Safety for Electric Shower Water Heater installation in Indonesia

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Abstract. Death casualties due to electrocution when showering using electric shower water heater (ESWH) have been reported. The cases included the use of either water heater with storage system or the instantaneous water heater. There are three factors that may contribute to the event, namely, the improper installation including the grounding and wiring systems, the equipment factor, and the human error. The first two factors are the most dominant. This paper presents scenarios when one may experience an electrocution during showering, the current safety regulations in Indonesia regarding the installation of the electric shower water heater, and the mitigations to avoid casualties. The additional of ELCB (Earth Leakage Circuit Breaker) may increase the safety factor as it protects the user from an electrical shock in shorter duration than the common Main Circuit Breaker (MCB). A successful ELCB depends also on the correct installation of protection earth wiring and grounding.

1. Introduction
Electric Shower Water Heater (ESWH) is one of the everyday house appliances in modern living. In the past, the price was high, and it required high electricity consumption that could only be afforded by the high-class people. However, nowadays, ESWHs at lower rates are available that could operate at only 350 - 400 Watts.

There are two general types of ESWH, namely, the one with the storage/ tank system and the instantaneous type. The basic principle for both is similar, i.e., bypassing the cold water into a heating element to produce hot water at the outlet. The process is known as "Joule's Heating." Figure 1 shows both types of ESWH.

Water heater with tank system consumes less power in comparison with the instantaneous one. The tank collects the water, and then, the system heats it regularly based on the reading of a thermostat sensor. The tank capacity varies from 15 to 100 liters, depends on the size of the ESWH system. Bigger capacity consumes more power.

In the instant water heater, the heating process runs faster. Consequently, it requires higher watts in comparison with the tank system. In Indonesia, the market generally sells instant ESWH with power ranges from 800 to 2400 Watts. Meanwhile, in developed countries, instant ESWHs with power above 5000 Watts are available. Higher watts mean faster heating process.
Both types ESWH provide earth-leak circuit breaker (ELCB) for user safety. However, death casualties have been reported during showering [1-7]. Further investigations, found there are factors that contribute to the accidents, namely:

- The improper installation including the grounding and wiring systems, for example: the cable ampacity is below the current rates, bad grounding systems, the unavailability of ELCB.
- The equipment factor, such as, substandard design (not comply to the IEC [8] standard), wiring insulation deterioration.
- Human error as this may happen when the ESWH is used by kids or people with handicap. As has been reported in [9].

2. Electrocution when showering

Electrocution happens when an electric current is passing the human body. This may occur with two possibilities:

- The body touches the live and the ground parts at the same time.
- The body touches two points with different voltage levels at the same time.

Electrocution with house appliances mostly occurs through the first. The severity level depends on the amplitude and duration of the current. The IEC 60479-1 provides a curve that relates the maximum duration vs. current amplitude that human body could stand for (see Figure-2) [9]. Table 1 explains the definition of zoning as provided by Figure 2.

According to table 1 and figure 2, ventricular fibrillation could be avoided if the duration of electrocution is less than 200 ms and the maximum current is 30 mA. Based on this recommendation, the IEC recommends the safety protection of (Earth Leakage Circuit Breaker) ELCB operates in 0.1 second (=100 ms) [10].

In Indonesia most of the housing grounding system is with TN C-S configuration, while in small case the TT system can also be found. Different scenarios could lead into electrocution; an example is given below (see figure 3); others could be found in [7]:

**Equipment status:**
- Hot wire has been deteriorated, the outer case becomes live and expose a safety concern.
- ELCB malfunction, or even the ESWH is not equipped with ELCB.
- The ESWH is grounded.

**Installation status:**
- The grounding system is TN C-S
- Main Circuit Breaker (MCB) is the only protection scheme.

In this scenario, the ELCB is neither installed nor properly works. An insulation breakdown produces a fault current to the earth. At the TN C-S grounding system, majority of fault current will flow through the ESWH casing (because of its low impedance), passing through the grounding system and back to the source. As a consequence, the fault current could be high up to 1000 A [11]. The MCB will trip after 0.4 seconds (400ms) [12]. A small part of fault current could flow to the user, I_v, with the amplitude
depends on the body’s impedance and the resistivity of the grounding system. This small current may be lethal as seen in Figure 2.

**Figure 2.** Zoning of duration vs. AC current (15-100 Hz) amplitude that a human could stand for [9].

**Table 1.** Physiological effects of electrocution based on zoning of time duration vs. current AC amplitude (15-100 Hz) [9].

| Zones          | Boundaries                           | Physiological effects                                                                 |
|----------------|--------------------------------------|---------------------------------------------------------------------------------------|
| AC-1           | Up to 0.5 mA curve a                  | Perception possible but usually no ‘startled’ reaction.                                 |
| AC-2           | 0.5 mA up to curve b                  | Perception and involuntary muscular contractions likely but usually no harmful        |
|                |                                      | electrical physiological effects.                                                     |
| AC-3           | Curve b and above                     | Strong involuntary muscular contractions. Difficulty in breathing. Reversible         |
|                |                                      | disturbances of heart function. Immobilization may occur. Effects increasing           |
|                |                                      | with current magnitude. Usually no organic damage to be expected.                    |
| AC-4 a         | Above curve c₁                       | Patho-physiological effects may occur such as cardiac arrest, breathing arrest, and   |
|                |                                      | burns or other cellular damage. Probability of ventricular fibrillation increasing     |
|                |                                      | with current magnitude and time.                                                     |
|                | c₁ ≤ i₃                              | AC-4.1 Probability of ventricular fibrillation increasing up to about 5 %.            |
|                | c₂ ≤ i₃                              | AC-4.2 Probability of ventricular fibrillation up to about 50 %.                      |
|                | Beyond curve c₃                      | AC-4.3 Probability of ventricular fibrillation above 56 %.                            |

a For durations of current flow below 200 ms, ventricular fibrillation is only initiated within the vulnerable period if the relevant thresholds are surpassed. As regards ventricular fibrillation, Figure 20 relates to the effects of current which flows in the path left hand to feet. For other current paths, the heart current factor has to be considered.

**Figure 3.** An electrocution due to insulation deterioration on phase cable on TN C-S grounding system.
3. Current safety regulations for ESWH Installations in Indonesia

Household electricity appliances in Indonesia should comply with the national standard SNI 7859:2013 [13]. The national standard adapts the IEC 60335-1: 2010 [14]. Furthermore, the SNI IEC 60335-2-21:2010 regulates the ESWH with tank system, while the SNI IEC 60335-2-35:2010 regulates the instantaneous type. Table 2 summarizes important clauses from the standards.

Table 2. Safety clauses for ESWH Installations according to SNI 7859:2013, SNI IEC 60335-2-21:2010 and SNI IEC 60335-2-35:2010.

| Chapter | About | SNI IEC 60335-2-21 for ESWH with Tank System | SNI IEC 60335-2-35 for Instantaneous ESWH |
|---------|-------|---------------------------------------------|------------------------------------------|
| 6.1     | Protection against electrical shock | Class I, II, or III | |
| 6.2     | Protection against water intrusion | For Outdoor at least IPX4, others at least IPX 1 | At least IPX1 |
| 8.1     | Protection to access to live parts. | Appliances must be constructed and enclosed so that there is adequate protection against accidental touch with the active part When tested with a voltage of 1.06 times rated voltage (for single phase), the maximum leakage current is as follows: | |
| 16.1    | Earth leakage | For stationary Class I heating appliances: 0.75 mA or 0.75 mA per kW input Peripheral rated power with a maximum of 5 mA (higher chosen) For Class II appliances: 0.25 mA For Class III appliances: 0.5 mA | |
| 22.6    | Supplementary insulation and reinforced insulation | Appliances must be constructed so that electrical insulation cannot be affected by water that can condense on cold surfaces or by liquid that can leak from containers, hoses, couplings and similar parts of appliances. Electrical insulation of class I appliances and construction of class II shall not be affected in the event of damage to the hose or seal leak. | |
| 22.18   | Parts connected to the protective impedance must be separated by double insulation or reinforced insulation | Current-carrying parts and other metal parts, whose corrosion can pose a hazard, must be resistant to corrosion under normal use conditions | |
| 22.27   | For class II appliances which are connected in normal use to gas or water networks, metal parts which are conductively connected to gas pipes or in contact with water must be separated from the active parts by double insulation or reinforced insulation | Parts connected to the protective impedance must be separated by double insulation or reinforced insulation | |
| 22.28   | For constructions other than class III, the handles, levers and buttons which are held or moved in normal use may not become active when basic insulation fails. If the hinges, levers, knobs are of metal and if the shaft or its spindle may become active in the event of insulation failure, then it must be adequately covered with insulation material or the accessible part must be separated from the shaft or the sprinkler with supplemental insulation | | |
| 22.36   | For appliances other than class III, parts that are continuously held by hand in normal use must be constructed so that when held in normal use, the operator's hand may not touch metal parts unless separated from the active part by double insulation or reinforced insulation. | | |
| 27.1    | Metal parts can be accessed from class 0 appliances and class I appliances which can become active when insulation is broken, must be permanently and reliably connected to the earthing terminal inside the appliance or to the ground contact of the device inlet. | | |
| 27.2    | The means of earthing terminal clamp must be sufficiently secure against accidental loose. | | |
| 27.5    | The connection between the earthing terminal or earthing contact with the earthed metal part must have a low resistance. | | |
| 29.1    | Clearance, creepage distances and solid insulation | Clearance must be less than the value specified in SNI 7859: 2013 | |
| 29.2    | Appliances must be constructed so that clearances, creepage distances and solid insulation are adequate to withstand the electrical stress to which the appliance can be exposed. | Appliances shall be constructed so that the creepage distance of not less than that corresponding to the working voltage, taking into account the material group and pollution levels. | |
| 29.3    | Additional insulation and reinforced insulation must have sufficient thickness or have an adequate number of layers, which can withstand electrical stress that can be estimated during use of the appliance. | | |

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Additional information...

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...Continued information...

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...Final remarks...

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4. Conclusion and recommendations

Three factors may contribute to the electrocution when using ESWH, namely, the improper installation including the grounding and wiring systems, the equipment factor, and the human error. To avoid such accidents, we recommend as follows:

To reduce the risk of accidents due to equipment factors:
- Only use a water heater from a reputable and experienced manufacturer.
- The ESWH must be equipped with a dedicated ELCB with a maximum leakage current setting of 30 mA (15 mA recommended).
- The ELCB should be connected with a 2-pole switch.
- An interval check on the ELCB should be provided, at least once a month by using an available button on the ESWH.
- Flexible hose should be made of non-metal material

To reduce the risk of accidents due to electrical installation factors:
- The installation must be carried out by certified electricians.
- Make sure the installation has a good earthing system. This includes continuity of protective cables (PE) and the installation of a grounding rod at one point.
- The ESWH installations must meet PUILL 2011 recommendations, including: sockets must be installed in Zone 3 and ESWH installations in Zone 2 or 3 with regard to water protection classes (i.e.: IPX 1 in Zone 3, IPX4 in Zone 2). The ampacity of the cables should be correct.
- The ELCB can be installed next to the MCB with a setting of 30 mA, especially in installations with the TT Earthing System.
- Checking and verifying household electrical installations needs to be carried out by the authorized institution for: a new installation, installation modification, and every 15 years.

To reduce the risk of accidents due to user factors:
- The user must read the installation and usage manual before using ESWH.
- Keep the lid/ outer case of the ESWH dry. Children or handicap person must be under supervision when using ESWH
- Repair and modification of ESWH may only be done by certified electricians or manufacturers.
- Safety education, e.g., the source of electricity must be extinguished first before helping the victim.

Improving regulations:
- Every ESWH in the Indonesian market must pass the SNI-tests and the SNI logo should be attached.
- The ELCB installation, along with its specifications, should be mentioned in the National Standards (SNI) for the ESWH products.

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