Characteristic analysis of low voltage arcing current considering short circuit impedance

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***Abstract*— Fire cases caused by an electrical short circuit (arc flash) at low voltage are still very high in Indonesia recently. Several studies about characteristic analysis of arc flash at low voltage has been done. In this study, an experiments of arc flash phenomena at low voltages using an artificial short-circuit device is conducted. The arc flash's experiment is applied to low voltage stranded conductor cable 1.5mm2 (24 filaments) with resistive load using some objects as short-circuit media (metallic objects, non-metallic objects, and solution). Low voltage arc flash characteristiscs such as maximum current, maximum power, duration and energy of each short circuit media to be analyzed. The results of this study is expected to design protective device (detector) that can be detected low voltage arc flash in future research.**

Keywords*— Arc Flash in Low Voltage; Characteristics of Arc Flash; Short-Circuit Media; Short-circuit Impedance

I. INTRODUCTION

The number of fire cases in Indonesia especially in residential area is increasing every year. In some cases, a fire occur consecutively. Fire cases mostly caused by electrical short circuit which was followed by arc fault phenomenon or so called arc flash as triggers fire. Based on data from the National Agency for Disaster Management (BNPB) Indonesia in August 2011 to April 2015 period, from 973 fire cases that occurred in residential areas 644 are caused by a electrical short circuit with an arc flash phenomenon.

Low voltage arc flash can occur either because involves direct physical contact between the conductors with different potential attached to a specific conductive media. It can occur in the cable conductor which the insulation has been damaged [1]. Cable damage is caused by heating, aging (aging), or because of nuisance animals for example rat. Low voltage arc flash cannot be detected by the protective devices in the distribution system which usually uses MCB (Miniature Circuit Breaker) and fuse [2].

MCB or fuse inability in detecting arc flash make fire can't not be detected early. Therefore, in this study will be discussed several issues, namely regarding the mechanism of occurrence of an arc flash, the characteristic of arc flash and short circuit media influence on the characteristics of the arc flash in low voltage. In this study, an experiments of arc flash phenomena at low voltages using an artificial short-circuit device is conducted. Problems in the study was limited to the analysis of the low voltage arc flash at 1.5mm2 stranded conductor cable 1.5mm2 with resistive load and using some objects as short circuit media i.e iron, stainless steel, an alloy (Cu 40%+Zn 40%), wet wood, wet ceramic, seawater and rainwater.

While the goal to be achieved in this study is to investigate the phenomenon, characteristics, and the influence of short-circuit media impedance of low voltage arc flash characteristics.

The method used in this study, first are study literature and data collection of characteristics analysis of the low voltage arc flash. After collecting the data required then the next is asembly of arc flash experimental device in form of a tools set of artificial short-circuit. Then the next step is to conduct experiments low voltage arc flash through several media short circuit. After conducting experiments, then the next step is to perform data processing of experimental results. The last step is the result of processing data were analyzed by considering the influence of short circuit media impedance, the number of filament of stranded conductors cable (for solid media) and the distance of arc (for media solution). Graphic data of the characteristics low voltage arc flash is analyzed in time domain.

II. CHARACTERISTICS OF ARC FLASH AT LOW VOLTAGE THROUGH THE SHORT CIRCUIT MEDIA

In general, low voltage arc flash is divided into two categories: (1) contact arcing (direct arc flash) and (2) non-contact arcing (an arc flash through the media). Low voltage arc flash or called arcing faults can occur in one of two ways, series arcing faults or parallel arcing faults. A series arcing fault can occur when one of the current-carrying paths (e.g. a single wire) in series with the load is unintentionally broken. Parallel arcing faults occur when there is an unintentional conducting path between two conductors of opposite polarity, such as between a phase and neutral conductor. Parallel arcing faults generally involve high currents, and are limited only by the impedance of the distribution system [3].

Research of the characteristics of indirect arc flash (through the specific short-circuit media) has been done before. One of them is parallel arc flash through high impedance media [4]. But the fact is happening on the field (distribution area), low voltage arc flash occurs not only through high impedance media. The examples of short-circuit media are metallic objects, non-metallic, solution and other objects that are easily found in low voltage distribution area (residential population).

Each of these short circuit media has different impedance values. The impedance value will greatly affect the characteristics of the arc flash that occurs. Low voltage arc flash through non-metallic media that relatively have high impedance value, generating a very low arc currents even approaching zero. Meanwhile, when low voltage arc flash through metallic media which relatively has a small impedance, resulting in a high arc current [5]. High current causes arc voltage decrease when arc flash occurs. High-frequency broadband noise is present in the arc flash current (from the tens of kilohertz to about I GHz). [6]. Meanwhile, the arc flash damage is proportional to the arc current and fault duration [7].

III. Experimental Of Low-Voltage Arc Flash

A. *Experimental Setup*

The design of parallel arc flash experimental devices aims to modeling the phenomenon of occurrence of arc flash directly. Scheme of the experimental circuit shown in Figure 1.

Low voltage arc flash experiment was conducted using a voltage source 220/380 Volt - 50Hz with a 1-phase resistive load. Arc flash experiment carried on stranded cables 1.5mm^2. The cable of this type has 24 filaments. The experimental device is equipped with fuses (6A) and a chamber from acrylic material to user safety when experiments were carried out. Current and voltage sensing when the experiment took place using Tektronix current probe A622 and voltage probes TestectTT-HV150. While data acquisition equipment used is PXIe-1073 and PXIe-5122 which is a tool from National Instrument. PXI associated with LABVIEW software that comes NI-SCOPE as Application programming Interface (API) and also as *driver* that controls *digitizer.* Experiments conducted with 1MHz sampling frequency.

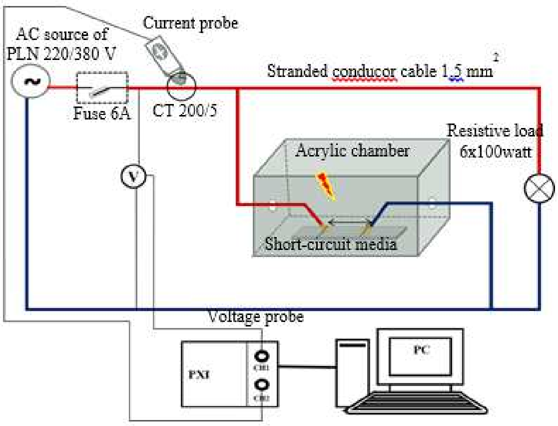


Figure 1. Scheme of parallel arc flash experimental

B. *Test Condition*

To carry out experiments (tests), different short circuit media were chosen. Tests conducted as natural as possible close to the natural phenomenon. Tests were carried out through each media consider certain parameters.

More in detail the tests were carried out in the following condition:

- Test of solid media (metallic and non-mettalic objetcs)

Arc flash through solid media such as metallic and non-metallic objects is made by considering the number of phase and neutral conductor filament. The number of filament is varied into 1, 3, 6, 12, 18, and 24 filament. In the metal media, dimension of metallic objects is used as constant variable (25cmx3.7cmx1.5mm).

- Test of solution media (rain water and sea water)

Arc flash through media solution is made by considering the distance of electric arc (arc distance). It applied because arc flash through solution media occurs at a specific distance.

IV. Result And Discussion

A. *Low voltage arc flash mechanism*

When low voltage arc flash through the metallic objects occurred, high current arise, generate flash of light with high intensity, and very high temperature of the order of tens of thousands of degrees, resulting in severe damage to equipment.

Arc flash does not occurs on non-metallic media like wet wood and wet ceramic. It happens because the non-metallic objects has relatively high impedance value when used at low voltage levels 220 / 380V.

Meanwhile, arc flash through the solution media occurs only in sea water that has high conductivity value that is equal to 233.77 $\mu\Omega^{-1}$/m and also occur at a specific distance is 5 cm. Arc flash through sea water not as tremendous as arc flash through on metallic objects.

Arc flash through the metallic media can be explained by Figure 2 below.

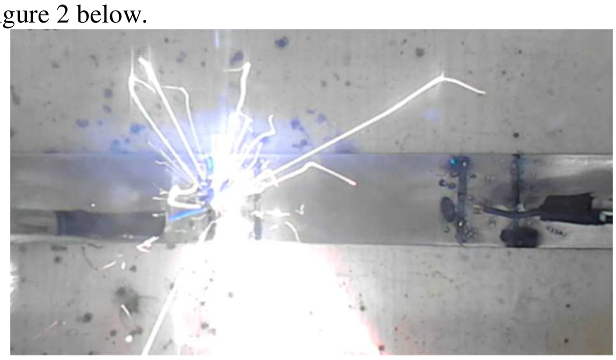


Fig 2. Low voltage arc flash through on metallic objects

B. Characteristic analysis

Short circuit impedance is impedance of short circuit media. Due to circuit of experiments is resistive, then the short-circuit impedance can be interpreted as a resistance value according the Equations 1 and 2 below.

- Impedance of R-L-C circuit :

$$Z = \sqrt{R^2 + ({X_L}^2 - {X_C}^2)} \qquad (1)$$

- If the circuit is resistive, then :

$$Z = R \qquad (2)$$

where, Z is total of circuit impedance (Ω); R for resistance/resistive reactance (Ω); X_L inductive reactance (Ω); X_C capacitive reactance (Ω).

The character of maximum current is proportional to the maximum power, while the character of energy is proportional to the duration of arc flash according to the following Equations 3 and 4 below.

*) Assumptions:

S (apparent power) = P (active power)

Due to circuit of arc flash experimental is more resistive and contains the value of Q (passive power) is very small so that its value is negligible.

$$P_{max} = I_{max} \ x \ V \qquad (3)$$

P_{max} is maximum power (Watt), I_{max} maximum current (A), and V voltage when maximum current occurs (V).

$$W = \sum (P_1 x t_1) + (P_2 x t_2) + \cdots + (P_n x t_n)$$

If t_1= t_2= t_3= t_n = t then obtained Equation below:

$$W = P_{total} \, x \, t \qquad (4)$$

where, P_n for power in-n time (watt), t is time (hours), and W is total energy (Wh / watthour).

Current and voltage waveform based on the number of conductor filament is shown in Figure 3. Whereas, graphic of characteristics of arc flash through the metallic media versus the number of filament of conductors cable is shown in Figure 4.

From the graph in Figure 4, is known that the number of conductors filament cable currently used in experimental arc flash does not has big influence on the value of the maximum current and power. A relatively large current is not enough to make a safety device (fuse) trip. In contrast, the number of conductors filament used during experiments is very influential on duration and energy value of arc flash. Duration here defined as the duration of the arc flash until the conductor filament melted.

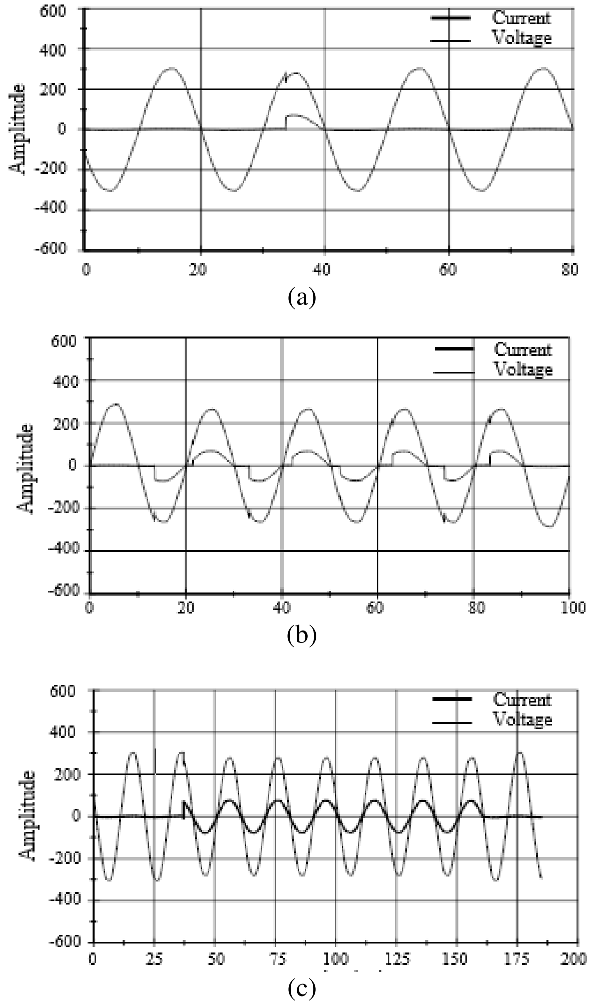
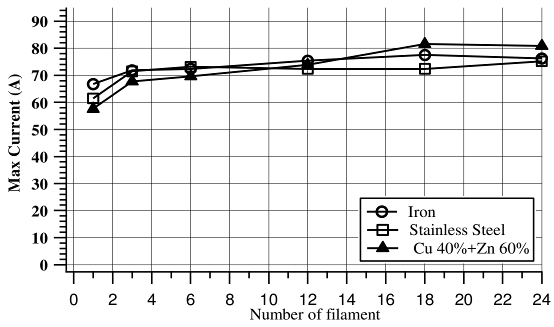
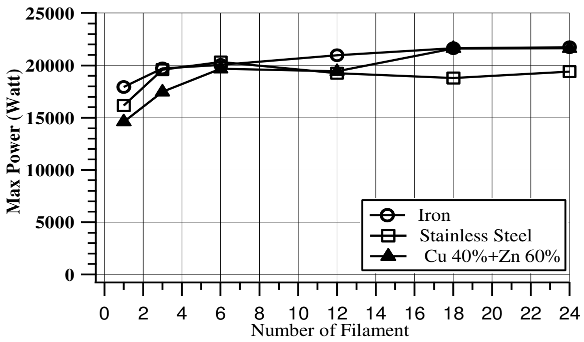


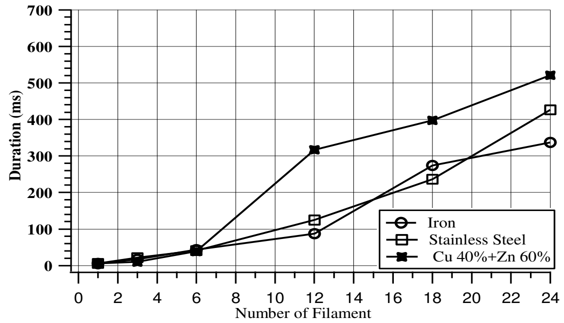
Fig 3. Current and voltage waveform based on the number of filament (a) < 3 filament, (b) 6-12 filament, dan (c) > 12 filament.



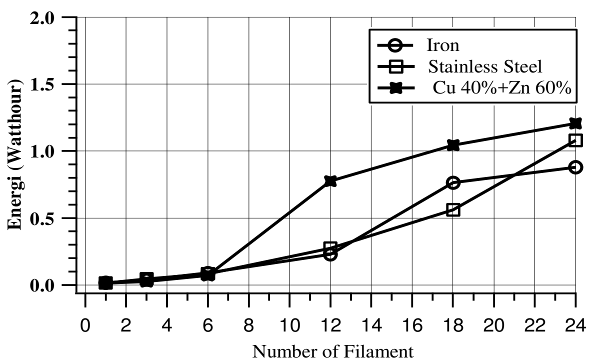
(a)



(b)



(c)



(d)

Fig 4. Characteristics graph of arc flash through the metal media versus the number of conductors filament (a) maximum current, (b) maximum power, (c) duration, and (d) energy

The value of arc flash characteristics in all of these metals is proportional to the impedance value of each metal, getting smaller impedance value causing current value of arc flash also getting bigger. Impedance value of metallic media from the smallest to largest is Cu 40%+Zn 60% (0,04 Ω), stainless steel (0,09Ω), and iron (0.43Ω).

In the experiment of arc flash that through metallic media, there are several experiments that can be detected by fuse. Arc flash current which can be detected by safety devices such as fuse is arcing currents with continuous wave with a very long duration. Old fuse that has been trip on several times, had to be replaced with new fuse. Its can cause the parameters of arc flash such as maximum current, maximum power, duration and energy of several trip events different between new fuse and old as shown by Table 1 below.

Table 1. Parameters value of trip event on arc flash experiment use new fuse and old fuse.

Parameter	Old fuse (f1)	New fuse(f2)
Maximum current	76.9 A	76.8 A
Maximum power	19909 watt	19845 watt
Duration	3.97 sekon	1.56 sekon
Energy	10.4 watthour	3.87 watthour

The trip events only affect the energy and duration value of arc flash. This means that when there is an arc flash that can be detected by fuse, a value that changes is does not has effect of current and power value.

The new fuse more sensitive to fault current than the old fuse. The old fuse who has never replaced can be one of the factors fire due to arc flash that occurs in the area of distribution (residential area).

To determine the duration and the energy difference between the arc flash that can not be detected and which can be detected by a safety device then graph as shown in Figure 5and Figure 6.

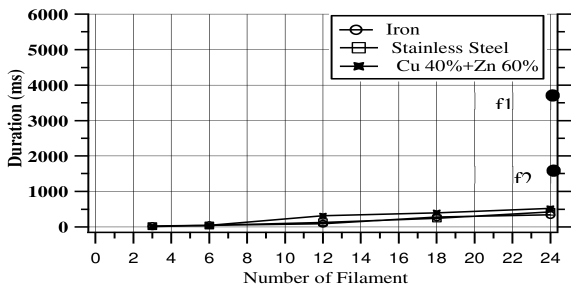


Figure 5. Graph difference in duration of arc flash between trip event vs non trip event

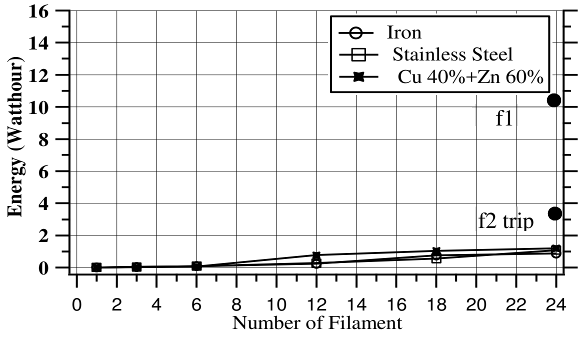


Fig 6. Graph difference in energy of arc flash between trip event vs non trip event

From the graph, there is a huge difference between trip event and non-trip event of arc flash.

Characteristics of arc flash through liquid media can be identified only in sea water media. Arc flash current that through on sea water media is shown in Figure 7. Meanwhile, the characteristic arc flash through on sea water is influenced by arcing distance as shown in Figure 8. Maximum current characteristic is proportional to the maximum power, and duration characteristic is proportional to the energy.

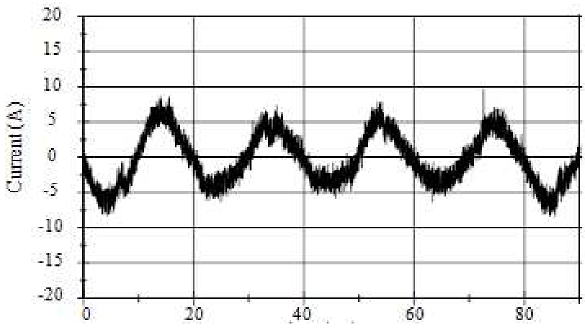
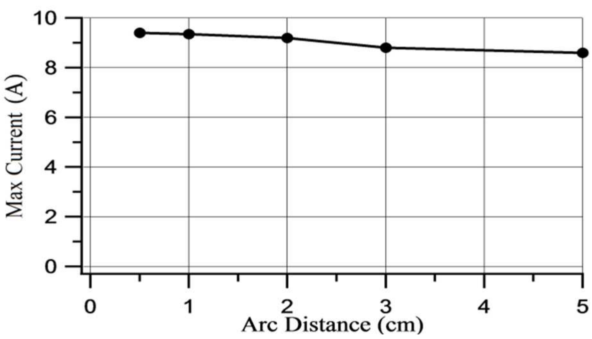
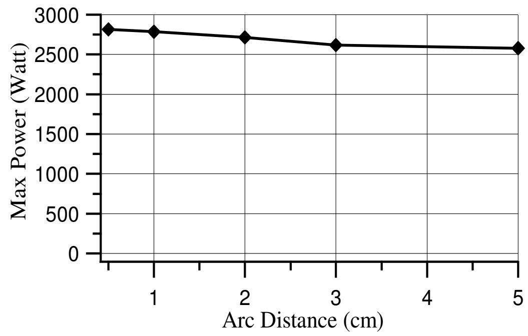


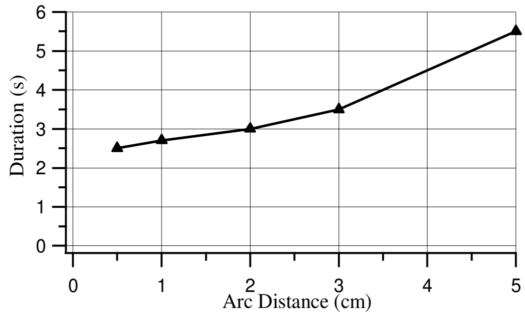
Fig. 7 Current waveform of arc flash through sea water media



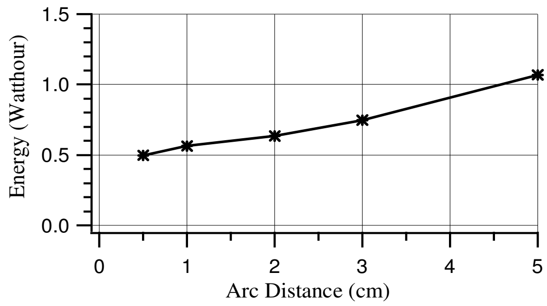
(a)



(b)



(c)



(d)

Figure 8. Graph of arc flash through sea water media characteristics versus arcing distance (a) maximum current, (b) maximum power, (c) duration, and (d) energy

Arc flash current thru seawater is much smaller than the arcf flash current thru the metallic media. Arc flash current value is affected by the impedance value. Impedance value is affected by the arcing distance. The relationship between arcing distance and impedance value is shown in Equation 5 below.

$$R = \frac{1}{k} \times \frac{l}{A} \qquad (5)$$

where, k is conductivity type of solution ($\mu\Omega^{-1}$/m); l arcing distance(m), and A cross-sectional area of cable conductor (mm^2)

Arcing impedance value at a certain distance shown in Table 2 below.

Table 2. Distance of arcing and impedance values of sea water media

Arcing distance (cm)	Impedance (Ω)
0.5 cm	14.26 Ω
1 cm	28.52 Ω
2 cm	57 Ω
3 cm	85.55 Ω
5 cm	142.6 Ω

Increasing arcing distance cause decreasing arc flash current, although not dropped significantly. Maximum power characteristic can be represented by the maximum current character. Whereas, the energy characteristic can be represented by duration character.

The duration is influenced by arcing distance between netral-phase conductor, thus indirectly the value of arc flash energy through the medium of sea water depends on the distance arcing. Increasing distance arcing can increasing energy value. Its happens because on large arcing distance, the energy required to melt the conductor is very big, while the current arcing that occurs in rain water media is relatively small. Arc flash through the medium of sea water did not cause the fuse trip entirely.

V. Conclusion

Low votage arc flash that through on specific media has characteristics that are influenced by the value of short circuit impedance media used. In addition, its characteristics are also influenced by several parameters such as the number of filament conductor (for metallic and non-metallic media) and the arcing distance (for media solution).

Electricity arcing thru several media produces noise which is quite high frequency. Parallel arc flash can not be detected by protection device because of the short duration despite the current generated is quite large.

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