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Seismic Vulnerability Mapping of the Lhokseumawe Region to Support the Spatial Plan of Lhokseumawe City

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Microtremor is a weak vibration on the surface of the earth that takes place continuously due to sources of vibration such as earthquakes, human activities, industry and traffic (Daryono, 2009). Microtremor data measured obtained 3 signals whose components are vertical (Up and Down), horizontal (North–South), and horizontal (East–West) components. After the signal is obtained it can then be analyzed using the HVSR method and the dominant frequency and amplification values are obtained. The HVSR method compares the spectrum ratio of the horizontal component microtremor signal to its vertical component (Nakamura, 1989). Lhokseumawe City is administratively included in the Province of Nangroe Aceh Darussalam (NAD). In 2004 there was an earthquake of magnitude 9.2 on the Richter Scale in the southern waters of the city of Banda Aceh, which caused a devastating Tsunami. In this event many people lost about 250 thousand lives and lost property that is not small in number (Logan, 2014) Due to the active regional tectonic pattern, the NAD region is a disaster-prone region. The tectonic area of NAD is strongly influenced by the subduction area between the Indian–Australian oceanic plate (Indian Australian Plate) against the European–Asian continental plate (Eurasian plate). The tectonic pattern greatly influences the geological conditions in the waters of the study area. The purpose of this research is to provide preliminary knowledge in the use of microtremors for mapping seismic microzonation. This microzonation mapping is needed for earthquake disaster mitigation purposes, microtremor data analysis can provide information on the value of a place that is very important for earthquake resistant building planning. Building structures that have the same value as the land value will experience resonance in the event of an earthquake. Then the last is the Seismic Vulnerability Index Mapping which is useful for predicting unconsolidated sediment zones at the ground surface when an earthquake occurs, so that further studies for earthquake prone areas can be carried out. The stages of the research method carried out are measuring field data which is divided into several measurement points in each district in the city of Lhokseumawe. At each measurement point, a three-component seismometer is installed to obtain the results of the soil's vulnerability in the area. Each measurement data is observed for 30 minutes at each point. The results of this study are the existence of areas that are very susceptible to seismic namely Ujung blang and Banda Sakti villages with seismic vulnerability index values (Kg) ranging from 0 cm/s^2 −30542.32 cm/s^2. The highest value is located at Ujong Blang villages which is 10397.1 cm/s^2. This is closely related to the total amount of damage to buildings in Lhokseumawe City due to the 2004 earthquake.

Keywords: Microtremor, HVSR, Earthquake.

RESEARCH ARTICLE

1. INTRODUCTION

The Earthquake can not be estimated when, where and how much magnitude. The greater the intensity of the earthquake, the greater the risk of damage and the number of fatalities. Various efforts to reduce this are needed [1]. One of the disaster management to minimize the impact of the earthquake can be done by mapping disaster-prone areas. The Indonesian archipelago is an archipelago that has a high level of seismicity and earthquake intensity. This is because Indonesia is located in the Pacific Circum

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lane which is a confluence of three tectonic plates namely the Eurasian plate in the north, the Pacific plate in the east and the Indo-Australia plate in the south [2].

In addition to earthquake disasters, there are also other disasters such as volcanic eruptions, floods, tsunamis and landslides whose frequency is very vulnerable in Indonesia. Indonesia's vulnerability to earthquakes and the lack of public knowledge of this disaster have caused the Indonesian people to not be able to avoid the effects of the disaster. The natural vibrations of any earthquake phenomenon can be determined using microtremor measurements. Microtremor is a weak vibration on the surface of the earth that takes place continuously due to sources of vibration such as earthquakes, human activities, industry and traffic. Measured microtremor data consists of 3 signals whose components are vertical (Up and Down), horizontal (North–South), and horizontal (East–West) components. After the signal is obtained it can then be analyzed using the HVSR method and the dominant frequency and amplification values are obtained. The HVSR method is to compare the spectrum ratio of the horizontal component microtremor signal to its vertical component [3]. Lhokseumawe City is administratively included in the Province of Nangroe Aceh Darussalam (NAD). In 2004 there was an earthquake of magnitude 9.2 on the Richter Scale in the southern waters of the city of Banda Aceh, which caused a devastating Tsunami. In this event many people lost about 250 thousand lives and lost property that is not small in number. Due to the active regional tectonic pattern, the NAD region is a disaster-prone region. The tectonic area of NAD is strongly influenced by the subduction area between the Indian–Australian oceanic plate (Indian Australian Plate) against the European–Asian continental plate (Eurasian plate) [8]. The tectonic pattern greatly influences the geological conditions in the waters of the study area. Geological structures that develop on land continuously offshore [9]. From shallow reflected seismic data, geological structures in the waters area will be traced. Penetration from seismic records obtained is very limited, which is no more than about 250 meters below the sea floor. Therefore, for geological structures that are far below the surface of the seabed, it is not visible but for geological structures that are active until the surface can be seen from its seismic character. From the shape of the seabed surface morphology from the coast to the offshore direction, the division of geological hazard level zones is made. The study area is part of the North Sumatra basin [10–12]. The geological condition of the study area is strongly influenced by regional geological conditions.

Geological conditions that are quite complicated are greatly influenced by the presence of geological activities such as the Indo–Australian Plate Subduction under the Eurasian Plate–Burma micro Plate which occurred at the beginning of the Miocene. Sloping subduction of plates under the western edge of Sumatra at the End of the Eocene—Early Oligocene results in the formation of the Sumatra Fore Arc. The purpose of this study is to provide initial knowledge in the use of microtremors for mapping seismic microzonation [13]. This microzonation mapping is needed for earthquake disaster mitigation purposes, microtremor data analysis can provide information on the value of a place that is very important for earthquake resistant building planning. Building structures that have the same value as the land value will experience resonance in the event of an earthquake [14]. The resonance effect will strengthen the earthquake vibration, causing the building to collapse when there is a strong earthquake. So after conducting a microtremor survey, it is recommended to construct buildings that are not the same as the ground resonance frequency to avoid the effects of resonance when an earthquake occurs. In addition to the danger of earthquake vibration resonance, very low characteristics are very vulnerable to the dangers of long-term earthquake wave vibrations that can threaten high-rise buildings [15]. By knowing the level of dominant frequency and using it in planning buildings it is expected to reduce the risk of earthquake hazards that may occur in the future. Then the last is the Seismic Vulnerability Index Mapping which is useful for predicting unconsolidated sediment zones at the ground surface when an earthquake occurs, so that further studies for earthquake prone areas can be carried out. The stages of the research method carried out are measuring field data which is divided into

Table I. Coordinates of measurement points.

No.	Point	*X*	*Y*
1	A1	97° 9′ 9.309″ E	5° 10′ 27.226″ N
2	A2	97° 8′ 18.033″ E	5° 10′ 24.384″ N
3	A3	97° 8′ 30.780″ E	5° 10′ 51.179″ N
4	A4	97° 8′ 13.598″ E	5° 11′ 11.276″ N
5	A5	97° 8′ 48.050″ E	5° 11′ 33.717″ N
6	A6	97° 8′ 5.347″ E	5° 11′ 42.008″ N
7	A7	97° 7′ 42.202″ E	5° 12′ 7.895″ N
8	A8	97° 7′ 43.542″ E	5° 12′ 23.026″ N
9	A9	97° 7′ 5.531″ E	5° 12′ 41.200″ N
10	A10	97° 6′ 50.838″ E	5° 12′ 17.100″ N
11	A11	97° 6′ 28.459″ E	5° 12′ 23.427″ N
12	A12	97° 5′ 7.850″ E	5° 12′ 47.769″ N
13	A13	97° 4′ 6.059′ E	5° 12′ 50.867″ N
14	A14	97° 3′ 37.213″ E	5° 13′ 22.632″ N
15	A15	97° 2′ 50.957″ E	5° 13′ 41.371″ N
16	A16	97° 2′ 53.865″ E	5° 13′ 8.152″ N
17	A17	97° 2′ 7.441″ E	5° 12′ 29.148″ N
18	A18	97° 4′ 58.606″ E	5° 11′ 48.593″ N
19	A19	97° 5′ 19.953″ E	5° 10′ 33.501″ N
20	A20	97° 4′ 48.276″ E	5° 9′ 59.434″ N
21	A21	97° 6′ 47.738″ E	5° 11′ 43.389″ N
22	A22	97° 7′ 20.760″ E	5° 10′ 49.728″ N
23	A23	97° 7′ 44.831″ E	5° 10′ 40.229″ N
24	A24	97° 6′ 31.648″ E	5° 10′ 2.953″ N
25	A25	97° 8′ 32.429″ E	5° 9′ 11.985″ N
26	A26	97° 8′ 58.723″ E	5° 8′ 10.112″ N

Fig. 1. Data collection points for tremor vibrations in Banda Sakti District (10 points).

several measurement points in each district in the city of Lhokseumawe. At each measurement point, a three-component seismometer is installed to obtain the results of the soil's vulnerability in the area. each measurement data is observed for 30 minutes at each point [16–17].

2. THEORY

Earthquake loads that work on building structures can be determined by doing calculations ground motion on the surface. Land movement parameters needed for planning of earthquake resistant infrastructure is maximum

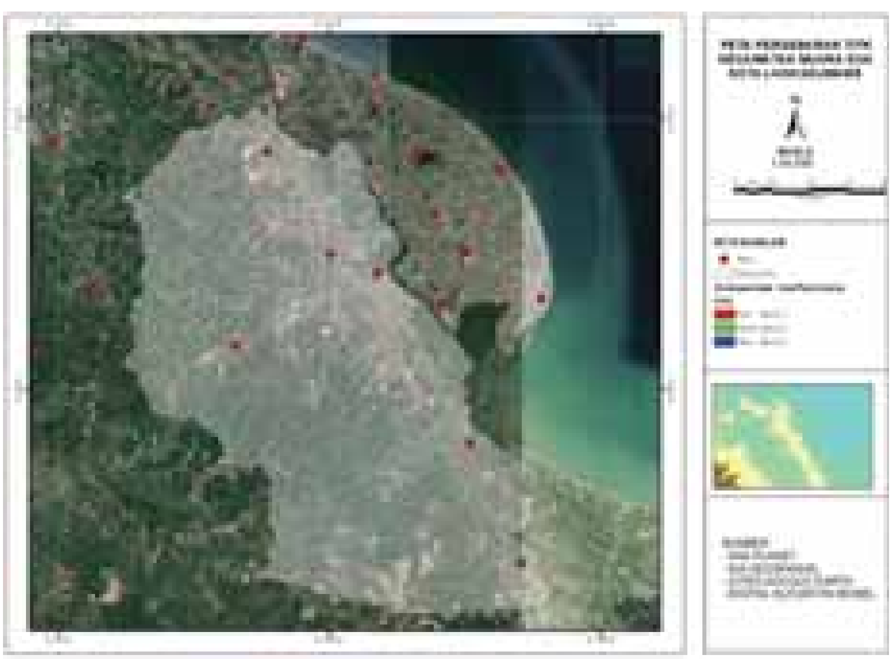


Fig. 2. Data collection points for tremor vibrations in Muara Dua District (10 points).

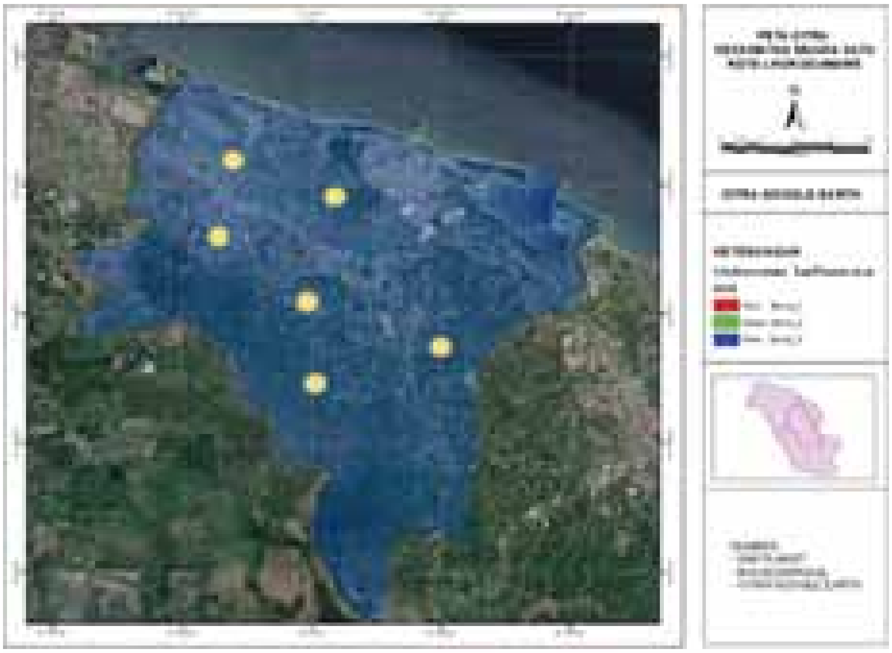


Fig. 3. Data collection points for tremor vibrations in Muara Satu District (6 points).

ground acceleration (Peak Ground) Acceleration/PGA), earthquake spectra response (seismic) response spectra) and history of acceleration time earthquake (acceleration time history/TH) [18].

The size PGA, Response Spectra and TH can be determined by analyzing wave propagation earthquake from bedrock to ground level. Movement of earthquake waves from bedrock to the surface is affected by the

Fig. 4. The process of taking field data with the research team.

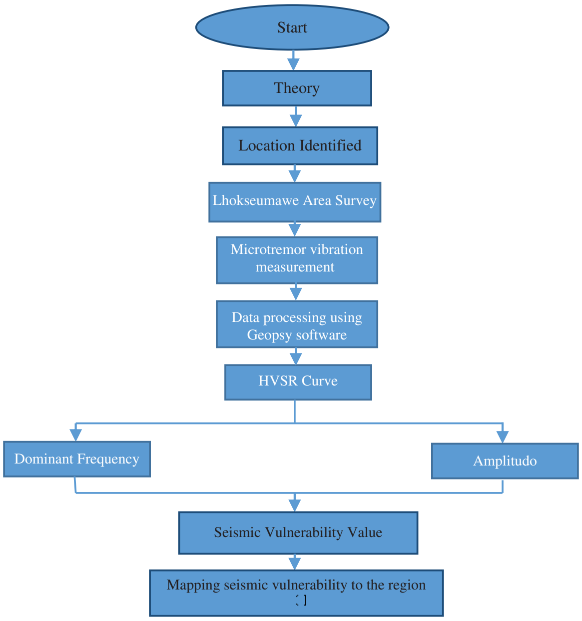


Fig. 5. Research flow chart.

condition of the soil layer where the earthquake wave propagates [4, 5].

The best way to look for amplification factors is to make observations see how the local geology influences at the time an earthquake occurred. Observation done by observing earthquake waves which is captured on the bedrock and on the surface soil. With recording data of earthquake waves on bedrock and on the surface, it can predicted the magnitude of the amplification factor layer sediment at one point of observation. Tools that used to record waves earthquake is a seismometer. To guarantee accuracy of recording earthquake waves then placement of seismometers in general carried out at points adjacent to source of the earthquake. Another approach that can also be done to predict the amplification factor is by conducting microtremor research [6]. Microtremor Research done by utilizing waves ambient (ambient vibrations) that appear on around the location of the seismometer. Analytical approach to predict the value of the amplification factor Nakamura's introduction was very easy because it ignores the geological conditions at the location observation. To get a factor value Nakamura's amplification introduced one analytical method known as Horizontal to Vertical Spectral Ratio (HVSR) [19].

Microseismic signals that have been successfully recorded by a three component seismometer will be filtered with a frequency value below 1 Hz [7].

3. MATERIAL AND METHODS

This research was conducted in the Lhokseumawe City area. Determination of data collection points is based on the ease of recording microtremors (not following certain rules) because in the Nakamura method the data analysis process does not depend on the distance between measurement points. The distance between points is determined by degrees of Longitude and Latitude, data recording at each point is carried out for ±30 (thirty) minutes [20]. In this study, recording was carried out at 26 (twenty six)

Table II. HVSR spectrum.

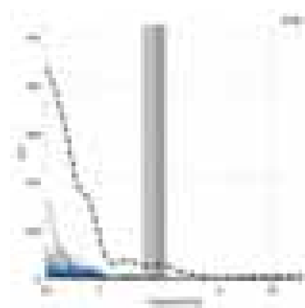
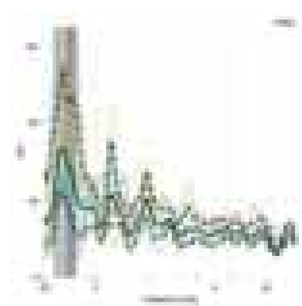
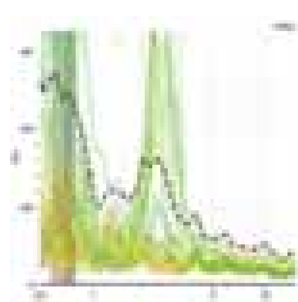
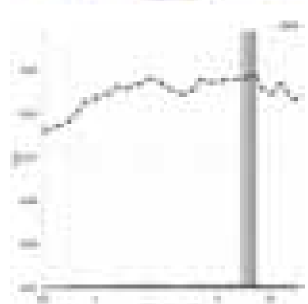
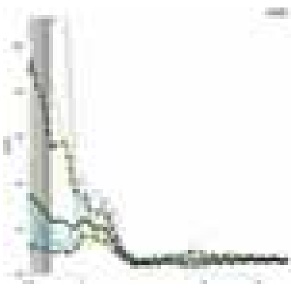
No.	Point	Spektrum	Nilai f_o, A
1	$A1$		$f_0 = 2,1907$ Hz $A = 2,1075$
2	$A2$		$F_o = 0,06$ Hz $A = 62$
3	$A3$		$f_0 = 0,6823$ Hz $A = 0{,}0988$
4	$A4$		$f_0 = 7,4$ Hz $A = 0{,}0013$

Table II. Continued.

No.	Point	Spektrum	Nilai f_o, A
5	*A*5		$f_0 = 0{,}59$ Hz $A = 2{,}9$
6	*A*6		$F_o = 3{,}0604$ Hz $A = 3, 15067$

points spread across three districts, namely Banda Sakti District (10 points), Muara Dua District (10 points) and Muara Satu District (6 points), with the coordinates of the measurement points as seen in Table I.

A number of microtremor vibration measurement points were taken in 3 districts in Lhokseumawe City. Measuring points of 26 points based on Table I are taken based on the order of the grid on the map [21].

In Banda Sakti District as Figure 1, 10 grid-based measurement points are considered to cover the whole area. The measurement points are sought not to be in the soil or hills. Likewise in Figures 2 and 3, which illustrates the point of taking tremor data in Muara Satu and Muara Dua. Figure 4 explains the documentation of taking tremor data for several days in several sub-districts in the city of Lhokseumawe [22–24].

Based on Figure 5, the entire stage of the study is the interpretation of data embodied in the Seismic Vulnerability Map, this research is planned and targeted for 2 (two) years with the following stages [25]:

I. 1st Year (2019), 26 data points were recorded (recorded) within the Lhokseumawe City area to obtain the dominant frequency value at each point. This frequency value becomes the basic reference in determining the seismic vulnerability index (Kg) value [26];

II. The 2nd Year (2020), the seismic vulnerability index (Kg) was determined and data interpretation was based on the dominant frequency values obtained in the year I. The final results of this study were the Seismic Vulnerability Map of Lhokseumawe City.

4. RESULT AND DISCUSSION

In this research microtremor data processing uses the HVSR method which produces an H/V curve. Argue that the H/V curve is formed from secondary waves, but the effect of large Raylegh waves can affect the shape of the H/V curve so that it is noise that must be removed. The H/V curve produces the dominant frequency value ($f0$) and amplification factor (A) used in the calculation of the seismic vulnerability index (Kg). dominant frequency value ($f0$), amplification factor (A) and seismic susceptibility index (Kg) are visualized by microzonation. This is done to determine the distribution of the level of vulnerability of an area if an earthquake occurs in the Lhokseumawe City area.

Recording data at 26 research location points in the city of Lhokseumawe for 2019 only obtained dominant frequency values for 6 locations that were processed using Geopsy software. The results obtained are shown Table II.

The H/V spectrum produces the dominant frequency values and amplification (A) that are used to calculate the seismic vulnerability index (Kg).

5. CONCLUSIONS

The results obtained from this study are the seismic susceptibility cm/s^2. This is closely related to the total amount of damage to buildings in Lhokseumawe City due to the 2004 earthquake. The results of this study are the existence of areas that are very susceptible to seismic namely Ujung blang and Banda Sakti villages with seismic vulnerability index values (Kg) ranging from 0 cm/s^2–30542.32 cm/s^2. The highest value is located at Ujong Blang villages which is 10397.1 cm/s^2. This is closely related to the total amount of damage to buildings in Lhokseumawe City due to the 2004 earthquake.

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References

1. Haerudin, N., Rustadi, R., Fitriawan, H., Siska, D. and Farid, M., **2019**. Earthquake disaster mitigation mapping by modeling of land layer and site effect zone in the kota baru of south lampung. *Jurnal Ilmiah Pendidikan Fisika Al-Biruni, 8*(1), pp.53–61.
2. Caffagni, E., Eaton, D.W., Jones, J.P. and van der Baan, M., **2016**. Detection and analysis of microseismic events using a matched filtering algorithm (MFA). *Geophysical Journal International*, *206*(1), pp.644–658.
3. Teekaraman, Y., Ramya, K. and Nikolovski, S., **2019**. Solution for voltage and frequency regulation in stand alone micro grid using hybrid multi objective symbiotic organism search algorithm. *Energies, 12*(14), pp.1–16.
4. Tejeswini, M.V., Jacob, I., Raglend, Yuvaraja, T. and Radha, B.N., **2019**. An advanced protection coordination technique for solar in

feed distribution systems. *Ain Shams Engineering Journal*, *10*(2), pp.379–388.

5. Gualtieri, L., Stutzmann, E., Capdeville, Y., Ardhuin, F., Schimmel, M., Mangeney, A. and Morelli, A., **2013**. Modelling secondary microseismic noise by normal mode summation. *Geophysical Journal International, 193*(3), pp.1732–1745.
6. Chen, H., **2014**. Development status of micro seismic monitoring technology in China. *IOSR Journal of Engineering, 4*(1), pp.16–19.
7. Aminzadeh, F., Tafti, T.A. and Maity, D., **2013**. An integrated methodology for sub-surface fracture characterization using microseismic data: A case study at the NW Geysers. *Computers & Geosciences, 54*(2), pp.39–49.
8. Sugianto, N., Farid, M. and Suryanto, W., **2016**. Local geology condition of Bengkulu city based on seismic vulnerability index (Kg). *ARPN: Journal of Engineering and Applied Sciences, 11*(7), pp.4797–4803.
9. Susilo, A. and Wiyono, S.H., **2013**. Frequency analysis and seismic vulnerability index by using nakamura methods at a new artery way in porong, Sidoarjo, Indonesia. *International Journal of Applied Physics and Mathematics, 2*(4), pp.227–230.
10. Teekaraman, Y., Ramya, K., Hariprasath Manoharan and Abirami, **2019**. State approximation in power system by using quasi derived originating procedure. *Measurement, 146*(16), pp.924–929.
11. Wang, X.L., Zwiers, F.W., Swail, V.R. and Feng, Y., **2009**. Trends and variability of storminess in the northeast atlantic region, 1874–2007. *Climate Dynamics, 33*(7–8), pp.1179–1195.
12. Yuvaraja, T. and Ramya, K., **2018**. Vector control of PMSM take over by photovoltaic source. *Applied Computational Electromagnetics Society*, *33*(2), pp.228–231.
13. Yuvaraja, T. and Ramya, K., **2018**. Analysis of wind turbine modeling using TSMC techniques. *COMPEL: The International Journal for Computation and Mathematics in Electrical and Electronic Engineering*, *37*(6), pp.1981–1992.
14. Yuvaraja, T. and Ramya, K., **2018**. Discretionary controller for hybrid energy storage system based on orderly control considering commercial value in decentralised microgrid operation. *COMPEL: The International Journal for Computation and Mathematics in Electrical and Electronic Engineering*, *37*(6), pp.1969–1980.
15. Ramya, K., Teekaraman, Y. and Ramesh Kumar, K.A., **2019**. Fuzzy based energy management system with decision tree algorithm for power security system. *International Journal of Computational Intelligence System, 12*(2), pp.1173–1178.
16. Teekaraman, Y., Pranesh Sthapit, Choe, M., Kim, K., **2019**. Energy analysis on localization free routing protocols in UWSNs. *International Journal of Computational Intelligence System, 12*(2), pp.1526–1536.
17. Yuvaraja, T. and Ramya, K., **2019**. Hierarchical distributed model scheme implementation in DC μgrid for numerous ground faults condition. *International Journal of Electrical Engineering & Education, 56*(4), pp.348–363.
18. Yuvaraja, T. and Ramya, K., **2019**. Statistical data analysis for harmonic reduction in 3Ø-fragmented source using novel fuzzy digital logic switching technique. *Circuit World*, *45*(3), pp.148–155.
19. Yuvaraja, T. and Ramesh Kumar, K.A., **2020**. Fuzzy control in H bridge MLI for solar PV system to enhance load sharing. *International Journal of Electrical Engineering & Education*, *57*(2), pp.64–72.
20. Yuvaraja, T. and Ramesh Kumar, K.A., **2020**. Enhanced frequency shift carrier modulation for H bridge multilevel converter to conquer the impact of instability in deputize condenser voltage. *International Journal of Electrical Engineering & Education*, *57*(3), pp.152–160.
21. Yuvaraja, T., Ramya, K. and Gopinath, M., **2018**. Meandering vector control strategy as D-STATCOM in renewable cluster grid for power optimization. *Materials Today: Proceedings*, *5*(1), pp.1257–1263.
22. Yuvaraja, T. and Ramya, K., **2016**. Implementation of control variables to exploit output power for switched reluctance generators in single pulse mode operation. *IJE Transactions A: Basics, 29*(4), pp.505–513.
23. Yuvaraja, T. and Ramya, K., **2016**. Visual and surface properties of CdTe thin films on CdS/FTO glass substrates. *International Journal of Electrical and Computer Engineering, 6*(2), pp.468–473.
24. Sharmila, A., Saini Ankur, Shubham Choudhary, Yuvaraja, T. and Rahul, S.G., **2019**. Solar powered multi controlled smart wheelchair for disabled: Development and features. *Journal of Computational and Theoretical Nanoscience, 16*(11), pp.4889–4900.
25. Ramya, K., Yuvaraja, T., Shiny M. Lorate, and Saanjanna, Y., **2019**. Energy balance analysis an impact of temperature variation in unified hydrogen based opto-source. *Journal of Computational and Theoretical Nanoscience, 16*(11), pp.4807–4811.
26. Yuvaraja, T. and Ramya, K., **2016**. A vigorous simple most extreme force point tracker for PV battery charger. *Environmental System Research*, *5*(25), pp.1–11.

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