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Intelligent IoT-Based Transformer Monitoring and Load Management System

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Abstract - The old systems have big problems when one transformer stops working. When this happens, it can cause the power to go out suddenly and the other good transformers get much work to do. It also takes a time to find and fix the problem because someone has to go and check it by hand. The power is out for a while. It costs more to fix. This happens because the whole system does not work well as it should.

This project is about making a smart system to watch over transformers and manage the load, on the transformers. The concept is to have better performance of the transformers, while being supervised by the smart system. It utilizes sensors to monitor voltage and current passing through the transformer, temperature, and the amount of work that the transformer is performing. If one transformer fails the system can find the problem. Test the other transformers to see how much they can do. Then it divides the work amongst them so that no one of them has much to do. When the other transformers can't keep up, the system sends a warning to the power people in charge to get a transformer to assist the other transformers until the broken transformer is repaired.

By watching the transformers all the time spreading the work out finding problems automatically and sending messages in real time the system stops big failures from happening reduces the time the power is out and makes sure people get power they can count on. It makes the system work better helps the transformers last longer and is a step, towards making the power distribution network smarter, safer and more reliable.

Keywords - Transformer Monitoring, IoT Load Management, Smart Grid, Raspberry Pi, Fault Detection, Load Sharing

I. INTRODUCTION

The electricity consumption is going up. This is putting a lot of pressure on the systems that deliver power the transformers that are used to distribute power. The transformers are very important because the transformers help control the voltage and the transformers make sure, we get the amount of power, from the transformers. We need the transformers to work properly so we can get the power we need from the transformers. These transformers can stop working. This happens when they get too hot or when they are overloaded. It also happens when we do not check on these transformers enough.

The way we take care of these transformers is not very good now. We usually just check on them by hand. Do not do much to protect them. This makes it really hard to find problems as they happen or to stop transformers from failing at the same time. When one transformer fails it can make the other transformers around it work hard and this can cause a big power outage.

In recent years, tremendous technological advances have been achieved, including the Internet of Things and embedded systems. This enables transformer monitoring through systems to be implemented. This paper introduces one of these systems that allows to monitor transformers continuously through the Internet of Things (IOT). It could also manages without manual input and automatically warn in case of any disturbance while it is away from the transformers, and make sure that we always have power, even if the transformers aren't working perfectly.

II.RELATED WORK

The monitoring and load management control of transformers is of critical importance. This is a very active field of research as solutions must be developed to make power distribution more reliable and efficient. In this portion of the work, the researcher will focus on the work of others in three areas that are important for the intelligent transformer monitoring and load management system we are discussing: systems that monitor things through the Internet, ways of managing loads and smart grid technologies. There are many intelligent transformer monitoring and load management systems in the spotlight.

2.1 IoT-Based Transformer Monitoring Systems

There are a lot of ideas out there regarding monitoring transformers' performances in real time via the internet. In 2020 Patil and his team developed a system that can use a phone and a special type of computer to measure, for example, how hot the oil is, how much electricity it is using and how much voltage is coming in. Kumar and Singh's system was pretty cool as they used the internet to send information to a website. This website made people aware of what was going on. In 2019, Sundaram and his team started observing other parameters such as voltage and power, using a computer.
Here are systems that demonstrate that remote monitoring of transformers is possible via the internet. Mostly just for

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taking in data and alerting when an issue occurs. They can't make their own decisions in order to solve issues, such as a transformer overheating. This is different since the system I'm referring to is able to see the data and adjust over time. Systems for monitoring the condition of transformers using IoT are extremely relevant to this.

2.2 Load Management and Relay-Based Switching Systems

Typically load management is performed using switching panels or simple over current protection relays. These relays disconnect the load when there is a problem. In 2018, Gupta and his colleagues designed a system that switches off unnecessary loads if the total demand is too high, based on a PIC microcontroller. In 2020, Mohan and his colleagues devised a method to switch loads from one distribution feeder to another with the help of a sort of computer. This system is able to identify faults in 200 milliseconds.

The thing is, these methods rely on a static plan – what loads to disconnect before determining if the back-up power can actually provide them with additional power. It's a different system that I am referring to. It always tests to see how much power both sources have, and only shares the load if the backup source has sufficient power. This way it prevents an overload. Moreover, none of the other systems with relays have a means of communication or indication of what is occurring during and after the switching of the load, making it difficult for any person operating the system to know what is happening in it during and after switching. These problems can be avoided through use of load management system and load transfer system. This proposed load management system is better as it takes advantage of load shedding mechanism as well as good load transfer scheme.

2.3 Smart Grid and Automated Distribution Systems

The cool thing about the smart grid is it's based on automation that makes the power distribution system function more efficiently. In 2005, some of the people named Amin and Wollenberg learned that if various components of the grid can communicate with one another, it is able to balance load and solve problems autonomously. Then some others, in 2012, did a study on the communication of the smart grid and they said that sharing data in real-time is a key factor in strengthening the smart grid. Arya and his team recently developed their own solution to load balance between the agents at the distribution transformer level and predicted the demand of the people using machine learning.

The problem is, these kinds of smart grid systems are generally created for the power company and require costly special equipment and software. This renders smaller entities, such as neighbourhoods, schools or rural areas less accessible to them. The system we're talking about can DO things, but at a much lower cost. It is built with the following computer parts: Raspberry Pi, PZEM sensors and relay modules and it uses free software tools. This allows smaller communities to afford and implement an affordable and effective grid system. The smart grid is a part of making our power distribution system better and our system is a big step forward in making it available, to everyone.

2.4 GSM and SMS-Based Alert Systems in Power Infrastructure

In power monitoring systems, there is a considerable usage of SMS alerts with GSM modules, since they are not connected to the Internet. For instance, Nwosu and his colleagues have created a system which, when it detected issues with transformers - either many amps or many volts - would send SMS alerts to engineers. So, Okonkwo and his team did something in 2019. They added individuals to the alert list. In this manner the important ones received the messages in first place. The system we're discussing is an SMS notification system. It is, about Okonkwo and his team and the system they operated on that utilizes these SMS alerts. It also has a website which presents the live situation and a small screen where information is displayed. If something goes wrong then it sends SMS notification at the time it attempts to solve the issue by turning things on/off, and moving loads around. This way, people are informed and the system is protected at the moment.

Research Gap

There are some issues with the existing systems. The following are not included: There is no provision to redistribute workload as necessary. They can also not make decisions on the fly. The monitoring, control and communication components are not effective. There is still lots of work to be done by operators.

These systems are hard to expand because they are too expensive and complicated. The new system we are suggesting is designed to fix all these problems. It is a low-cost and fully automated system that can be embedded into existing infrastructure. It overcomes the limitations of systems.

The proposed system addresses the absence of automated load redistribution mechanisms. It also improves real-time decision-making capabilities. In addition, it integrates monitoring, control and communication subsystems. The new system reduces the need, for operator intervention. It is also more scalable.

III. METHODS AND MATERIALS

The new system is an independent framework that constantly checks the transformer parameters moves loads around smartly and protects against overloads. It has features like power sensing switching that is controlled by relays a display that shows what is happening on site alerts that are sent remotely using GSM and a way to monitor everything from a browser all in one system. The system is divided into five parts: power sensing, control, switching, display and communication and web monitoring. These parts work together to make sure the system runs smoothly is reliable and works completely on its own without any issues. The transformer parameter monitoring system and the load redistribution system work together to deliver functionality. The system is fully autonomous and dependable making it a great solution, for monitoring and protection.

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A. Power Sensing and Data Acquisition

The system uses two PZEM-004T v3.0 energy measurement modules to keep track of parameters from Power Source 1 and Power Source 2 all the time. Each module tracks six things: voltage, current active power, energy consumption, supply frequency and power factor. The modules talk to the processing unit using the Modbus RTU protocol. This protocol is sent over channels. There is a background thread. It checks the sensors every 2 seconds. It uses the Modbus library, in Python. The Modbus protocol is used here.

The modules and the processing unit communicate with each other using Modbus RTU.The readings that are always being taken are stored in a shared memory cache. Shown on the monitoring interface in real time. The PZEM-004T v3.0 energy measurement modules are always capturing data from Power Source 1 and Power Source 2.

B. Embedded Control System

The core processing unit is made using a Python-based Flask application that runs on the Raspberry Pi 4 Model B. This part of the system looks at the power measurements all the time. Checks them against the threshold values that the operator has set to see what state the system is in.

When the system finds an overload, it starts a response to fix the problem. At the time it watches the total load from both sources to find out if there is a serious problem that needs to be fixed right away. The Raspberry Pi 4 Model B controls all the actions of the system including turning relays on and off cutting off power and sending alerts. The system saves what it was doing in a file. This includes things, like relay positions and threshold settings.

This is especially helpful if the load changes quickly. The Raspberry Pi 4 Model B. Then checks again. This helps it work properly and not get damaged. The core processing unit is, in charge of all these things.

C. Relay-Based Load Switching Mechanism

Raspberry Pi is connected to a board which has six relays, on it. The Raspberry Pi is actually connected to this board with the six relays. These relays do all the switching. We have relays R1 through R4 that help switch between sources. Then we have relays R5 and R6 that are like protectors for PS1 and PS2.

They make sure that if something goes wrong, they cut off the power to prevent any damage. All the relays work in a way that they are normally closed. This means that they usually connect the power source to the thing that needs power. If there is a problem the controller opens the relay and switches to a different power source.

The live and neutral wires are both switched at the time. This makes sure that the power is completely cut off. After some time, the system automatically goes back to normal. The relay is reset. The Raspberry Pi and the relay board work together. They make things happen when you use them.

The relay board is very important. It helps to keep the equipment safe so it does not get broken. The Raspberry Pi and the relay board are a team. The relay board protects the equipment when you are using the Raspberry Pi.

The relays R5 and R6 are very important because they protect PS1 and PS2 from overload.

D. Overload Detection and Load Sharing Logic

- The system uses steps one after another to find and fix overloads:
- It checks details from both sources every 2 seconds by continuously asking sensors for updates.
- The system then checks if the power being used is more than what's allowed for each source.
- Before doing anything, it waits 2 seconds to make sure the overload is not a quick spike.
- If the overload continues after 2 seconds the system automatically turns off the source that is overloaded by switching the relay.
- The load that was connected to the source that was turned off is then automatically transferred to the source that is still working.
- If both sources together are using power than they can handle the system shuts down using the DTR emergency protocol and turns off both sources.
- The system also keeps a record of every switch and alert, on the monitoring dashboard with times so that operators can look at them later.

E. Local Display and GSM Alert Communication

The system uses a 16×2-character LCD panel that is connected to a PCF8574 I2C backpack module. This gives people at the site a way to see what is going on. The display shows the voltage and power for both sources when everything is working normally. If something goes wrong it starts scrolling through messages about what is wrong and how the load is being shared.

The display updates are handled by a part of the program that works in the background. This way the LCD display always does what it is supposed to do. Does not get in the way of the system when the system is, in charge or trying to figure out what is going on.

When the system has a problem it sends a message to the people who need to know about the system problem. The system uses a GSM module to send these messages to the people who need to know about the problem, with the system. The GSM module and the PS2 PZEM sensor share the connection so they have to take turns using it. The sensor uses

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the connection first then the GSM module can send its message. The system sends messages for things like when the load sharing starts when a relay is turned off and when there is an emergency. The system waits for 60 seconds before sending another message so people do not get many messages at once if something is wrong, for a long time.

F. Web Dashboard and Remote Monitoring

This interface talks to the Flask backend using API calls. It gets system data every 3 seconds. The interface does a lot of things. Here are some of them:

- It shows numbers for voltage, current, power and frequency for both sources
- It shows what is happening with the relays and how the load is distributed
- Users can set their limits for when a source is overloaded
- It shows charts of how powers used over time
- It shows a list of all events with the time they happened
- It shows a picture of the circuit that changes when the relays switch
- It has a simulation mode so users can try it without needing the hardware

G. System Workflow and Process

On startup it initializes all the hardware. Recalls the actions of things previous to it. The PZEM sensors begin to take a measurement every 2 seconds. These measurements are checked against the limits the system has. If everything is normal the two power sources work on their own.. In case of a fault, the system switches relays to correct the fault. Transfers a load to the other source. If a fault, or overload occurs, it alerts the LCD display and to the web dashboard, and by SMS. Data is received to the interface every 3 seconds and everything is updated. It records all the events which can be reviewed later. The interface is constantly transmitting information and changing its display. It is important that the system workflow be preserved. The Monitoring Dashboard is where users can be made to know what is going on. There are several features to the system. The interface is very useful. The system is made to work. Monitoring of the system is done using the browser based interface.

H. Hardware and Software Specifications

Hardware Components:

• Raspberry Pi 4B –Micro Processor
• PZEM-004T Sensors – Power measurement
• 6-Channel Relay Module – Load switching
• 16×2 LCD Display – Local monitoring
• GSM Module – SMS communication
• CP2102 Converter – Serial interface

Software Stack:

• Backend: Python, Flask
• Sensor Interface: minimal Modbus
• GPIO Control: RPi.GPIO
• LCD Driver: smbus2
• GSM Communication: pyserial
• Frontend: The Software Stack uses Next.js, React and Tailwind CSS for the frontend.
• Communication: REST APIs

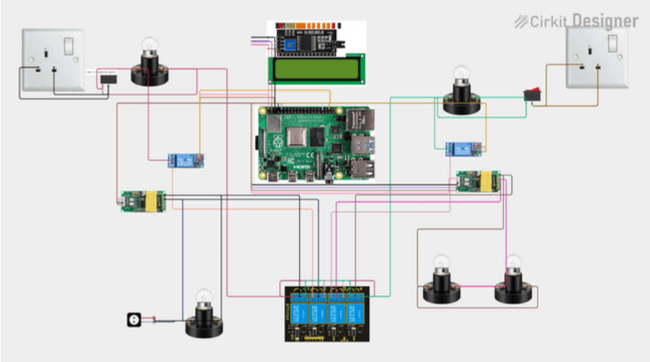

Fig 1. Architecture Diagram

IV . EXPERIMENTAL STUDY

This section is concerned with the implementation details and experimental evaluation result of the proposed system on transformer parameter tracking and load distribution management. The system was tested to determine if it can detect overload conditions for time electrical measurements and send an alert. Embedded hardware and web-based software technologies were used to develop the system. The sensor data and physical relays were controlled by a main processing unit, the Raspberry Pi 4 Model B. Next.js was used to create the monitoring interface. Was interactive. The back-end was implemented using a Flask server framework, which received API requests and processed the sensor data. The system underwent testing in scenarios to find out how it will perform in the real life situation. The system had a standard load and operated without any problems in the test. It measured voltage, current and displayed them on a web dashboard and LCD display. The system was put under a load on the test to see how it copes under the load. The overload was detected by the system. Launched load redistribution progress. It found the source point without any manual intervention and shifted the load to the other source without any manual efforts.

The system refreshed the LCD panel and web dashboard to display the system status. Additional tests were conducted to determine the capabilities of the system during an emergency. The system triggered the alarm. SMSed to the designated person. It also alerted on the web dashboard and LCD display. This testing of the communication between each system module was also done. The data transfer between the front and back ends was both rapid and error-free. The serial communication was stable and without errors among the sensing modules, the GSM unit and the raspberry pi controller. The system was also subjected to stability tests, the system was run for a period of time with varying loads. It proved to be reliable and precise. The relay actuation mechanism failed in no way. The cooldown period seemed to be successful. Prevented redundant triggering. The SMS alerting capability is also been a standalone test. GSM module transmitted SMS messages at the proper time to the registered number.

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All the system events were properly captured in the alert log present in the dashboard interface. The LCD display was very clear about the status of the system. The outcome results of the evaluation is that the proposed system is well functional. It can monitor the system continuously find overloads and redistribute the load. System operation is reliable. Applicable for actual transformer protection and distribution level load management applications. System is a one system embedded platform, including sensing, switching control and multi-channel communication. The system continuously monitors, identifies overloads with accuracy and provides effective load redistribution. The coordination of the hardware components and software components is satisfactory and the system is practical which can be applied in the real life. The system is a solution for the tracking and management of the transformer parameters and load distribution.

The working principle of the system is based on transformer parameters tracking and load distribution management. The control of the transformer parameters and load distribution is crucial for good operation of the system. The system provides continuous monitoring and precise overload identification with the transformer parameter tracking and load distribution management functions. The system is an example of parameter tracking and load distribution management in a real world system by using transformer. The features of the system are the parameter tracking and load distribution management for the transformer.

The system uses transformer parameter tracking and load distribution management to achieve its goals. The evaluation results show that the proposed system is a good solution for the tracking of the parameters of the transformer and load distribution management. The system uses transformer parameter tracking and load distribution management to work. The system consists of the transformer parameter tracking and load distribution management.

V. RESULTS

The outcome we obtained after using the system, indicates that it is actually effective in a smart monitoring of transformers in time sharing loads and protecting from overload. The system combines all the elements of sensing, control, communication and visualization in a single area to operateindependentlywithoutanyproblems.

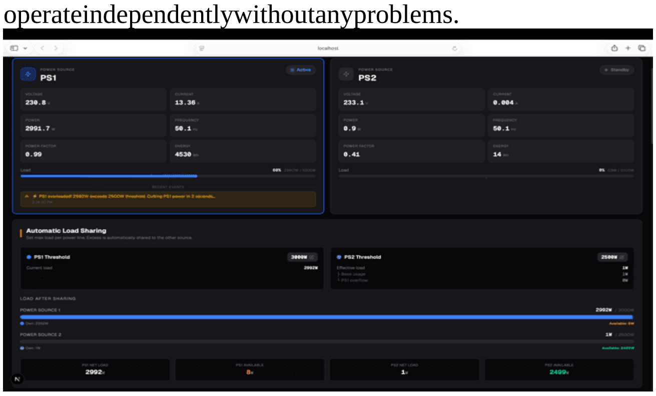

Fig. 2. Web dashboard home interface for transformer monitoring.

This is what the main interface of our system looks like. It shows an overview of our two power sources, PS1 and PS2.The interface displays electrical information in real-time, like voltage, current, power and frequency. The dashboard is the place where users can monitor the system and switch between different sections, such, as:

- Relay control
- Load settings
- Alert logs

All these sections help users keep track of the systems status.

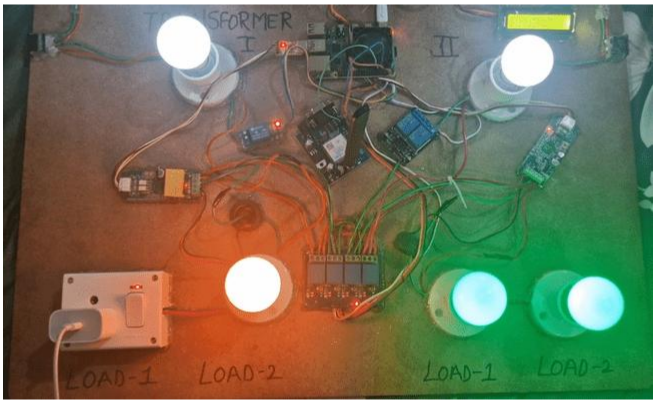

Fig. 3. System initialization and hardware status display.

This picture shows what the system looks like when it first starts up. At this point all the hardware parts, like sensors and relays and communication modules are ready to go. The system checks to make sure everything is connected. Then it gets ready to keep watching and controlling things all the time. The system does this so that the sensors and the relays and the communication modules are all working together.

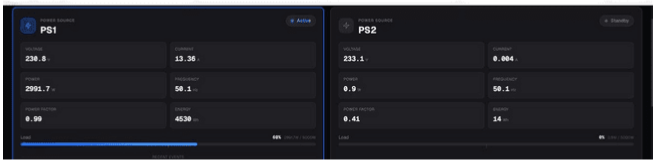

Fig. 4. Real-time power monitoring interface.

This picture shows us the live monitoring panel. It gets updates all the time on things from both power sources. The system gives us correct and up to date information. This helps users see what is going on with the load now through the Next.js dashboard. The Next.js dashboard is really good, for tracking things in time.

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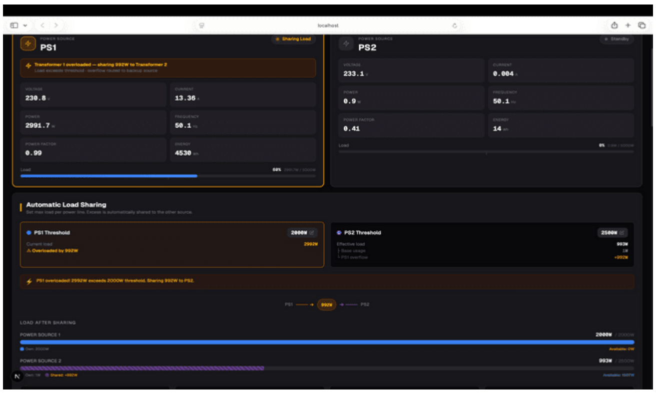

Fig. 5. Overload detection and warning indication.

This picture shows what happens when one power source has to handle more than it is supposed to. The system sees that one power source is overloaded and it shows a warning message. It also shows a countdown timer before it starts to share the load with power sources. This way the system does not do anything when the power source just gets a little too much to handle for a very short time. The system is trying to prevent doing the thing because of a sudden spike in the power that the power source has to handle. The power source and the load sharing are important, to the system.

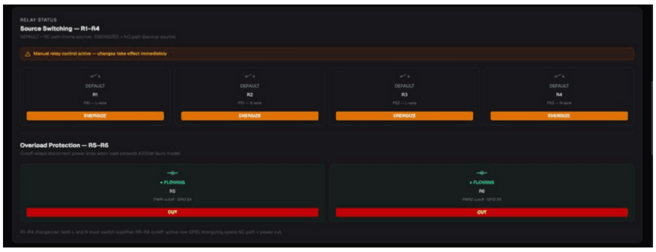

Fig. 6. Relay control panel and switching status.

This picture shows us the relay control interface. It tells us what is happening with all the relays from R1 to R6. We can see what is going on when the relays are switching on and off. If we need to we can manually change the state of the relays. The relay control interface gives us flexibility and control over the system. We have control, over the relays.

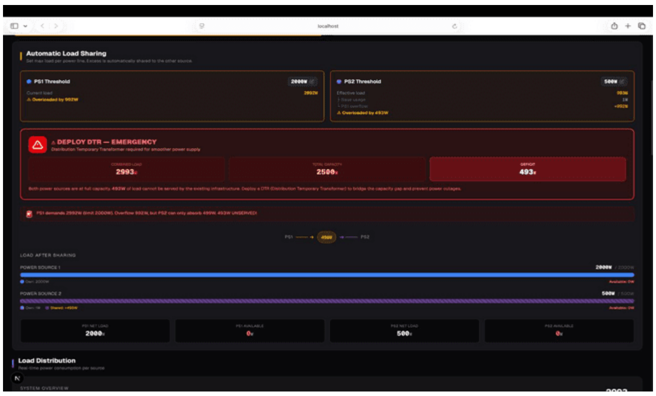

Fig. 7. Emergency shutdown (DTR) condition.

This picture shows a bad situation where the total load is too much for the system to handle. The system has to shut down away by turning off the power from both places and sending out warnings. This keeps the transformers from getting hurt. Makes sure the system is safe. The system safety is the thing here so the emergency shutdown protocol is very important, for the system safety.

Fig. 8. LCD display output for local monitoring.

THIS FIGURE IS THE SCREEN THAT APPEARS WHEN YOU LOG ON TO THE COMPUTER. IT IS A REAL-TIME VOLTAGE AND POWER INDICATOR. WHEN THERE IS A FAULT OR OVERLOAD THE LCD DISPLAYS WARNING MESSAGES. THIS ASSISTS USERS WHO ARE WATCHING ON-SITE WHO DON'T NEED TO VISIT THE WEB DASHBOARD.

VI . CONCLUSION

The system they created is working excellent and proves the feasibility of smart and automated monitoring and management system of transformer load. This system is constructed of hardware and open source software. It helps to resolve some issues regarding the protection of the transformer at present. For instance, it can automatically switch to another load if one of them is busy. It also alerts away when it has issues. All this without requiring another person to do by hand.

The main part of the system is present. Uses an RPi 4 Model B as the processor. It also has sensors to record the amount of energy consumed. It features a relay module with the ability to switch power sources. Software has been programmed in Python and other programming languages. It comes with an interface that allows people to view real-time activity. Can transmit messages when needed. The system is quite ingenious. Is able to identify when a transformer is overloaded. When it does it can move to another power source away. It also has a protocol in place to deal with emergencies. If both power sources get too busy it will turn them both off. Send out a message to the people in charge of the electricity.

The system also takes care of the devices' communication. Ensures they don't interfere with one another. So, the system that they created is actually quite good. Shows that it is possible to have smart and automated load sharing and protection for transformers. It employs Internet of Things (IoT) technology, embedded systems and special communication devices. It does all that with hardware which is not outrageously priced. The system makes it less likely that the transformers will be damaged. This also means that the people are not required to keep an eye on the system at all

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times. Should there be a malfunction, the repair crew will be alerted immediately. They may want to add additional features to the system in the future. They may, for instance, employ machine learning to forecast when a transformer is likely to become overloaded. They might make it possible to use more, than two power sources.

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