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Integrating IoT Technology for Improved Distribution Transformer Monitoring and Protection

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Abstract **– This research study focuses on developing and implementing an IoT-based distribution transformer monitoring and protection system. The traditional methods of transformer protection and monitoring have proven to be inefficient and time-consuming, leading to the need for a more modern and effective solution. In this study, a low-cost prototype system is proposed to handle and control the main functions and problems of the distribution transformer through the internet. The proposed system allows for easy monitoring and protection of the transformer, enabling electric companies to improve efficiency and reduce labour and tool costs. The system is validated using Proteus software to simulate and obtain results from the hardware. The system results are displayed in multiple ways, including LCD, system bar, and internet, making it easier for electric companies and consumers in developing countries like Pakistan to monitor and control distribution transformers efficiently. This research study aims to provide valuable insights into the effectiveness of IoT-based distribution transformer monitoring and protection systems and their potential benefits in enhancing transformer performance and efficiency.**

Keywords **– IoT, monitoring, temperature protection, transformer.**

I. Introduction

With the increasing population, towns are expanding daily, and their power demand is increasing with time and population. The power demand is directly proportional to the population, where increasing demands need more power production or generation. The power produced to reach consumers must follow a specific route, starting with generating stations and ending with distribution units. These distribution units include distribution transformers.

The transformer is an electrical device used to step up or step-down voltages, which work on the principle of mutual induction [1]. The distribution transformer [2] is one of the essential devices in the electrical system, which does not require more maintenance than other devices. However, because of its importance in providing the required power to consumers, this article focused on its major maintenance parameters. Protecting transformers is essential to keep the power system running and stable.

The distribution transformer is a step-down transformer used to distribute the power to different consumers, usually used to step down 11 kV to 220 V (Phase to Neutral) and 440 V (phase to phase). It has two types of pole-mounted [3] and ground-mounted distribution transformers.

All consumers require a consistent supply, which is only possible with complete control, protection, and monitoring of all the essential and effective parts of the system. The distribution transformer is one of the most important essential devices.

The suggested solution uses a microcontroller and the Internet of Things (IoT) [4] to monitor and protect a Pole Mounted Transformer (PMT) (see Fig. 1). With the help of such a system, the transformer may be protected and monitored without additional resources, personnel, money, or time. Moreover, in this proposed system, the input and output power of the transformer to determine the losses, efficiency, and electricity consumption were focused.

Fig. 1. Pole Mounted Transformers [5].

The goals of the prototype model are as follows:

- Overload protection of DT (distribution transformer);
- DT under and over-voltage protection;
- DT oil level monitoring;
- DT temperature, humidity, and external cooling system monitoring when overheated;
- IoT-based display and control of the foregoing protection and monitoring techniques over the internet.

The structure of this research paper is designed to present the proposed integration of IoT technology for improved distribution transformer monitoring and protection clearly and concisely. Section II provides a comprehensive literature

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review of traditional transformer protection and monitoring methods. Section III details the proposed system model and specifications, highlighting its unique features and benefits. The paper then presents the proposed system's simulation and hardware validation results in Section IV, demonstrating its effectiveness in improving transformer performance and efficiency. Finally, Section V concludes the paper by summarising the research findings and discussing the potential benefits of IoT-based distribution transformer monitoring and protection systems in electrical engineering.

II. Literature Review

Compared to other electrical devices, the transformer is old electrical equipment with a simple design. The mutual induction principle states that when electric current travels through a conductor, an electromotive force (EMF) [6] is induced, which then flows through the conductor and allows electric current to flow. The transformer steps up or down the voltages and currents depending on the number of turns on the primary and secondary sides. The transformer is classified into four types: distribution transformer [7], power transformer [8], autotransformer [9], and current transformer [10]. The distribution transformer is used in the distribution side of the electrical system to step down voltages from substations (typically 11 kV to 440/220 V).

The protection of transformers has many schemes and ways introduced when the transformer is used for the first time. Because of the faults in transformers, innovators are forced to develop solutions and protection strategies to overcome the various sorts of faults in transformers. With time, these protection strategies reveal some flaws, prompting others to devise new ways to protect transformers. In [11], work on transformer protection and theft control with the help of IoT [12] is performed, where it calculates the losses of the transformer and provides intelligent protection. However, the work is not focused on monitoring the transformer, protection from heat damage, and low oil level protection.

The references [13], [14] drive the importance of the work where the primary transformer blasts and fires occur because of the slow response due to unknown reasons.

In [15], the authors used the concept of only transformer monitoring using the Global System for Mobile communication (GSM) technology. GSM is second-generation mobile communication technology requiring a Subscriber Identity Module (SIM) to work [16].

Similar work in [17], work focused on monitoring the transformer data using an IoT, can be found in the proposed prototype of this article. Similar data as of [17] were used but with the feature of protection.

III. Proposed System Model and Specification

The Arduino mega [18] will regulate and measure the readings of the distribution transformer with the help of sensors and other hardware components in the proposed system.

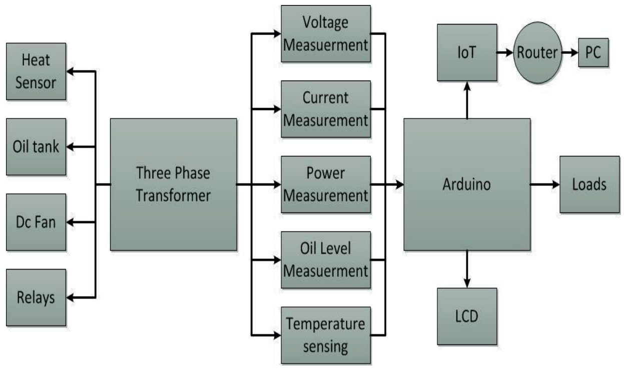

Fig. 2. System block diagram.

The Arduino will link all parameters to the ESP8266, which will be connected to the internet and deliver the data to the server or site. The parameters can be previewed and controlled easily via the internet. The details of the components used are as follows.

A. Three Phase Transformer

The transformer is a small three-phase transformer with three windings in each phase. To design the three-phase transformer, there were some parameters which are calculated as follows:

- Core area = Horizontal side × Vertical side of the reel;
- Core area = 2.5 cm × 3.5 cm = 8.75 cm^2;
- 42 / core area = 42 / 8.75 = 4.8;
- Voltage × 4.8 = 220 × 4.8 = 1056 turns;
- N1 = N2 = 1056;
- P = 500 W (3 phase) = 288 W (single phase);
- I = 2.85 A (3 phase) = 1.6 A (single phase);
- S = 1 kVA (3 phase) = 577 kVA (single phase).

Fig. 3. The designed transformer.

B. Relay

The suggested model for integrating IoT technology for improved distribution transformer monitoring and protection system incorporates a 5 V DC single pole double throw (SPDT) relay [19] that can be triggered to open or close the circuit in response to supplied pulses to its load. The relay serves as a critical component for the protection and control of the transformer. The proposed system utilizes an Arduino or the internet for relay control, enabling efficient and remote monitoring of the transformer performance.

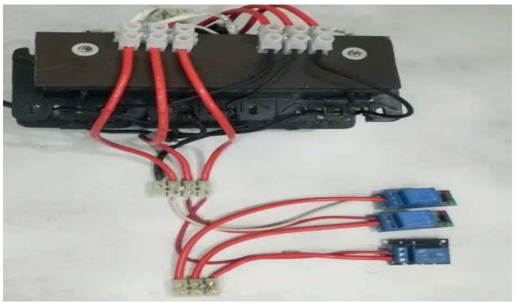

Fig. 4. Relay arrangements.

C. Electrical Wire

The wire used is a 7/29 wire gauge, which has 7 gauges and 29 strands for the input side and 7/20 strands for the output side and is used for general wiring. The wires are 20 meters long and come in red and black hues.

D. Arduino Mega

The Arduino Mega, an open-source microcontroller based on the ATmega2560 microchip, offers a simple and flexible solution for designing and producing a variety of electronic devices. The microcontroller features a 16 MHz crystal oscillator, 54 digital input/output pins, 16 analogue inputs, 4 UARTs (hardware serial ports), a USB connection, a power jack, an ICSP header, and a reset button. It comes equipped with all the necessary components to get started, such as a USB cable for computer connectivity and an AC-to-DC adapter or battery for power supply. The Arduino Mega's comprehensive features and open-source architecture make it an ideal choice for prototyping and developing electronics projects.

E. Power Factor Circuit

A circuit from [20] is used to determine power factors, which employs current and voltage transformers to measure power factors, and a zero cross detector to determine the phase difference between them.

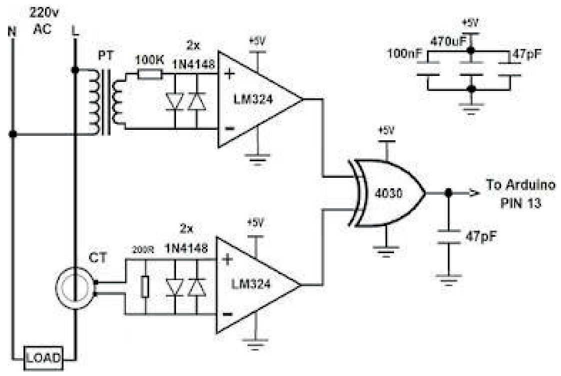

Fig. 5. Power factor circuit [20].

F. Voltage Sensor

The ZMPT101B sensor [21] measures voltage to determine over and under-load conditions. The sensor is made of a small potential transformer that steps down and rectifies the voltage from the power source into DC voltages, which are then connected to the Arduino's analogue pin.

G. Current Sensor

To ensure the safety and integrity of the load and transformer, the proposed system incorporates a current sensor that measures the RMS current of the system and detects overload conditions. Specifically, the system utilizes an ACS712 current sensor [22] rated for 5A, which uses the Hall Effect to measure AC and is equipped with all the necessary circuitry for current detection in a compact module. By incorporating this current sensor, the system can accurately measure current and prevent potential faults that could damage the load or transformer.

H. Temperature Sensor

The temperature sensor monitors and protects the transformer by monitoring its temperature and humidity to prevent it from overheating [19].

I. Oil Level Sensor

An ultrasonic sensor is used to monitor the oil level. There are three different levels of oil: low, medium, and full.

J. Oil Tank

A small tank is used to demonstrate how the tank works and how much oil is inside. The 11cm-long tank has a valve to drain the transformer's oil, allowing for various oil levels.

K. Power Supply

A 5 V DC power supply capable of delivering 500 mA has been built to provide a stable power source for the proposed prototype's circuits. The power supply consists of a voltage transformer, diodes, capacitors, and a voltage regulator IC 7805 that regulate the transformer output to 5 volts. Given the low current rating of the desired supply, the proposed model employs three separate power supplies, one for each phase, to ensure a consistent, rectified, and adequately shaped DC voltage output for the circuit.

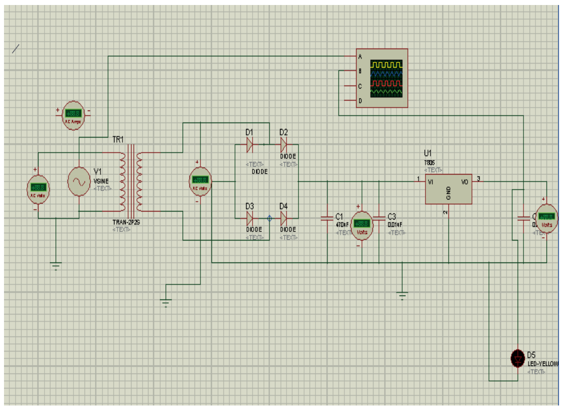

Fig. 6. Power supply circuit.

L. Liquid Crystal Display

Liquid Crystal Display (LCD) displays the parameters, results, calculations, and measured data in the transformer place. The LCD used is 20 by 4, where 20 are the columns, and 4 are the rows.

M. Cooling Fan

A cooling fan is used to demonstrate the cooling purpose of the transformer where it will be operated when overheating conditions will meet, and it will keep running until the temperature of the transformer is cooled down.

Table I represents the materials used in this prototype model with their details.

TABLE I

MATERIALS USED

#	Component Name	Quantity	Details
1	Three Phase Transformer	1	1 kVA
2	Relay	5	5 V dc
3	Electrical Wire	20 m	7/30 and 4/30
4	Arduino Mega	1	-
5	Power factor circuit	3	CT, PT, XOR
6	Voltage Sensor	3	ZMPT sensor
7	Current sensor	3	ACS 712 (5 A)
8	Temperature Sensor	3	DHT11
9	Oil Tank	1	11 cm length tank
10	Oil Level Sensor	1	Ultrasonic sensor
11	Power Supply	3	DC (5 V)
12	IoT module	1	ESP8266
13	LCD	1	20 by 4
14	Cooling Fan	1	12 V DC small fan
15	Tools	-	Tap, screw driver, etc.

Transformer monitoring is done by transformer tripping, and the protection stage is used to make the transformer safe by using relays. Cooling the transformer is important to save the transformer from getting overheated.

System data can be shown in two ways: on an LCD in the control room or on the transformer, and on the internet, where data can be displayed to multiple locations at the same time regardless of the operating system (e.g., mobile, desktop, browser or any device with internet).

Based on these computations, the system will calculate input and output power, transformer losses, and efficiency.

$$\text{Efficiency} = (\text{Output Power} / \text{Input power}) \times 100 \quad \text{Losses} = \text{Input power} - \text{Output power} \quad (1)$$

To make Arduino's built-in microprocessor interpret the data, the analogue data will be transformed into digital data using an Analog-Digital Converter (ADC). The Router connects the IoT chip to the internet using a specific Internet Protocol (IP) address. The application will establish a specific command to monitor the displayed data, allowing the system to be remotely monitored and operated without manual labour.

IV. RESULTS

A. Simulation Results

Proteus software is used to simulate the various circuitries used in the project. Temperature is measured using a DHT11 sensor, which measures both humidity and the temperature of the transformer, assisting in detecting an overheating scenario. A small DC fan is used to demonstrate the transformer's cooling function, which will turn on whenever the temperature exceeds the normal range. The conditions set in the program are provided in Table II.

TABLE II

FAULTS AND CONDITIONS

No.	Parameter	Condition
1	Overvoltage	> 240 V
2	Under voltage	< 200 V
3	Overload	> 1.5 A
4	Over-temperature	> 35 °C
5	Oil level Empty	> 9 cm
6	Oil level Low	> 7cm & < 9 cm
7	Oil level Medium	> 4cm & < 7 cm
8	Oil level Full	< 4 cm

Different loads simulate the power factor (PF) circuit (capacitive, inductive, and resistive).

The circuit findings are calculated for various loads.

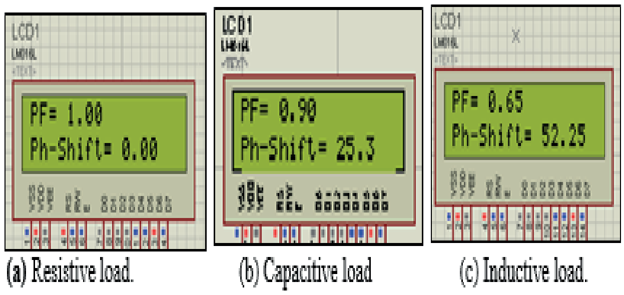

Fig. 7. Results of the PF with different loads.

The exhibited results were verified in the hardware portion, nearly identical to those simulated, demonstrating that the task was completed as expected and desired. The power factor data were confirmed using the premise that the power factor of a resistive load must be one, where we applied a bulb load and reviewed the results, which were as expected, proving that the power factor reading was correctly measured. The project's designed power supply is simulated to determine the supply's exact output voltage and current (see Fig 8). The circumstances of excess and under-voltage are simulated and tested. The simulation of the three conditions is shown in Figs. 9–11 (normal, over, and under-voltage conditions).

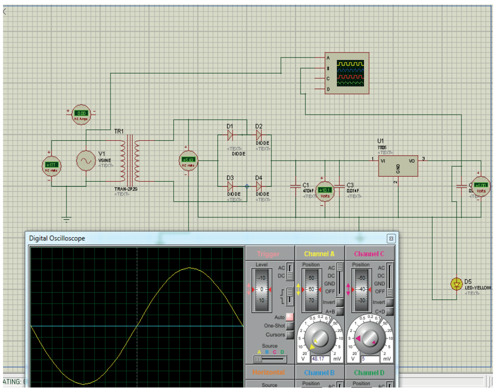

Fig. 8. Power supply simulation and output waveform.

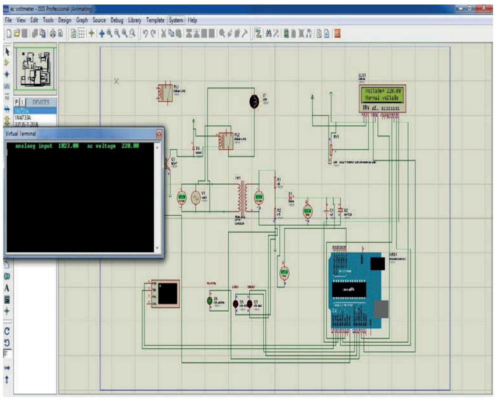

Fig. 9. Normal condition.

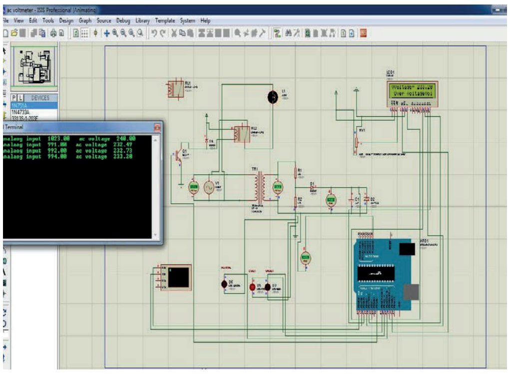

Fig. 10. Over-voltage condition.

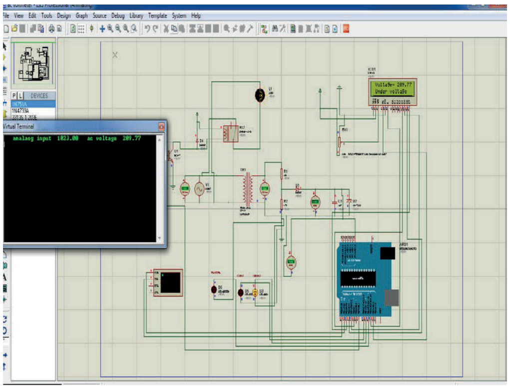

Fig. 11. Under-voltage condition.

B. Hardware Results

Due to a limited budget and resources, a prototype model was created to support the proposed notion. All of the significant aspects and parameters are included in the design. Separate components without specified circuits include the relay, voltage sensor, current sensor, transformer, cooling fan, and oil tank. On the other hand, the power factor, power supply, and LCD circuits are all designed on the printed circuit board (PCB).

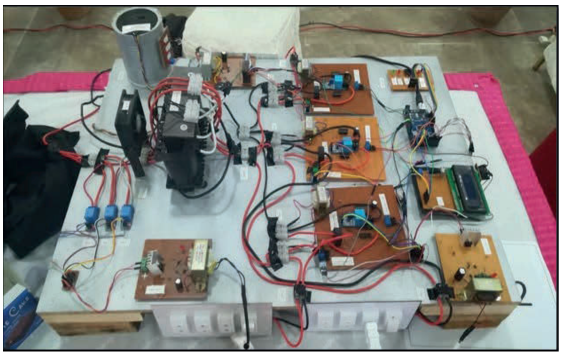

Fig. 12. Prototype hardware.

Three approaches were used to display the results of the planned and designed hardware:

- System Status Bar;
- LCD;
- Internet.

These three methods all achieve the same goal of ensuring that the suggested design will supply the correct data and that the data will be controllable and visible in several locations simultaneously.

C. System Status Bar

The system status and working condition are represented using LEDs, as shown in Fig. 13.

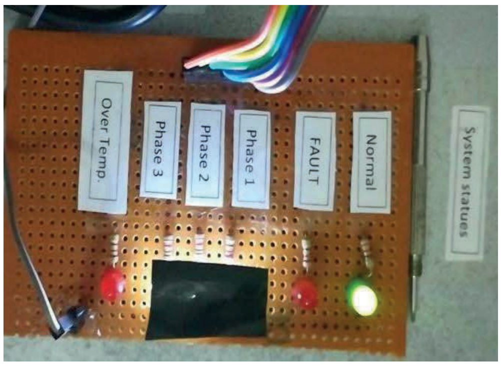

Fig. 13. Status Bar.

The statutes of each phase, faults, and other parameters are displayed using LEDs, which help detect the faults occurring on the transformer.

D. LCD Results

Different measured and calculated parameters are shown in LCD, where the results are shown with the delay of 1 second of each phase value results. The LCD results for each phase (e.g., V1, V2, and V3) can be seen in Fig. 14.

Fig. 14. LCD results.

E. Android Application (TCP/UDP Terminal)

Results will also be shown on the internet to the lineman, control room, or any related person with the help of a browser or mobile application that must be installed on the mobile phone.

Fig. 15. Results of the system in the android application (TCP/UDP Terminal).

Fault conditions and alerts will be sent automatically when the fault occurs to the app, and the required circuit switching will be done. When the user wants to know about the current values and quantities of the system, some commands are sent to show the data, which can be seen in Table III.

TABLE III
SOFTWARE COMMANDS

No.	Command	Working
1	"1"	Shows the value of voltage, current, power factor, and power of Phase 1
2	"2"	Shows the value of voltage, current, power factor, and power of Phase 2
3	"3"	Shows the value of voltage, current, power factor, and power of Phase 3
4	"x"	Shows the value of temperature, humidity, and oil level
4	"y"	Shows the values of apparent and reactive power, the efficiency of the three phases

V. CONCLUSION

Integrating IoT technology for improved distribution transformer monitoring and protection is a promising approach to enhance distribution transformers' reliability, efficiency, and safety and make their monitoring and protection faster than traditional methods. In this context, a prototype model has been developed, which employs the internet and Arduino to control the transformer remotely. The proposed concept can also be implemented using old methods such as GSM, but the internet is the preferred choice due to its availability and lower cost. Although other protection and monitoring techniques are available, they have the limitation of reprogramming. The objective of the proposed prototype system is to simplify, enhance, and accelerate transformer control. This low-cost approach benefits electric companies and consumers in developing countries. The Proteus software simulates the proposed prototype model, verifying its authenticity using the hardware results. To ensure the safety and security of the system parameters, the system findings are displayed in multiple ways (e.g., on an LCD, in the system bar, and on the internet). Furthermore, the proposed work could be improved by incorporating power factor improvement using a capacitor bank to maintain the power factor of the supply.

REFERENCES

[1] Q.-T. Ta, T. C. Le, S.-C. Khoo, and W.-N. Chin, "Automated mutual induction proof in separation logic," *Formal Aspects of Computing*, vol. 31, no. 2, pp. 207–230, Apr. 2019. https://doi.org/10.1007/s00165-018-0471-5

[2] K. Ashok, D. Li, D. Divan, and N. Gebraeel, "Distribution transformer health monitoring using smart meter data," in *2020 IEEE Power & Energy Society Innovative Smart Grid Technologies Conference (ISGT)*, Washington, DC, USA, Feb. 2020, pp. 1–5. https://doi.org/10.1109/ISGT45199.2020.9087641

[3] M. Pourakbari-Kasmaei, F. Mahmood, and M. Lehtonen, "Optimized protection of pole-mounted distribution transformers against direct lightning strikes," *Energies*, vol. 13, no. 17, Aug. 2020, Art. no. 4372. https://doi.org/10.3390/en13174372

[4] L. Atzori, A. Iera, and G. Morabito, "The internet of things: A survey," *Computer Networks*, vol. 54, no. 15, pp. 2787–2805, Oct. 2010. https://doi.org/10.1016/j.comnet.2010.05.010

[5] Business Recorder, "Around 200 000 people benefit from K-Electric's Ujala project." [Online]. Available: https://www.brecorder.com/news/332596 Accessed: Dec. 24, 2021.

[6] B. Polat and R. Daşbaşı, "On conservation of electromotive force in Hertzian electrodynamics," in *2020 International Conference on Electrical, Communication, and Computer Engineering (ICECCE)*, Istanbul, Turkey, Jun. 2020, pp. 1–6. https://doi.org/10.1109/ICECCE49384.2020.9179200

[7] R. R. Pawar, P. A. Wagh, and S. B. Deosarkar, "Distribution transformer monitoring system using Internet of Things (IoT)," in *2017 International Conference on Computational Intelligence in Data Science (ICCIDS)*, Chennai, India, Jun. 2017, pp. 1–4. https://doi.org/10.1109/ICCIDS.2017.8272671

[8] E. Ali, A. Helal, H. Desouki, K. Shebl, S. Abdelkader, and O. P. Malik, "Power transformer differential protection using current and voltage ratios," *Electric Power Systems Research*, vol. 154, pp. 140–150, Jan. 2018. https://doi.org/10.1016/j.epsr.2017.08.026

[9] Y. Chen, H. Wang, M. Zhu, M. Liu, and X. Cai, "Modular DC-DC auto-transformer: Topology, operation, and system design," *IET Power Electronics*, vol. 14, no. 13, pp. 2289–2302, Jul. 2021. https://doi.org/10.1049/pel2.12178

[10] N. Yan, J. Hu, J. Wang, D. Dong, and R. Burgos, "Design analysis for current-transformer based high-frequency auxiliary power supply for sic-based medium voltage converter systems," in *2020 IEEE Applied Power Electronics Conference and Exposition (APEC)*, New Orleans, LA, USA, Mar. 2020, pp. 1390–1397. https://doi.org/10.1109/APEC39645.2020.9124436

[11] S. Sridhar, H. Bharath, V. Vishvesh, K. V. Gowtham, and H. Girish, "IoT based-Transformer power theft detection and protection," *International Journal of Engineering Research*, vol. 5, no. 4, pp. 992–1128, 2016. [Online]. Available: https://www.academia.edu/27200338/IoT_based_Transformer_power_theft_detection_and_protection

[12] A. Ur Rehman, S. Ur Rehman, I. U. Khan, M. Moiz, and S. Hasan, "Security and privacy issues in IoT," International Journal of Communication Networks and Information Security, vol. 8, no. 3, pp. 147–157, Apr. 2016. https://doi.org/10.17762/ijcnis.v8i3.2074

[13] D. Patel, J. Juthani, H. Parikh, R. Bhavsar, and U. Darbar, "Distribution transformer overload protection tripping circuit," Int. J. Appl. or Innov. Eng. Manag., vol. 4, no. 3, pp. 255–259, Mar. 2015. [Online]. Available: https://docplayer.net/21049843-Distribution-transformer-overload-protection-tripping-circuit.html#google_vignette

[14] J. Sanguinetti, "Evaluation of highly efficient distribution transformer design and energy standards based on load," M.S. thesis, 2012. [Online]. Available: https://digitalscholarship.unlv.edu/thesesdissertations/1623/

[15] U. V. Waghmare, A. Agarwal, R. Rusia, A. Wankar, and P. Atkari, "Transform protection using microcontroller-based relay and monitoring using IoT and gsm," *Journal of Research in Engineering and Applied Sciences*, vol. 5, no. 2, pp. 65–70, 2020.

[16] S. U. Rehman, A. Hussain, F. Hussain, and M. A. Mannan, "A comprehensive study: 5G wireless networks and emerging technologies," in *Proc. 5th Int. Elect. Eng. Conf.*, IEP Karachi, Feb. 2020. https://www.researchgate.net/publication/342109635_A_Comprehensive_Study_5G_Wireless_Networks_and_Emerging_Technologies

[17] W. K. A. Hasan, A. Alraddad, A. Ashour, Y. Ran, M. A. Alkelsh, and R. A. M. Ajele, "Design and Implementation smart transformer-based on IoT," in *2019 International Conference on Computing, Electronics & Communications Engineering (ICCECE)*, London, UK, Aug. 2019, pp. 16–21. https://doi.org/10.1109/iCCECE46942.2019.8941980

[18] S. Ur Rehman, M. H. Raza, and A. R. Khan, "Delta 3D printer: metal printing," *Journal of Electrical Engineering, Electronics, Control, and Computer Science*, vol. 5, no. 3, pp. 19–24, 2019. https://jeeeccs.net/index.php/journal/article/view/130

[19] S. Ur Rehman, H. Mustafa, and A. R. Larik, "IoT based substation monitoring & control system using Arduino with data logging," in *2021 4th International Conference on Computing & Information Sciences (ICCIS)*, Karachi, Pakistan, Nov. 2021, pp. 1–6. https://doi.org/10.1109/ICCIS54243.2021.9676384

[20] C. M. Diniş, G. N. Popa, and A. Iagăr, "Power factor measuring device using microcontroller for single-phase consumers," *Journal of Physics: Conference Series*, vol. 1781, no. 1, 2021, Art. no. 012046. https://doi.org/10.1088/1742-6596/1781/1/012046

[21] I. Abubakar, S. N. Khalid, M. W. Mustafa, H. Shareef, and M. Mustapha, "Calibration of ZMPT101B voltage sensor module using polynomial regression for accurate load monitoring," *Journal of Engineering and Applied Sciences*, vol. 12, no. 4, pp. 1077–1079, Feb. 2017. https://www.arpnjournals.org/jeas/research_papers/rp_2017/jeas_0217_5728.pdf

[22] A. T. N. Angga, A. M. Ravi, D. Priyambodo, A. M.a Realdo, F. Ivanuri, L. N. Safitri, N. P.a Zakariz, and M. S. Messiah, "Use of ACS 712ELC-5A current sensor on overloaded load installation safety system," *Applied Technology and Computing Science Journal*, vol. 4, no. 1, pp. 47–55, Jun. 2021. https://doi.org/10.33086/atcsj.v4i1.2088

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