of safety cost on the selection of voltage

In order to ensure the electrical safety of devices, namely, the devices may not cause electric shock at normal operation and single failure (incl. other failures caused by it), various safety standards on voltage and electricity at home and abroad stipulate relevant requirements on electrical insulation or protective isolation [18-23], which on the one hand are of safety concerns, but on the other hand, it will increase the device cost and induce trade barriers with the corresponding technical means. Therefore, when defining the voltage level of buildings in China, we should consider the economic factor by reducing the manufacturing cost as much as possible, or at least do not need to pay additional cost.

The general idea on electrical insulation is identical in different industries and different countries, but the specific requirements are different. Several representative typical requirements will be presented here. The national standard GB-4943[18] modifies and adopts the safety requirements in EC-60950[19] and is regarded as the safety standards of information appliance, it stipulates: if operation voltage $U \leq 42.2V$ peak value or 60V DC value, it only needs to conduct the functional insulation trail at 500V for testing the dielectric strength; if operation voltage $U$ exceeds this range, it needs to conduct the functional insulation trail at least at 1000V, in addition, it may also require to conduct
basic insulation, additional insulation or reinforced insulation according to different product design schemes. Generally, DC 60V is an important boundary value in information appliances.

The national standard GB-8898\(^{[20]}\) modifies and adopts the safety requirements in IEC-60065\(^{[21]}\) and is regarded as the safety standards of audio, video or similar electronic devices, it stipulates: if power voltage \(U\) exceeds 35V peak value or 60V DC value, it is deemed as dangerous charged voltage, therefore the number of cycle operation for manually operated mechanical switch with DC exceeding 24V is limited. Requirements on minimum electric clearance and creep distance are shown in Table 11. Generally, DC 35V and 60V are two important boundary values in audio and video devices.

**Tab.11 Requirements for the minimum clearance and creepage distance in GB-8898**

| Work voltage/V ≤ voltage (of AC or DC) | Minimal electric clearance and creep distance/mm |
|--------------------------------------|-----------------------------------------------|
| 35                                   | 0.2                                           |
| 45                                   | 0.2                                           |
| 56                                   | 0.3                                           |
| 70                                   | 0.3                                           |
| 90                                   | 0.4                                           |

The linear interpolation is permitted to be used between two adjacent points, and the calculated interval value should be rounded to one place after the decimal point.

The British safety standard, BS EN 60215 *Safety Requirements on Radio Frequency Transmission Equipment*, proposes that if peak voltage value \(≤ 72V\), the voltage is within the scope of electrical safety \(^{[22]}\); there is no definite requirements on minimum electricity clearance and creep distance on devices with voltage within this scope. Generally, DC 72V is the clear boundary value for such devices.

The NEBS (Network Equipment-Building System) of the standard GR-1089-CORE makes a more detailed classification of safe voltage range for contacting with bare hands \(^{[23]}\), this paper only extracts the section about DC (excluding the relevant data of AC), see Table 12 for the relevant conclusion. In Table 12, the access control for A1 voltage is applicable for the people with no knowledge on electrical safety so as to avoid dangerous operation (such as connecting the wire with positive and negative electrode directly); the protective measures for A2 voltage aim at protecting non-professionals from contacting A2 voltage, if the device is connected with power by connector, the connector should be shielded, which should be in line with: the conductive part of the connector cannot be touched by unintentional act; only the small parts of human body with section size \(< 12\text{mm}\) (such as fingers) can touch the conductive part of connector, while the large parts, such as palms and hand backs, cannot touch the conductive part, it means that when human body connects the conductive part of connector, there will be high resistance in human body. Since A2 voltage is applicable for general household electrical devices, it is reasonable to assume that adult users may have the same competence in using these devices as the general employees listed in Table 12 because even for the DC supply with lower voltage, the users may not have no awareness of electrical safety at all.

In this standard, DC 30V and 80V are two important boundary values.

Note: USB interface and network cable belong to A1 class, normal-48 V device belongs to A2 class.

Ordinary people refers to those who have no idea about the risk of electric shock; ordinary employee refers to the general employee in telecommunication companies; professional refers to the trained maintainers who may connect the charged communication circuit directly.

It may concluded from the above criteria that the safe voltages for devices are generally similar, but the specific voltage selection may vary with different countries and different industries. GB-4943/IEC-60950 and GB-8898/IEC-60065 are the most influential standards, the relevant devices should be subject to the authentication of 3C in China and the authentication of CE and market surveillance in EU, therefore, 60V is deemed as an important boundary value.
Currently, the most widely used low-voltage DC devices are communication equipment and IT equipment, and the common voltages of these devices worldwide include +24V, -48V and -60V, of which, -48V is the most common voltage. For the communication devices with nominal operation voltage of -48V, the range of operation voltage may be ± 20% of this value, i.e., from -53.5V (for floating charge) to -56.5V (for equalizing charge); for some devices which have to operate the system of -60V at the same time, the range of operation voltage may be wider (-36V~-72V), but once the device manufacturer declares that the device may operate with wider voltage range, then the corresponding safety requirements should be subject to the maximum operation voltage (-72V), which may increase the cost of safety design and safety test; therefore, for devices which only operate the system of -48V, the manufacturers may declare that the range of operation voltage is below 60V, even though the real voltage value may be higher than it.

To sum up, 60V is the appropriate nominal voltage level in DC supply for buildings. Meanwhile, considering the certain permissible deviation range for each voltage level, the recommended permissible deviation range for 60V is (-10%, 0) by reference with such range of AC 220V (-7%, +10%).

5. Conclusion
This paper focuses on the selection of building DC supply voltage and make analysis and calculations from the perspective of human safety, main conclusions are reached as follows:
1) Human safety is the critical factor in the selection of building DC supply voltage;
2) When connecting with electrical equipment at normal operation in dry environment by different electrodes and shock methods, for any DC voltage \( \leq 72 \text{V} \), it will not cause skin scars, organ damages or more dangerous injuries, but it cannot rule out the non-destructive effects such as sense of pain or muscle contraction;
3) When connecting with electrical equipment at normal operation in dry environment, for any DC voltage \( \leq 72 \text{V} \), it will not cause unconscious cardiac muscle response, and when connecting the electrode which is just unplugged, it will not cause sense of tingling;
4) It is recommended to take 60V as the nominal voltage for building DC supply based on a comprehensive consideration of human safety, operation voltage range of devices and safety cost, meanwhile, the real operation voltage should be \( \leq 60 \text{V} \), and the permissible deviation range is (-10%, 0).

References
[1] SULZBERGE C L.Triumph of AC-from Pearl Street to Nigara.IEEE Power& Energy Magazine, 2003. 99(3):64-67.
[2] SALAMONSSON D,SANNINO A.Low-voltage dc distribution system for commercial power systems with sensitive electronic loads.IEEE Transactions on Power Delivery, 2007, 22(3): 1620-1627.
[3] Guangdong South China Household Electric Appliances Research Institute.DC household electric appliances technology and development prospect. China Appliance Technology. 2009(22):48-49.
[4] CIEZKI J G,ASHTON R W. Selection and stability issues associated with a navy shipboard dc zonal electric distribution system.IEEE Transactions on Power Delivery, 2000, 15(2): 665-669.
[5] ANG Yanyan.Analysis on the main connection and operation of dc traction power supply system of Beijing subway.Digital Technology&Application.2010.8:180-181.
[6] YOKOMIZU Y.YEHIA D M.HOKA D.et al.Formulated representation for upper limitation of deliverable power in low-voltage dc distribution system.IEEE Transactions on Power and Energy.2011.131(4):362-368.
[7] Wang Dan, Liu Yiran,Liang Xiang,et al. DC distribution network voltage class series. Automation of Electric Power Systems. 2015.5:19-20.
[8] Boroyevich D, Cvetkovic I, Dong D, et al. Future electronic power distribution systems: a contemplative view. 2010 12th International Conference on Optimization of Electrical and Electronic Equipment. Russia: IEEE 2010:1369-1380.

[9] PRATT A, KUMAR P, ALDRIDUE T V. Evaluation of 400 V DC distribution in telco and data centers to improve energy efficiency. International Telecommunications Energy Conference, September 20-October 4, 2007, Rome, Italy.

[10] SONG Qiang, ZHAO Biao, LIU Wenhua, et al. An overview of research on smart DC distribution power network [J]. Proceedings of the CSEE, 2013, 33(25): 9-19.

[11] HOSHI H, TANAKA T, NORITAKE M et al. Consideration of inrush current on dc distribution system. Proceedings of the 34th IEEE International Telecommunications Energy Conference. September 30-October 4, 2012, Scottsdale, AZ. Piscataway: IEEE press, 2012:1-4.