Frequency changing effect on current transformer class 0.5s

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Abstract. This paper is aiming the frequency effect to a current transformer instrument, which is used to measure current that flow in a conductor. As technology is developing, the usage of a non-linear load is higher. This will cause a problem in the power quality of an electrical system. This disturbance in power quality influencing the working frequency on an electrical system. As a current transformer is one of the equipment in the system, when the primary of a current transformer is disturbed, it could also affect the secondary side. The result shows that the frequency changing has an effect on error ratio and phase displacement on a current transformer class 0.5s, which will decrease while the frequency is increase but still within the standard limit. Frequency changing also has an effect on Security Factor on an instrument, which will increase when the frequency is increasing. So, it is important to keep frequency within the fundamental frequency.

1. Introduction
Current Transformer (CT) is an electrical component or instrument that is used to measure current that flow in a conductor. CT is needed to reduce the current on the system into a smaller value [1]. Low voltage current transformer (LVCT) is used in a utility company in Indonesia to measure customer, energy starting from rated power 53 kVA up to 200 kVA. In Indonesia’s electrical utility standard, it was stated that within this contract power rating, the energy measurement is using LVCT class 0.5s to measure billing energy. It is used because it could decrease the losses in utility billing energy [2].

The development of technology is now supporting efficiency energy. Load becoming more efficient and less power needed, but it could affect power quality and a stability system, especially it is generating or changing the frequency in the system. A stability electrical network is needed in power quality measurement. CT is connected to energy meter and used to measure the energy. So, it is important to measure the current accurately CT is designed to work on 50 Hz (60Hz) frequency. In some measuring condition that has a disturbance in CT’s primary current, it could present errors in the measurement either in error current ratio or phase displacement [3], a frequency response of the current transformer is affected error ratio [4].

Based on an explanation above, this research is aiming at the effect of frequency changing on current transformer measurement. Through the result of this research, the effect will obtain, so it could be tested in a practical and field test and the behaviour can be analysed.

2. Transformer
A current transformer produces a reduced current proportional to the current in the circuit. It is also used as an isolation form high voltage in the monitored circuit. Current that is generated in the
secondary winding is proportional to the winding ratio, as noted in equation 1. There are some points consider to choose a current transformer.

\[ I_p N_p = N_s I_s \]  

(1)

2.1. Burden
A secondary load of a current transformer or also known as a burden is a limit of impedance that can be connected to a transformer secondary winding. It could affect the accuracy of the measurement if the burden is higher than its design [5]. A burden can be calculated, as noted in equation 2.

\[ P_N = \frac{(AW)^2 Q_{FE} K}{I_{FE}} \text{ [VA]} \]  

(2)

2.2. Accuracy classes
Accuracy class is a percentage of error limit that is allowed while doing a transformation. The accuracy of a current transformer takes an important role while doing a measurement. CT should be well designed and tested to make sure the outcome value of the secondary winding is proportional to the primary current flowing on the bus bar or cable.

Error Accuracy limit of the current transformer is specified either in IEC 60044-1 or in PLN Standard D3.014-1:2009 as it is shown in Table 1. This accuracy limitation is specified at the rated frequency and the error should not exceed the value presented in Table 1. Error ratio of current transformer measurement is noted in equation 3.

\[ \% E = \frac{K_n I_s - I_p}{I_p} \times 100\% \]  

(3)

2.3. Phase displacement
Phase displacement is a deviation between the secondary waveform and the primary waveform in the system. To have the best transformer, the phase displacement should be zero, so there is no gap between the primary wave and the secondary. The limitation standard of phase displacement in a current transformer is also noted in the standard which is shown in Table 2. Phase displacement of a current transformer is noted in equation 4. On standard, phase displacement is noted in the form of minute, but we can measure phase displacement in degree. The relationship between the minute and degree is shown in equation 5.

\[ \varphi_{im} = \varphi_1 - \varphi_2 \]  

(4)

\[ 1 \text{ minute} = \frac{1}{60} \]  

(5)

2.4. Factor safety instrument
Factor safety is a comparison between a rated instrument limit primary current (IPL) with the primary rated current. IPL is a primary rated current minimum when the composite error is more than equal to 10%. Factor safety can be measure as equation 6. Composite error is shown in equation 7. The highest possible value of error ratio and phase displacement indicated by this composite error.

\[ FS = \frac{IPL}{I_p} \]  

(6)
\[ C_\varepsilon = \frac{100}{I_p} \sqrt{\frac{1}{T} \int_0^T (K_a i_s - i_p)^2 dt} \]  

\[ (7) \]

### Table 1. Error ratio standard limit (in percent).

| Accuracy Class | % Nominal Primary Current |
|----------------|--------------------------|
|                | 1%           | 5%          | 20%         | 100%        | 120%        |
| 0.2            | 0.75         | 0.35        | 0.2         | 0.2         | 0.2         |
| 0.2s           | 0.75         | 0.35        | 0.2         | 0.2         | 0.2         |
| 0.5            | 1.5          | 0.75        | 0.5         | 0.5         | 0.5         |
| 0.5s           | 1.5          | 1.5         | 0.75        | 0.5         | 0.5         |
| 1.0            | 3.0          | 1.5         | 1.0         | 1.0         |

### Table 2. Phase displacement standard limit (in minute).

| Accuracy Class | Nominal Primary Current (%) |
|----------------|-----------------------------|
|                | 1%           | 5%          | 20%         | 100%        | 120%        |
| 0.2            | 30           | 15          | 10          | 10          |
| 0.2s           | 30           | 15          | 10          | 10          |
| 0.5            | 90           | 45          | 30          | 30          |
| 0.5s           | 90           | 45          | 30          | 30          |
| 1.0            | 180          | 90          | 60          | 60          |

### 3. Research method

This research was done in the laboratory and it is aiming to measure the effect on frequency changing in low voltage current transformer especially class 0.5s. Three ratios window type current transformers class 0.5s were tested in this research. CT ratios that were tested in this research are 100/5A, 200/5A and 300/5A. This research used Nano-crystalline alloy design in toroidal core CT, which has a better value of error ratio and phase displacement than FeSi toroidal core CT [6]. Detail specification of the CT is shown in Table 3.

### Table 3. Detail specification of the current transformer.

| Description               | Specification     |
|---------------------------|-------------------|
| Highest Rated Voltage     | : 0.72 kV         |
| Power frequency rated voltage | : 3 kV           |
| Rated Frequency           | : 50 Hz           |
| Accuracy Class            | : 0.5s            |
| Burden                    | : Min 2,5 VA      |
| FS                        | : 5               |

![Figure 1. Schematic diagram of the test.](image-url)
The test circuit arrangement is shown in Figure 1. During the research, the frequency was raised through the test equipment CT Analyzer from 50 Hz, 150 Hz, 250 Hz and 350 Hz. This was done due to the limitation of the equipment. Then error ratio, phase displacement, excitation curve, and factor safety instrument is shown on the computer. All the result is noted and ready to be analysed.

4. Result and discussion
This Section will discuss the result of the experiment. From the testing, we can get error ratio, phase displacement, safety factor and excitation curve.

4.1. Error ratio result
The result of the error ratio when the frequency is changing is shown in Table 4 and Figure 2 up to 4. From Table 4, we could get the increment of rated current will affect the error ratio. In CT 100/5A, the error ratio is increased to the negative value. In CT 200/5A, the error ratio is getting closer to zero when the load is increasing. In CT 300/5A, also showing the error ratio is getting closer to zero when the load is increasing. When the error ratio is getting closer to zero, it is indicating that the primary current is proportional to the secondary winding terminal. From the result, it is also shown that the increment of the frequency is getting the error ratio closer to zero.

| Ratio            | % Rated Current | 50 (Hz) | 150 (Hz) | 250 (Hz) | 350 (Hz) |
|------------------|-----------------|---------|----------|----------|----------|
| Ratio 100/5A     | 1%              | -0.027  | -0.009   | -0.005   | -0.005   |
|                  | 5%              | -0.068  | -0.015   | -0.008   | -0.005   |
|                  | 20%             | -0.134  | -0.037   | -0.002   | -0.008   |
|                  | 100%            | -0.122  | -0.057   | -0.031   | -0.020   |
|                  | 120%            | -0.115  | -0.057   | -0.033   | -0.021   |
| Ratio 200/5A     | 1%              | -0.188  | -0.064   | -0.040   | -0.030   |
|                  | 5%              | -0.185  | -0.062   | -0.039   | -0.030   |
|                  | 20%             | -0.137  | -0.063   | -0.041   | -0.031   |
|                  | 100%            | -0.071  | -0.045   | -0.036   | -0.030   |
|                  | 120%            | -0.068  | -0.043   | -0.035   | -0.030   |
| Ratio 300/5A     | 1%              | -0.064  | -0.018   | -0.012   | -0.010   |
|                  | 5%              | -0.062  | -0.017   | -0.012   | -0.010   |
|                  | 20%             | -0.059  | -0.017   | -0.011   | -0.010   |
|                  | 100%            | -0.033  | -0.015   | -0.011   | -0.010   |
|                  | 120%            | -0.030  | -0.014   | -0.011   | -0.010   |

Figure 2. Error ratio result on CT class 0.5s ratio 100/5A.
Figure 3. Error ratio result on CT class 0.5s ratio 200/5A.

Figure 4. Error ratio result on CT class 0.5s ratio 300/5A.

Table 5. Phase displacement results at different ratios and various frequencies.

| Ratio          | Rated Current | 50 (Hz) | 150 (Hz) | 250 (Hz) | 350 (Hz) |
|----------------|---------------|---------|----------|----------|----------|
| Ratio 100/5A   | 1%            | 22.037  | 8.548    | 5.298    | 3.902    |
|                | 5%            | 18.511  | 8.071    | 5.140    | 3.797    |
|                | 20%           | 11.609  | 6.534    | 4.554    | 3.515    |
|                | 100%          | 5.838   | 3.689    | 3.108    | 2.658    |
|                | 120%          | 5.977   | 3.382    | 2.909    | 2.534    |
| Ratio 200/5A   | 1%            | 11.315  | 4.002    | 2.450    | 1.745    |
|                | 5%            | 7.298   | 3.555    | 2.266    | 1.653    |
|                | 20%           | 2.379   | 2.238    | 1.773    | 1.404    |
|                | 100%          | 0.523   | 0.682    | 0.804    | 0.784    |
|                | 120%          | 0.668   | 0.542    | 0.698    | 0.708    |
| Ratio 300/5A   | 1%            | 4.815   | 1.717    | 1.051    | 0.763    |
|                | 5%            | 3.867   | 1.565    | 0.998    | 0.721    |
|                | 20%           | 1.959   | 1.254    | 0.884    | 0.661    |
|                | 100%          | 0.445   | 0.593    | 0.567    | 0.488    |
|                | 120%          | 0.510   | 0.506    | 0.517    | 0.456    |
Phase displacement results when the frequency is changing also shown in this study. It is shown that the frequency is having a reverse relationship, when the frequency increase, the phase displacement decreases, the result is shown in Table 5 and Figure 5 to 7.

4.2. Excitation curve result
The excitation curve is one of the important things to learn the characteristic of a transformer. The excitation curve result is shown in Figure 8 to 10. From Figure 8, the excitation voltage for CT 100/5A is increasing when the frequency increases. The saturation voltage is higher but the excitation current
is almost the same. This characteristic also happens with CT 200/5A and 300/5A that are shown in Figure 8 up to 10.

**Figure 8.** Excitation curve CT 100/5A (a) 50 Hz (b) 150 Hz (c) 250 Hz (d) 350 Hz.

**Figure 9.** Excitation Curve CT 200/5A (a) 50 Hz (b) 150 Hz (c) 250 Hz (d) 350 Hz.
The factor safety effect is shown in this study. Factor safety is related to IPL and composite error. The composite error will increase, following the frequency. The results of the factor safety measurement are shown in Table 6. CT 100/5A, due to frequency increase, the factor safety instrument will increase and over the standard limitation. This characteristic also happens in CT 200/5A and 300/5A. The increment of a frequency will make factor safety over the limitation than the standard design, which is noted in Table 3.

| Ratio      | Factor Safety |
|------------|---------------|
| 100/5A     | 2.370 6.273   |
| 200/5A     | 2.060 6.052   |
| 300/5A     | 1.940 5.723   |

5. Future work and recommendation

Future research can be done through this result. The parameter the study regarding the frequency changing effect can be added in accordance with the real working condition, such as changing the humidity or temperature or altitude affected to this result. On the other hand, this result can also trigger to future research on how to make a good design to minimize ratio error and phase displacement.

6. Conclusion

This research presented the effect of frequency changes in current transformers. The result obtains, error ratio and frequency are having a cross relationship. When the frequency increases, the error ratio will decrease and getting closer to zero but keeps within the standard of accuracy class.

Phase displacement of a current transformer class 0,5s also has a cross relationship. It will be decreased while the frequency is increasing. So, we can conclude that this type of current transformer
is suitable to be used as a billing energy instrument. On the other hand, the changing of the frequency should be aware because the result shows that the excitation voltage and safety factor of the current transformer will increase and getting higher while the frequency is increasing. From this result, it is important to maintain the primary current is working in the specified working frequency.

Acknowledgement
The authors want to sincerely acknowledge “Publikasi Terindeks Internasional” (PUTI) for providing the research funding. Hope this research can be useful for further research.

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