International Journal of Applied Power Engineering (IJAPE)
Vol. 13, No. 4, December 2024, pp. 1014~1020
ISSN: 2252-8792, DOI: 10.11591/ijape.v13.i4.pp1014-1020

Assessing transformer health through analysis of dissolved gases in cooling oil

Sapto Nisworo[1], Arnawan Hasibuan[2], Muzamir Isa[3], I Made Ari Nrartha[4], Misbahul Jannah[2], Muhammad[2]
[1]Department of Electrical Engineering, Faculty of Engineering, Universitas Tidar, Magelang, Indonesia
[2]Department of Electrical, Universitas Malikussaleh, Lhoseumawe, Indonesia
[3]School of Electrical System Engineering, University Malaysia Perlis, Perlis, Malaysia
[4]Department of Electrical Engineering, Faculty of Engineering, Mataram University, Mataram, Indonesia

Article Info

Article history:

Received Dec 10, 2023
Revised Jul 19, 2024
Accepted Aug 15, 2024

Keywords:

Dissolved gas analysis
Insulation system failure
Rogers ratio
Transformer fault
Transformer oil

ABSTRACT

Gases can form within the insulation system for various reasons while a transformer is in operation. If these gases are not promptly and properly managed, they can negatively impact the transformer's performance. Using the dissolved gas analysis (DGA) method to identify and assess the type and quantity of dissolved gases in transformer oil can uncover potential issues within the transformer. This information is crucial for guiding preventive maintenance and necessary repairs. Dissolved gas analysis testing was conducted by extracting transformer oil samples to identify signs of disturbances in the transformer based on the dissolved gas content. This research was conducted at the Paiton plant operations and maintenance services division. The condition of transformers was assessed by analyzing dissolved gases using the Rogers ratio method. Results indicate that the transformer at Paiton 9 is in good condition but overheating has occurred and requires treatment. Conversely, the transformers at Paiton 1 and 2 are in poor condition, showing signs of electrical faults and excessive heat. Despite several attempts to add inhibitors and conduct frequent testing, the transformers remained in poor condition, necessitating their replacement or repair.

Corresponding Author:

Sapto Nisworo
Department of Electrical Engineering, Faculty of Engineering, Universitas Tidar
Magelang 56116, Indonesia
Email: saptonisworo@untidar.ac.id

1. INTRODUCTION

The nominal price of transformers is currently relatively expensive but contributes greatly to the distribution of electricity which is a primary human need, making transformer maintenance important to pay attention to, one of the efforts is the need for regular preventive maintenance on all operational components of the transformer, one of which is the transformer cooling oil element [1], [2]. In general, disturbances in transformer operation cannot be separated from thermal disturbances and electrical disturbances [3]. Disturbances that occur repeatedly and are not handled quickly and appropriately will result in damage and cessation of the distribution of electric power [4], [5]. The power transformer is a crucial piece of electrical equipment in the power system, and its reliability is directly linked to the safety of the entire system. The concentration of dissolved gas in oil can be obtained by monitoring the dissolved gas analysis (DGA) technology and then faults in the transformer can be found in a relatively short time [6].

The ongoing influence of substantial electromagnetic forces leads to changes in the windings of the power transformer. Preventing the movement of the developing power transformer windings which leads to major damage is very important, therefore the detection and maintenance of the transformer needs to be carried out routinely so that the transformer can operate reliably. The sweep frequency response analysis (SFRA) method was developed to diagnose the mechanical condition of the transformer winding [7]. The method employed to assess the condition of the transformer windings produces precise results. The power flow calculation is carried out using the Newton-Raphson method [8], [9]. The results obtained 5 lines that have a higher IP than the slack bus, so the 5 lines are simulated by removing the line from the power flow model [10]. It is also obtained that these 5 lines affect the power flow of other lines, also increasing the generation of reactive power and power losses in the lines [11].

In its operating system, transformer oil produces certain gases, where this gas is often one of the causes of damage to transformers because the more gas contained in transformer oil will cause several negative impacts such as increased temperature, increased pressure, formation of spark plugs, risk of fire and other things that often go unnoticed [12]. Maintenance of oil or oil that functions as a lubricant in a transformer can be done by purifying the gas contained therein, where the purification is carried out in the form of evaporating the water contained in the transformer oil at the boiling point of the water [13], [14]. The result is CO2 produced from the oxidation reaction, after which the oil is regenerated by adding inhibitors to neutralize CH* residues formed from chemical decomposition. Oil purification is done to make it more efficient because the oil can be reused by returning the oil content to like new without the need to replace the transformer oil [15], [16].

The continued operation of the transformer is highly dependent on the age and quality of the isolation system [17]. This research will focus on the insulation system, particularly transformer oil, to identify signs of problems, necessary preventive maintenance, and corrective measures to ensure the transformer’s operational reliability. Maintenance of the isolation system can be carried out by testing the transformer oil to determine whether the transformer is in good or bad condition, and the method that can be used is the dissolved gas analysis (DGA) test [18]. The DGA test is an approach that can be applied to all types of oil (liquid insulation) and is carried out in an effort to increase the reliability of the power transformer operating system by analyzing several types of dissolved substances in the transformer oil [19]. The results of the DGA test carried out on transformer oil will obtain data on the concentration of various types of disturbing gases dissolved in the transformer oil which will then be analyzed and studied using the Rogers ratio method so that the indication ratio code for the disturbance that occurs is in accordance with the IEEE C57.104-2008 standard [20]. Based on this, it will provide an overview of the further actions that need to be taken on the transformer regarding preventive maintenance or repairs [21].

This research delves into aspects of the DGA method for transformer condition analysis in more detail than previous relevant studies. Where in this research a special study was carried out on all types of gas dissolved in transformer oil [22]. Then each gas content will be compared with each other in terms of type and level and then processed using the Rogers Ratio method to obtain a ratio code which will later be adjusted to the standard determination level of transformer disturbance (IEEE C57.104-2008) [23], where the aim of this comparative analysis of dissolved gas is to obtain a higher level of accuracy to find indications of disturbance in the transformer, its causes and description of the treatment that must be carried out based on the level of disturbance [24], [25].

2. METHOD

Dissolved gas analysis (DGA) is a diagnostic technique used to evaluate the condition of power transformers by analyzing the types and concentrations of gases dissolved in transformer oil. The process begins with the careful collection of oil samples from the transformer while it is in operation, ensuring that the samples accurately reflect the current state of the insulation system. After collection, the samples are prepared by filtering and sealing them to prevent contamination before being sent to a laboratory for analysis.

In the laboratory, gas chromatography is employed to separate and quantify the dissolved gases, such as hydrogen, methane, ethylene, and carbon monoxide. The concentrations of these gases are then compared to established diagnostic standards, such as the Rogers ratio method and IEEE C57.104-2008 guidelines, to identify potential faults like overheating or insulation breakdown. The results are compiled into a report that outlines the transformer's condition and provides recommendations for maintenance or repairs, enabling timely interventions to prevent failures and enhance the reliability of the transformer. This research was conducted at the PT Java Bali Paiton 9 and PT Java Bali Paiton 1 and 2 generator facilities located in Paiton District, East Java. The study focused on analyzing generator units 1, 2, and 9. A visual representation of the research process is provided in Figure 1.

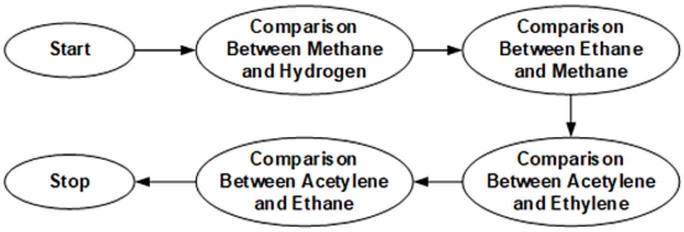

Figure 1. Research methods

This research utilized the dissolved gas analysis (DGA) method to analyze the various gases present in the transformer oil, serving as a parameter to assess the transformer's condition when interference is indicated based on the insulation system. The analysis begins by extracting a transformer oil sample using the gas chromatography method to identify the dissolved gases. By extracting oil samples, we can find out how much and what types of gases are mixed in the transformer oil. These gases are then compared to each other, including comparisons between methane and hydrogen, ethane and methane, acetylene and ethylene, and acetylene and ethane. The Rogers ratio method is used to determine the ratio code from these comparisons. The obtained ratio code is compared with the IEEE C57.104-2008 standard to identify the type of fault that occurs, such as short circuit or overload. Based on the results of this identification, preventive maintenance actions can be carried out to prevent further damage, and repair steps can be planned if damage occurs.

The condition of a transformer's insulation can be assessed by analyzing the types and quantities of gases dissolved in its oil. For instance, elevated methane levels indicate abnormal electrical activity causing significant heat damage to the insulation. A rapid increase in acetylene concentration signals an urgent need for transformer repairs. The presence of ethane and ethylene gas in transformer oil generally indicates a problem with the electrical contacts, such as the tap-changer, or the grounding system. This condition is often caused by excessive current due to imperfect grounding. However, it is important to remember that the gas composition in transformer oil can change due to external factors, such as exposure to sunlight which can slowly change the gas content of the oil.

3. RESULTS AND DISCUSSION

Transformer oil was subjected to multiple tests over a four-day period. The outcomes of these tests, divided into four specific intervals, are summarized in Table 1. The analysis of dissolved gases in transformer oil provides critical insights into the operational health of the transformers at PT PJB Paiton. As shown in Table 1, the concentration of dissolved gases in transformer oil samples indicates that the transformer at Paiton 9 is in good condition, with acceptable levels of gases such as hydrogen (H2) and methane (CH4).

Table 2 presents the results of transformer oil testing, which was conducted over four periods, with each test conducted once every three months. In contrast, Table 2 highlights concerning levels of gases in transformers at Paiton 1 and 2, where elevated concentrations of ethylene (C2H4) and acetylene (C2H2) suggest potential electrical faults and overheating issues. Readers should pay particular attention to the Rogers ratio values presented in Table 2, as these ratios are essential for diagnosing the operational health of the transformers. The analysis reveals that while Paiton 9 requires minor maintenance due to overheating, the transformers at Paiton 1 and 2 exhibit significant signs of distress, necessitating immediate corrective actions to prevent further damage.

3.1. Quantification of dissolved gases in transformer oil

To calculate the value of the dissolved gas ratio in transformer oil, a comparison was made between methane and hydrogen, ethane and methane, acetylene and ethane, and acetylene and ethylene. The results of the gas comparison for PT. PJB Paiton 9 are presented in Table 3. The quantification of dissolved gases in transformer oil is crucial for assessing the condition of the transformers and identifying potential issues. As presented in Table 3, the analysis compares the concentrations of various gases, including methane (CH4), hydrogen (H2), ethylene (C2H4), and acetylene (C2H2). The data indicates that the ratios of these gases can reveal significant insights into the operational status of the transformers. For instance, elevated levels of hydrogen and methane may suggest abnormal electrical activity, while increased concentrations of ethylene and acetylene can indicate potential insulation breakdown or electrical arcing.

The results of the dissolved gas comparisons for PT. PJB Paiton 1 and 2 are presented in Table 4. Table 4 further illustrates the concentrations of specific gases during different test periods, allowing for comparative trend analysis. The focus is on changes in gas levels over time, as these fluctuations may indicate worsening conditions that require immediate attention.

By analyzing the specific gases present within the transformer and calculating their ratios according to the IEEE.C57.104-2008 standard, it is possible to identify the nature of the problems affecting the transformer. The results of these calculations are summarized in Table 5. Table 5 presents the Rogers ratio values derived from the gas comparisons, which are essential for diagnosing the type of faults present in the transformers. It is important to note that a high Rogers ratio may indicate severe issues, necessitating urgent maintenance. Table 6 shows the code ratio resulting from the comparison of dissolved gases. Table 6 summarizes the overall dissolved gas analysis, which provides a comprehensive picture of the transformer's health. Examining the data in these tables provides a clearer understanding of the current condition of the transformer and the actions needed to ensure its reliability and longevity.

Table 1. Oil test results of PT. PJB Paiton 1 and 2 transformers on May 6-10, 2019

Material	Period I	Period II	Period III	Period IV
H_2O	20.2	22.6	20.9	25.5
H_2	8.6	6.8	7.4	5.0
CH_4	401.4	392.0	400.4	376.5
C_2H_2	3.4	4.0	3.9	3.6
C_2H_4	1008.4	1002.6	1026.0	998.5
C_2H_6	262.5	258.0	275.3	252.6
CO	677.0	666.0	683.4	632.9
CO_2	4892	4124	5000	4766
TDCG	2361	2329	2404	2269

Table 2. Transformer oil test results of PT. PJB Paiton 9 on May 6-10, 2019

Material	Period I	Period II	Period III	Period IV
H_2O	9	14.7	11.9	10.5
H_2	5.0	5.0	5.0	5.0
CH_4	7.1	7.8	6.8	6.7
C_2H_2	0.5	0.5	0.5	0.5
C_2H_4	3.7	2	2	2
C_2H_6	3.7	3.8	2	2.2
CO	245	279.7	315.6	329.5
CO_2	819	1170	1522	1469
TDCG	262	264	326	343

Table 3. Analysis of dissolved gases

No	Methane hydrogen	Ethane methane	Ethylene ethane	Acetylene ethylene
1	46.6744186	0.008470354	2.512207275	0.003371678
2	57.10810811	0.687562438	2.557653061	0.00398927
3	54.10810811	0.687562438	2.562437562	0.00380117
4	75.3	0.670916335	2.652058433	0.003605408

Table 4. Analysis of dissolved gases

No	Methane hydrogen	Ethane methane	Ethylene ethane	Acetylene ethylene
1	1.42	0.521126761	1.0	0.135135135
2	1.56	0.487179487	0.526315789	0.25
3	1.36	0.294117647	1.0	0.25
4	1.34	0.328358209	0.909090909	0.25

Table 5. Dissolved gas calculation on May 6 to 10, 2019

Period	Acetylene ethylene	Methane hydrogen	Ethylene ethane
Period I	0	2	1
Period II	0	2	1
Period III	0	2	1
Period IV	0	2	1

Table 6. Analysis of dissolved gases

Date	Acetylene ethylene	Methane hydrogen	Ethylene ethane
October 31, 2018	1	2	1
January 1, 2019	1	2	0
February 27, 2019	1	2	1
April 9, 2019	1	2	0

3.2. Gas analysis using the Rogers ratio technique

The analysis involves comparing the dissolved gas results in transformer oil with the IEEE.C57.104-2008 standard. This comparison helps determine whether the transformer is experiencing a disturbance or is in normal or abnormal condition. It also identifies necessary actions if a fault is found, preventing further deterioration, ensuring the transformer's functionality without compromising its performance, and extending its lifespan.

Based on the collected data, the concentrations of carbon monoxide and carbon dioxide at PT. PJB Paiton 9 exceed the established gas standard limit of 250 ppm, with an average value of 350 ppm dissolved in the transformer oil. Additionally, the ethylene gas concentration in the generator transformers at PT. PJB Paiton 1 and 2 surpasses the standard limit of 50 ppm, reaching an average value of 1000 ppm. The presence of abnormally high levels of acetylene, hydrogen, and ethylene gases at PT. PJB Paiton 1 and 2 signifies a deteriorating transformer condition. This indicates a need for immediate maintenance and reduced operational efficiency. Conversely, increased carbon dioxide and carbon monoxide levels suggest a relatively healthy transformer, capable of continued operation.

Overall, the results of the analysis of dissolved gases in transformer oil show that the concentrations of carbon monoxide and carbon dioxide at PT. PJB Paiton 9 exceed the standard limits, with an average value of around 350 ppm, while the ethylene levels in Paiton 1 and 2 reach an alarming 1000 ppm, far above the acceptable threshold. Compared to previous studies, such as the study by Nurul [1], which reported lower gas levels in normally operating transformers, this study shows a significant decline in transformer health. The increasing levels of acetylene, hydrogen, and ethylene observed in Paiton 1 and 2 are in line with indicators of severe electrical disturbances, emphasizing the need for immediate maintenance and continuous monitoring to prevent catastrophic failure.

4. CONCLUSION

This study assessed the operational health of transformers at PT PJB Paiton through the quantification of dissolved gases in transformer oil. The findings reveal that while the transformer at Paiton 9 is operational, it faces overheating issues that require immediate intervention. In contrast, the transformers at Paiton 1 and 2 are in critical condition, exhibiting elevated levels of ethylene and acetylene, which indicate significant electrical faults and insulation degradation. These results align with previous research emphasizing the effectiveness of dissolved gas analysis (DGA) as a diagnostic tool for transformer health.

By employing the Rogers ratio method in accordance with IEEE C57.104-2008 standards, this study validates the relationship between gas concentrations and transformer failures. The identified gas signatures not only support existing theories but also underscore the importance of regular maintenance to prevent severe operational failures. Overall, this research enhances the understanding of transformer behavior under stress and contributes valuable insights for improving predictive maintenance strategies, thereby advancing the field of transformer reliability.

REFERENCES

[1] V. Vita, G. Fotis, V. Chobanov, C. Pavlatos, and V. Mladenov, "Predictive maintenance for distribution system operators in increasing transformers' reliability," *Electronics*, vol. 12, no. 6, p. 1356, 2023, doi: 10.3390/electronics12061356.

[2] A. Hasibuan, M. Isa, M. I. Yusoff, S. R. A. Rahim, and I. M. A. Nrartha, "Effect of installation of distributed generation at different points in the distribution system on voltage drops and power losses," in *AIP Conference Proceedings*, 2021, p. 20134, doi: 10.1063/5.0044192.

[3] L. Marti, A. Rezaei-Zare, and A. Narang, "Simulation of transformer hotspot heating due to geomagnetically induced currents," *IEEE Transactions on Power Delivery*, vol. 28, no. 1, pp. 320–327, 2013, doi: 10.1109/TPWRD.2012.2224674.

[4] G. A. Ajenikoko *et al*., "Analysis of Power Transformer Failure in Ogbomoso Sub-Station of Ibadan Electricity Distribution Company," *Mathematical Theory and Modeling*, vol. 10, no. 6, pp. 49-58, 2020.

[5] M. Jannah *et al*., "Internet of things-based electrical energy control and monitoring in households using spreadsheet datalogger," *International Journal of Electrical & Computer Engineering*, vol. 14, no. 4, pp. 3931-3941, 2024, doi: 10.11591/ijece.v14i4.pp3931-3941.

[6] Z. Zhou *et al*., "Validity Evaluation Method of DGA Monitoring Sensor in Power Transformer Based on Chaos Theory," in *2018 IEEE Conference on Electrical Insulation and Dielectric Phenomena (CEIDP)*, 2018, pp. 402–405, doi: 10.1109/CEIDP.2018.8544854.

[7] M. Gutten, R. Janura, M. Šebök, D. Korenčiak, and M. Kučera, "Measurement of short-circuit effects on transformer winding with SFRA method and impact test," *Metrology and measurement systems*, vol. 23, no. 4, pp. 521–529, 2016, doi: 10.1515/mms-2016-0044.

[8] A. Hasibuan, S. Masri, and W. A. F. W. B. Othman, "Effect of distributed generation installation on power loss using genetic algorithm method," *IOP Conference Series: Materials Science and Engineering*, vol. 308, no. 1, p. 012034, 2018, doi: 10.1088/1757-899X/308/1/012034.

[9] R. A. de Oliveira and M. H. J. Bollen, "Susceptibility of large wind power plants to voltage disturbances—Recommendations to stakeholders," *Journal of Modern Power Systems and Clean Energy*, vol. 10, no. 2, pp. 416–429, 2022, doi: 10.35833/MPCE.2020.000543.

[10] M. D'orto, S. Sjöblom, L. S. Chien, L. Axner, and J. Gong, "Comparing different approaches for solving large scale power-flow problems with the Newton-Raphson method," *IEEE Access*, vol. 9, pp. 56604–56615, 2021, doi: 10.1109/ACCESS.2021.3072338.

[11] S. Nisworo, S. Setiawan, D. Pravitasari, A. Trihasto, and Z. A. Kusworo, "Contingency Analysis of Electric Power Flow as a Power System Operation Approach," in *2022 5th International Conference on Power Engineering and Renewable Energy (ICPERE)*, 2022, pp. 1–5, doi: 10.1109/ICPERE56870.2022.10037422.

[12] L. R. Chandran, G. S. A. Babu, M. G. Nair, and K. Ilango, "A review on status monitoring techniques of transformer and a case study on loss of life calculation of distribution transformers," *Materials Today: Proceedings*, vol. 46, pp. 4659–4666, 2021, doi: 10.1016/j.matpr.2020.10.290.

[13] B. Pahlavanpour and A. Wilson, "Analysis of transformer oil for transformer condition monitoring," in *IEE Colloquium on An Engineering Review of Liquid Insulation (Digest No. 1997/003)*, pp. 1/1-1/5, 1997, doi: 10.1049/ic:19970012.

[14] F. Bressolle, M. Bromet-Petit, and M. Audran, "Validation of liquid chromatographic and gas chromatographic methods. Applications to pharmacokinetics," *Journal of Chromatography B: Biomedical Sciences and Applications*, vol. 686, no. 1, pp. 3–10, 1996, doi: 10.1016/S0378-4347(96)00088-6.

[15] S. Nisworo, D. Pravitasari, and L. Pukasari, "The Effect of Harmonics on Purification Scheduling of Transformer Oil to Restrain the Degradation Rate," *2020 International Conference on Smart Technology and Applications (ICoSTA)*, 2020, pp. 1–4, doi: 10.1109/ICoSTA48221.2020.1570614589.

[16] C. Elsässer, A. Micheluz, M. Pamplona, S. Kavda, and P. Montag, "Selection of thermal, spectroscopic, spectrometric, and chromatographic methods for characterizing historical celluloid," *Journal of Applied Polymer Science*, vol. 138, no. 21, p. 50477, 2021, doi: 10.1002/app.50477.

[17] N. Perumalsamy, G. Sivasankar, R. M. Elavarasan, S. Kumar, and B. Khan, "Design of Faulty Switching Detection and Alert System to Prevent Fatality of Servicemen During Transformer Maintenance," *IEEE Access*, vol. 10, pp. 77362–77374, 2022, doi: 10.1109/ACCESS.2022.3193098.

[18] H.-C. Sun, Y.-C. Huang, and C.-M. Huang, "A review of dissolved gas analysis in power transformers," *Energy Procedia*, vol. 14, pp. 1220–1225, 2012, doi: 10.1016/j.egypro.2011.12.1079.

[19] H. Kan and T. Miyamoto, "Proposals for an improvement in transformer diagnosis using dissolved gas analysis (DGA)," *IEEE Electrical Insulation Magazine*, vol. 11, no. 6, pp. 15–21, 1995, doi: 10.1109/57.475904.

[20] E. J. Kadim, C. F. Hee, N. Azis, J. Jasni, S. A. Ahmad, and M. Z. A. A. Kadir, "Dissolved gas analysis of transformers based on rough set and fuzzy logic methods," *2015 IEEE Conference on Energy Conversion (CENCON)*, 2015, pp. 268–271, 2015, doi: 10.1109/CENCON.2015.7409552.

[21] L. Martins, F. J. G. Silva, C. Pimentel, R. B. Casais, and R. Campilho, "Improving preventive maintenance management in an energy solutions company," *Procedia Manufacturing*, vol. 51, pp. 1551–1558, 2020, doi: 10.1016/j.promfg.2020.10.216.

[22] C. Boonseng, R. Boonseng, and K. Kularbphettong, "Electrical Insulation Testing and DGA Analysis for the Diagnosis of Insulation Faults and Failures in 24 MVA Transformers for Distribution Systems," in *2020 8th International Conference on Condition Monitoring and Diagnosis (CMD)*, 2020, pp. 70–73, doi: 10.1109/CMD48350.2020.9287279.

[23] R. Furqaranda, A. Bintoro, A. Asri, W. K. A. Al-Ani, and A. Shrestha, "Analysis Oil Condition of Transformer PT-8801-A by Using the Method TDCG, Rogers Ratio, Key Gas, and Duval Triangle: A Case Study at PT. Perta Arun Gas," *Journal of Renewable Energy, Electrical, and Computer Engineering*, vol. 2, no. 2, pp. 47–54, 2022, doi: 10.29103/jreece.v2i2.8567.

[24] S. Bustamante, M. Manana, A. Arroyo, P. Castro, A. Laso, and R. Martinez, "Dissolved gas analysis equipment for online monitoring of transformer oil: A review," *Sensors*, vol. 19, no. 19, p. 4057, 2019, doi: 10.3390/s19194057.

[25] Y. Wibisana, M. J. R. Turnip, and D. R. C. Sihombing, "Diagnostic Magnetic Shunt Anomaly of Power Transformer 150/20 kV 60 MVA at Tambun Substation," in *2019 2nd International Conference on High Voltage Engineering and Power Systems (ICHVEPS)*, 2019, pp. 1–4, doi: 10.1109/ICHVEPS47643.2019.9011140.

BIOGRAPHIES OF AUTHORS

Sapto Nisworo received a Ir. degree in electrical engineering from the Universitas Tidar in 1983, and M.T. degree in electrical engineering from Gadjah Mada University, Indonesia, in 2001, and Dr. degree from Gadjah Mada University in 2015. He is currently a senior lecturer in the Department of Electrical Engineering, Universitas Tidar, Indonesia. His research interests are new and renewable energy, and power electronic engineering. He is a member of the Institution of Engineers Indonesia. He can be contacted at email: saptonisworo@untidar.ac.id.

Arnawan Hasibuan is an associate professor at Faculty of Engineering in Universitas Malikussaleh, Aceh, Indonesia. He works as senior lecturer and researcher at Undergraduate Program of Electrical Engineering and Master Program of Renewable Energy Engineering. Interest in research in the field of power systems, renewable energy, system control. Apart from teaching, he is also active as chief editor at the Journal of Renewable Energy, Electrical, and Computer Engineering (JREECE) and the Jurnal Solusi Masyarakat Dikara (JSMD). He can be contacted at email: arnawan@unimal.ac.id.

Muzamir Isa received his B. Eng. in electrical engineering from UTM, Skudai, Johor, Malaysia in 2001. After two years of working experience with Telekom Research & Development Sdn Bhd, in Serdang, Selangor, he joints KUKUM as vocational training officer. After 6 months, he started his graduate studies in 2003 at Tun Hussein Onn University College (KUITTHO) for M. Eng degree in electrical power engineering. He has been with KUKUM as a lecturer since December, 2004. He is lecturer of School of Electrical Engineering in KUKUM. He is a deputy dean in students affairs and alumni. His research interests include renewable energy, fuel cell engineering, lightning protection system, and high voltage engineering. He can be contacted at email: misa@unimap.edu.my.

I Made Ari Nrartha is an associate professor at Faculty of Engineering in Mataram University, Nusa Tenggara Barat, Indonesia. Interest in research in the field of power systems, renewable energy, and system control. He can be contacted at email: nrartha@unram.ac.id.

Misbahul Jannah is a lecturer at Faculty of Engineering in Universitas Malikussaleh, Aceh, Indonesia. He works as senior lecturer and researcher at Undergraduate Program of Electrical Engineering. Interest in research in the field of power systems, renewable energy, and system control. He can be contacted at email: mjannah@unimal.ac.id.

Muhammad is a lecturer at Faculty of Engineering in Universitas Malikussaleh, Aceh, Indonesia. He works as senior lecturer and researcher at Undergraduate Program of Electrical Engineering. Interest in research in the field of power systems, renewable energy, and system control. He can be contacted at email: muhammad.te@unimal.ac.id.