An-Najah National University

Faculty of Graduate Studies

A PROPOSED METHOD FOR MITIGATION THE UNBALANCED CURRENTS IN POWER DISTRIBUTION NETWORK WITH PV SYSTEMS

By

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Supervisor

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This Thesis was Defended Successfully on 24/04/2025 and approved by:

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Dedication

With profound gratitude to Allah, the Most Merciful, the Most Compassionate.

To the noble spirit of our beloved Prophet Mohammad (Blessings and Peace be upon him), whose teachings illuminate my path.

To my precious parents, whose sacrifices and love have been my guiding light.

To my beloved wife, the heart of my heart, whose unwavering love, patience, and belief in me have been my strength and solace.

To my dear brothers and sisters, whose support and companionship make life’s journey beautiful.

To all of you,

I dedicate this work with all my love and gratitude.

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Deep thanks to all my teachers at An Najah National University.

Declaration

I, the undersigned, declare that I submitted the thesis entitled:

A PROPOSED METHOD FOR MITIGATION THE UNBALANCED CURRENTS IN POWER DISTRIBUTION NETWORK WITH PV SYSTEMS

I declare that the work provided in this thesis, unless otherwise referenced, is the researcher’s own work, and has not been submitted elsewhere for any other degree or qualification.

Student's Name: احمد رائد عارف سكيك

Signature: احمد سكيك

Date: 24/4/2025

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A PROPOSED METHOD FOR MITIGATION THE UNBALANCED CURRENTS IN POWER DISTRIBUTION NETWORK WITH PV SYSTEMS

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Abstract

This thesis proposes a hardware prototype to address the problem of phase unbalance in low-voltage electrical distribution networks. Phase unbalance occurs when a disproportionate number of households draw power from one or two of the three-phase lines, resulting in increased power losses, line overloading, voltage drops, and, in extreme cases, blackouts. The growing integration of rooftop solar panels further intensifies this issue, as the amount of power injected into each phase varies depending on fluctuating solar generation. This study is significant because it offers a practical and scalable solution to enhance the performance of modern power grids with high penetration of distributed solar energy.

To address the issue of unbalanced currents in residential power distribution systems, this study developed a smart monitoring and balancing system utilizing a microcontroller and WiFi technology. The system continuously monitors power flow across the three-phase lines, tracks each household's electricity consumption and solar generation, and automatically reallocates house connections among the phases to maintain load balance. This is achieved without any interruption in power supply, as the study assumes the use of hybrid inverters equipped with battery storage, which ensures continuous electricity delivery even during phase interchange operations.

Meanwhile, the system dynamically adapts to real-time variations in load and generation, enhancing both flexibility and resilience. The simulation results, after implementing the proposed system, demonstrated a substantial reduction in power losses—from 138 kW to 9 kW. This improvement corresponds to cost savings of $193.20, or approximately $3.75 per household. The system also achieved a simple payback period of less than one month. Furthermore, the minimum network voltage improved significantly from 206 V under unbalanced conditions to 221 V following the implementation of the balancing solution.

Keywords: Power Distribution Network; Current Imbalance; Load Balancing; Photovoltaic (PV) Systems; Voltage Stability; Power Loss Reduction; Smart Grid; Real-time Monitoring.

Chapter One

Introduction

1.1 Background

Power systems are an important part of the infrastructure of every country, providing services that are essential to the modern way of life. Power systems are important for the stable functioning of all modern societies. the power system stability is decided by return to its normal operating condition after being subjected to any physical change or disturbance [4].

One of the most important factors that affect the stability and reliability of power system networks is the balance of the currents that are flowing into the network. If power system currents are not balanced, then the power system is not able to return to the normal condition. There are many disadvantages of the difference in the currents of the power systems like the overloading of transmission lines, the drop in voltage, the reliability of power systems ,the failure of the power system [5] [6].

The unbalance of the power system current may occur because of:

A. Unequal Phase Impedances of Loads

B. Discontinuity in the Transmission Line

C. Generator Tripping

The study aims to find the effect of power system current imbalance on the stability and reliability of power systems and the voltage stability of power systems under different imbalance conditions.

1.2 Statement of Problem

Growing energy needs, shrinking fossil fuel reserves, increasing global concern about greenhouse gases have moved research interests towards renewable energy sources such as Solar photovoltaic (PV) and Wind energy conversion system for electricity production. Now that PV prices are falling and are fitted for residential areas, it is the viable alternative as a green energy solution. Retrieved from micro power generators.

Recently, a rush of solar panels getting installed on houses and businesses is being seen This switch to renewable energy is great for the environment but adds an extra layer of complexity when it comes to managing the power grid [7]. Solar panels. Also called photovoltaic systems, change the sunlight directly into electricity. This gives clean energy but the problem is that the amount of electricity it produces which is being changed as the sun rises and sets, and hides behind the clouds. It makes it difficult to keep a steady and balanced load across the three phases of the power system [8]**.**

The overload of the load occurs when there is a significant difference between the pavements of one phase concerning the other two phases. The variation can be interpreted as when two pavements are jam-packed, but the third pavement is empty. This overload happens due to various reasons such as, not all houses, renters while the pavement power, and unequal power distribution. The unstable nature of the solar power also leads to the uneven occurrence of load in three phases**.**

When the load becomes unnaturally distributed, it puts a strain on the power system. The transformers which transform the high-voltage electricity into a safer amount are put under high stress and can also overheat, resulting in their incapability to function**.**

1.3 Objectives

The main aim of the project is "Intelligent Load Balancing for a Reliable Grid". This project is designed to develop a smart system which can be used against the load imbalance problems which is mainly in the area where the number of solar panels are used. In this system, each house or the building in the system uses the energy from the three different phases of the power supply system. The system monitors the consumption of energy of each house/building and the voltage generated by the solar panels. The energy is transferred by the system for the three different phases automatically and dynamically so that the power supply remains reliable and the grid remains balanced. This process also increases the productivity of the grid and also helps in reducing the consumption of non- renewable sources [9].

1.4 Significance of the Study

The study is vital due to the following reasons:

A: It leads to a stable power system that ensures that a reliable and stable power system is maintained.

B: Prevent power outages in the community [10].

The current energy system is rife with instability, and renewable energy can be used in evading this energy while making sure more power is accessible to it. The chapter also represents the motivation for this introduction to the current trends [11].

1.5 Literature Review

1.5.1 Renewable Energy Sources

Renewable energy and power transition have became a prevalent topic today, and both solar photovoltaic and wind energy are two renewable energy sources that have slowly come to the forefront. The primary aim of the transition and ever-growing trend is to meet the global energy demand [12].

The fossil fuel energy source is unable to provide the energy of the world, and that too sustainably, and the traditional fossil fuel is also limited. The limited source of fossil fuel includes coal, oil and natural gases, and these fossil fuels are consumed at an alarming rate [13].

Solar power methods are capable of adopting renewable energy sources in the world. Increasing energy rates and in order to limit the greenhouse house gases has made the need to increase these types of solar power systems. Fossil fuel energy cannot serve the world and that too in a sustainable manner. The traditional fossil fuel is also limited. The fossil fuel limited source includes oil, coal and natural gases. The fossil fuel is rapidly consumed. The solar energy is one of the best that being acquired . The sunlight shines more than enough for our energy needs in the world. The cost of the solar power technology is decreasing and there are several developments in the solar power units. There are plenty of solar energy devices that have been used over the years by the people. The solar devices are quite easy to be used than any device for producing energy [14] [15].

1.6 Impact of Current Imbalance

The process of integrating Photovoltaic (PV) system into the distribution networks has been rampant owing to the enlightenment the push for need for renewable sources of energy. The penetration level of the PV systems which should not exceed 10% at the distribution network [1].

As the variations in the intensities of the solar radiation can also play a pivotal role to form a cause of high-level penetration of PV system in distribution networks. The variability in the power generated may result owing to the variations in solar radiation. The imbalances in the generation of power is difficult to regulate if it crosses the limits, thus creating imbalance in current in their respect to phases. Though fault may occur at any phase while occurring at operation, it has a significant effect on the three-phase operation, especially in low-voltage (LV) distribution network voltage networks. Sometime the PV installations were not evenly distributed among the three phases of the distribution network and if such conditions occurred, it led to unbalancing on the distribution of electric power in the network [2].

High penetration of PV in the low-voltage distribution network results in a transformation imbalance in the current. The unbalanced operation can still manage to cause some malfunctioning or failures. But, an adjoined case of LV PV penetration is the already operationally imbalanced network. It means that when a network has high PV penetration combined with those operational already having imbalances. The power cables and the transformers are one of the most affected devices by the occurrence of unbalanced operation. The occurrence of unbalanced operation is a big factor that the rate of overloading increases that both the transformers and the power cables may operate to significantly higher than their rated conditions. Due to the type and the level of generated power, the power cables suffer heavy stress. The power cables and the transformer apart from overloading also operates to generate more loss of power, reduces the efficiency. Thus it not only affects the capacity of the transformer but also reduces the lifespan and reliability [3].

The transformers and power cables are used for generating and transferring the electric power and associated variable. If the transformers and power cables accelerate their way of operating, it eventually leads to overheating and wear and tear. The fast wear and tear decrease the aircraft wing of the transformer per se and the power cables. The operations of a transformer that has a low wing are a severe risk and may fail due to creates a severe risk to the operation of the transformer and may eventually fail a high PV penetration that leads to several operational imbalance is paramount, and though, disruptive devices of power-generation aim to create strategies under which the operation and malfunctions can be avoided up to a certain extent. So, with the high penetration technique, the operation's advancement is inevitable, and it has to force that altered and modified. The advance monitoring technique should be used with the low voltage alternating source the that they can help to accommodate before still distribute the power in a balanced manner. The box supply systems have to be made transparent in a way that allows. Those strategies must be human devised that along with the new features that are already available with the box supply schemes. Actual techniques of advancing in high PV penetration with already operational imbalance networks include dynamic voltage regulator techniques that show the real-time voltage level's vectorial representation [41].

High penetration PV system is furthered, and the increasing number of related faults' current unbalance model and control have triggered many advanced prognostic methodologies. The rising level of the penetration of PV means that there are more of the solar cells that are operated in a guided manner. This works by calculating the total peak power rating and by adding new devices generated in those two months [42].

Scenarios have to be presumed that along with 20% PV penetration in the Australia PV and electric power network that climb fast and varied in normal situations. The current balance is not significant, but it is an attribute that can go out of order at instances devoid of time-frame. High photovoltaic (PV) power integration has led to various latest advancements in power generation electronics. PV methods mean that the use of solar light is used to make electricity as a single current's power sources. Thus, with high photovoltaic power penetration, converters of the power generation system will also work in an imbalanced way while obtaining the line currents required in a balanced form and symmetrically [43].

1.7 Existing Solutions for Current Imbalance

The existing solutions to the balance problems can be divided into the following two types:

1. Reconfiguration in the design stage.

2. Power flow control in the operation stage. There are several power electronic devices and several algorithms that have been proposed for improving the unbalance problems due to load variations in real-time.

Here are summaries of a few numbers of research papers compiled PV in power network based papers interrelated with unbalanced load distribution and the proposed solutions for the issues by them:

1.7.1 Voltage Regulation in Unbalanced Power Distribution Systems

This solution explains about the voltage regulation challenges in power distribution systems with high penetration of PV systems. And these voltage regulation issues have become an unbalance which is a severe overvoltage and is due to the arbitrary connection of rooftop PV generation. The paper illustrates the advanced control strategies and voltage regulation devices including OLTC (On-Load Tap Changer) and switched capacitors. These plays a very crucial role in the enforcement of voltage stability in the network to eliminate the issues [16].

1.7.2 Multifunctional Distributed MPPT Controller for 3P4W Grid-Connected PV Systems

This article explains the multifunctional maximum power tracking controller (MPPT) that were designed for 3P4W grid connected PV systems. This is a novel controller, and a Four-leg three-level T-type multilevel inverter is designed to perform distributed MPPT as a neutral current compensation for the unbalanced loads and total harmonic distortion reduction and the primary purpose of providing reactive power generation and improve the efficiency of the PV system by developing the power quality and reducing the total harmonics [17].

1.7.3 Techniques for Compensation of Unbalanced Conditions in LV Distribution Networks

This paper discusses various techniques for compensating the unbalanced conditions in LV distribution networks along with the inclusion of PV systems. As per Risto, the use of MADRL(Multi-Agent Deep Reinforcement Learning) in voltage control is more effective in prolonging the unbalanced and enhanced system stability [17].

1.7.4 Power Quality Improvement of Photovoltaic Generator Interfaced with Grid Employing Optimized Fuzzy-Based STATCOM

D.Veena, Dr G Ramesh. In this paper the power quality problems in the distributed system supplying PV system is discussed. Inverter based STATCOM (Static Synchronous Compensator) minimum rating is tended to address the problem [16]s by supplying inductive or capacitive or both reactive power types [18].

Maximum power point tracking algorithm for Grid-interfaced photovoltaic system with voltage regulation

N.Sasikala, M Nishad, E Priyadharsini To improve the DC-Link voltage the IIR filter is used and also the simulation work is done using MATLAB/Simulink.

1.7.5 Dynamic Voltage Control for Load Unbalance Study in Real power support of DG interfaced Smart Grid In GENERAL

This report is considered with real-power control of DER (Distributed Energy Resources) to coordinate voltage in the unbalanced source when a balanced load is powered by DER. The phasor-based analysis is adopted.

These papers have suggested real power and voltage control, advanced controllers and multifunction converters, optimization techniques to the integrated systems to keep the system extending the power quality [17].

Chapter Two

Methodology

2.1 Data Collection

Information for two transformers in Merka – Jenin has been collected .There names are Mesrara Transformer and wad transformer.

Calculations of voltage and power losses have been collected before and after balancing by changing the number of houses on each phase.

2.2 Mesrara Transformer Analysis

Mesrara Transformer

Number of houses = 29 houses

Apparent Power rated = 160 KVA

Turns ratio = 33000/400

Cable length = 1300 m

Table 1

Average Currents at high voltage side of MesraraTransformer

	Phase A	Phase B	Phase C
Current(I)	1.1 A	1.4 A	1.95 A

Table 1 presents the average current values for each phase on the high-voltage side of the Mesrara Transformer. These measurements are essential for assessing load distribution and identifying current imbalances that could lead to inefficiencies.

Currents at low voltage side: $I_{A\ Secondary\ side} = I_{A\ Primary\ side}$ * turns ratio

$I_{A\ Sec} = 1.1 * \frac{33000}{400} = 90.75$ A

$I_{B\ Sec} = I_{B\ Brim}$ * turns ratio

$I_{B\ Sec} = 1.4 * \frac{33000}{400} = 115.5$ A

$I_{C\ Sec} = I_{C\ Brim} *$ turns ratio

$I_{C\ Sec} = 1.95 * \frac{33000}{400} = 160.87$ A

Table 2

Average Currents at Low voltage side of MesraraTransformer

	Phase A	Phase B	Phase C
Current(I)	90.75 A	115.5 A	160.87 A

Table 2 shows the result value of current on the low voltage side of a Mesrara transformer. Turns ratio has been used to determine the value of current on low voltage Mesrara.

Voltage at Sending end at phase C = 240 V

Voltage at Receiving end at phase C = 210 V

Voltage drop = $V_{sending\ end} - V_{receiving\ end} = 240 - 210 = 30$ V

Number of houses on phase C $\approx \frac{current\ of\ phase\ c}{total\ current} * total\ houses$

Number of houses on phase C $\approx \frac{160.87}{90.75+115.5+160.87} * 29 \approx 13$

Consumption per house $= \frac{current\ of\ phase\ c}{number\ oh\ houses} = \frac{160.87}{13} = 12.3\ A$

Figure 1

Sketch for phase C before the improvement of MesraraTransformer

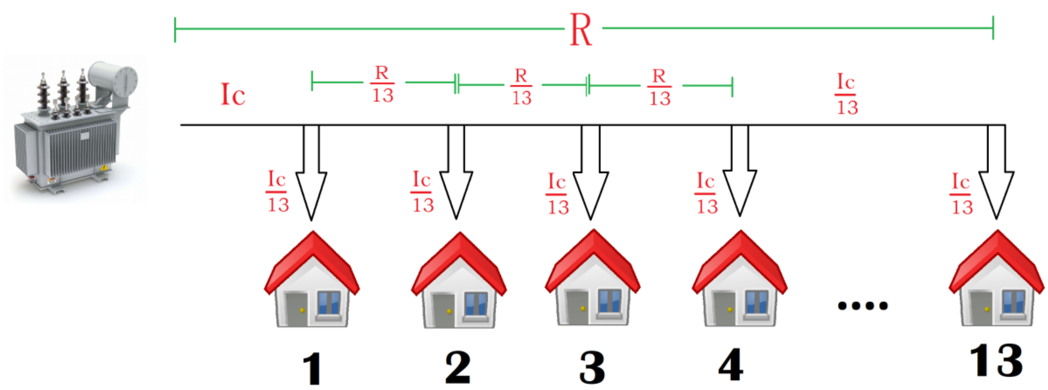


Figure 1 shows flow of current in Phase C before the load was redistributed. It represents initial imbalance in the system.

$$\Delta V = \sum_{n=1}^{13}\left(\left(Ic - \frac{nIc}{13}\right) * \frac{R}{13}\right)) \quad (2.1)$$

$= (160.87 * \frac{R}{13})$ $+ ((160.87 - \frac{160.87}{13}) * \frac{R}{13}) + ((160.87 - \frac{2*160.87}{13}) * \frac{R}{13})$

$+ ((160.87 - \frac{3*160.87}{13}) * \frac{R}{13}) + ((160.87 - \frac{4*160.87}{13}) * \frac{R}{13})$

$+ ((160.87 - \frac{5*160.87}{13}) * \frac{R}{13}) + ((160.87 - \frac{6*160.87}{13}) * \frac{R}{13})$

$+ ((160.87 - \frac{7*160.87}{13}) * \frac{R}{13}) + ((160.87 - \frac{8*160.87}{13}) * \frac{R}{13})$

$+ ((160.87 - \frac{9*160.87}{13}) * \frac{R}{13}) + ((160.87 - \frac{10*160.87}{13}) * \frac{R}{13})$

$+ ((160.87 - \frac{11*160.87}{13}) * \frac{R}{13}) + ((160.87 - \frac{12*160.87}{13}) * \frac{R}{13})$

$+ ((160.87 - \frac{13*160.87}{13}) * \frac{R}{13})$

$\Delta V = (160.87 * \frac{R}{13}) + (148.5 * \frac{R}{13}) + (136.1 * \frac{R}{13}) + (123.7 * \frac{R}{13})$

$+ (111.3 * \frac{R}{13}) + (99 * \frac{R}{13}) + (86.6 * \frac{R}{13}) + (74.2 * \frac{R}{13}) + (61.8 * \frac{R}{13})$

$+ (49.49 * \frac{R}{13}) + (37.1 * \frac{R}{13}) + (24.75 * \frac{R}{13}) + (12.37 * \frac{R}{13})$

$$\Delta V = \frac{1125.78\ R}{13} = 240 - 210 = 30$$

R = 0.346 ohm

Power losses in phase C

$$P_{loss} = \sum_{n=1}^{13}((Ic - \frac{nIc}{13})^2 * \frac{R}{13}) \quad (2.2)$$

$$P_{loss} = \left(\frac{1125.78}{13}\right)^2 * 0.346 = 2.594\ Kw$$

Now the 3 phases will be balanced by changing the number of houses on each phase :

I_{total} = 90.75 + 115.5 + 160.87 = 367.12 A

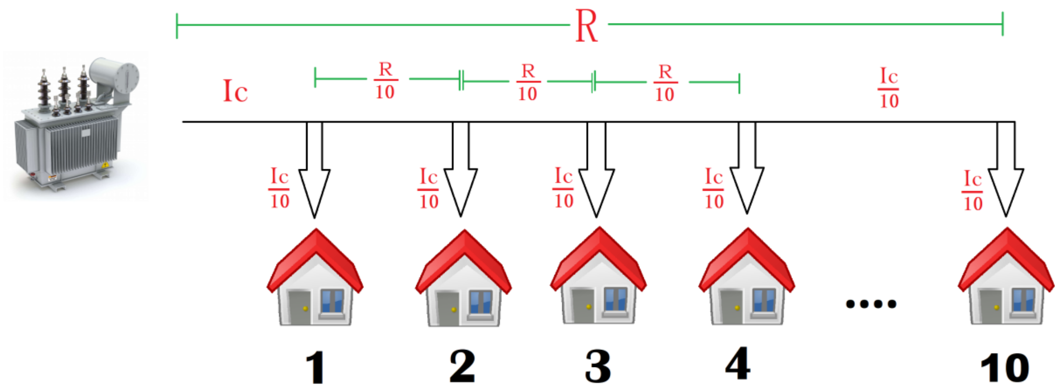
$I_c = \frac{I\ total}{3} = \frac{367.12}{3} = 122.3$

New number of Houses on Phase C = $\frac{29}{3} \approx 10$

Consumption per house = $\frac{current\ of\ phase\ c}{number\ oh\ houses} = \frac{122.3}{10} = 12.3\ A$

Figure 2

Sketch for phase C after the improvement of MesraraTransformer



All the loads are redistributed to the phases so, the Figure shows a balanced current in Phase C.

New voltage drop

$$\Delta \boldsymbol{V} = \sum_{n=1}^{10}\left(\left(\boldsymbol{Ic} - \frac{\boldsymbol{nIc}}{\mathbf{10}}\right) * \frac{\boldsymbol{R}}{\mathbf{10}}\right)) \quad (2.3)$$

= (122.3* $\frac{R}{10}$) + ((122.3 -$\frac{122.3}{10}$)*$\frac{R}{10}$) + ((122.3-$\frac{2*122.3}{10}$)*$\frac{R}{10}$)

+ ((122.3-$\frac{4*122.3}{10}$)*$\frac{R}{10}$)   + ((122.3-$\frac{3*122.3}{10}$)*$\frac{R}{10}$)

+ ((122.3-$\frac{6*122.3}{10}$)*$\frac{R}{10}$)+ ((122.3-$\frac{5*122.3}{10}$)*$\frac{R}{10}$)

+ ((122.3-$\frac{8*122.3}{10}$)*$\frac{R}{10}$)+ ((122.3-$\frac{7*122.3}{10}$)*$\frac{R}{10}$)

+ ((122.3-$\frac{10*122.3}{10}$)*$\frac{R}{10}$)   + ((122.3-$\frac{9*122.3}{10}$)*$\frac{R}{10}$)

= (122.3* $\frac{R}{10}$) + (97.84* $\frac{R}{10}$) + (85.61* $\frac{R}{10}$) + (73.38* $\frac{R}{10}$) + (61.15* $\frac{R}{10}$)   + (48.92* $\frac{R}{10}$) + (36.69* $\frac{R}{10}$) + (24.46* $\frac{R}{10}$) + (12.23* $\frac{R}{10}$)

= $\frac{562.5\ \ R}{10}$ = $\frac{562.5}{10} * 0.346 = 19.4\, V$

$V_{receiving} = V_{sending} - \Delta V$

$V_{receiving}$ = 240 – 19.4 = 220.6 V

New Power losses in phase C

$$P_{loss} = \sum_{n=1}^{10}((Ic - \frac{nIc}{10})^2 * \frac{R}{10}) \quad (2.4)$$

$P_{loss} = \left(\frac{562.5}{10}\right)^2 * 0.346 = 1.094\ Kw$

character	means
ΔV	Voltage drop
n	Number of the houses
Ic	Current on phase C
R	Resistance
P loss	Power losses

$V_{Receiving\ end}$ Voltage at the end

$V_{sending\ end}$ Voltage at the transformer

Table 3

Comparison between before and after the improvement of MesraraTransformer

	Before	After
ΔV	30	19.4
$V_{receiving\ end}$	210	220.6
P_{loss}	2.594	1.094

Table 3 indicates that comparison chart is provided in pairs. Here one table gives a before improvement scenario value, and the other gives after improvement resultant value. Based on this table, the performance of a given transformer can be analyzed. The drastic change in load balancing has been improved and transformed all these before values to after balanced values, and this is what makes their considerable difference.

2.3 Wad Transformer Analysis

Wad Transformer

Number of houses =15

Apparent Power rated =80 KVA

Turns ratio = 33000/400

Cable length =250 m

Table 4

Average Currents at high voltage side of Wad Transformer

	Phase A	Phase B	Phase C
Current (I)	0.91 A	0.42 A	0.44 A

Table 4 presents the average current values for each phase on the high-voltage side of the Wad Transformer. These measurements are essential for assessing load distribution and identifying current imbalances that could lead to inefficiencies.

Currents at low voltage side:

$I_{A\ Sec}$ = $I_{A\ Brim}$ * turns ratio

$I_{A\ Sec} = 0.91 * \frac{33000}{400} = 75$ A

$I_{B\ Sec}$ = $I_{B\ Brim}$ * turns ratio

$I_{B\ Sec} = 0.42 * \frac{33000}{400} = 34.6$ A

$I_{C\ Sec}$ = $I_{C\ Brim}$ * turns ratio

$I_{C\ Sec} = 0.44 * \frac{33000}{400} = 36.3$ A

Table 5

Average Currents at Low voltage side of Wad Transformer

	Phase A	Phase B	Phase C
Current (I)	75 A	34.6 A	36.3 A

Table 5 shows the result value of current on the low voltage side of a Wad transformer. Turns ratio has been used in order to determine the value of current on low voltage Wad.

Voltage at Sending end at phase C = 230 V

Voltage at Receiving end at phase C = 220 V

Voltage drop = $V_{sending\ end} - V_{receiving\ end}$ = 230 – 220 = 10 V

Number of houses on phase C $\approx \frac{current\ of\ phase\ c}{total\ current} * total\ houses$

Number of houses on phase C $\approx \frac{75}{75 + 34.6 + 36.3} * 15 \approx 8$

Consumption per house = $\frac{current\ of\ phase\ c}{number\ oh\ houses} = \frac{75}{8} = 9.37\ A$

Figure 3

Sketch for phase C before the improvement ofWadTransformer

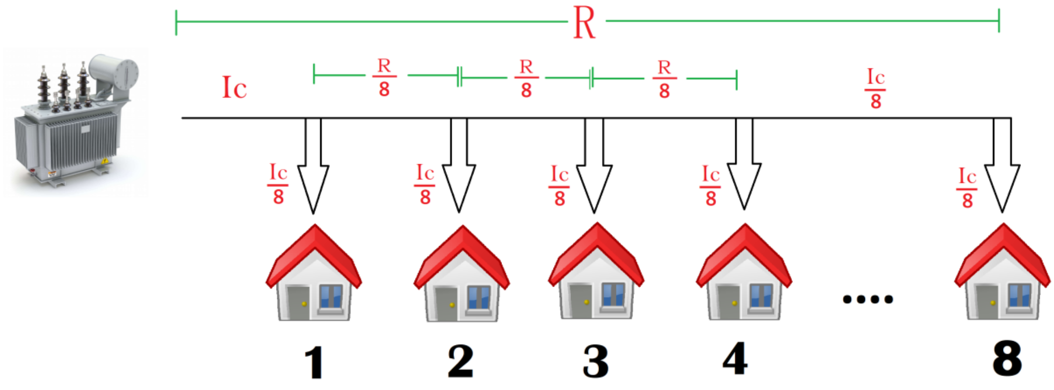


Figure 3 shows the flow of current in Phase C before the load was redistributed. It represents initial imbalance in the system

$\Delta V = \sum_{n=1}^{8}\left(\left(Ic - \frac{nIc}{8}\right) * \frac{R}{8}\right))$

$= (75* \frac{R}{8})\ + ((75 -\frac{75}{8})*\frac{R}{8}) + ((75 -\frac{2*75}{8})*\frac{R}{8}) + ((75 -\frac{3*75}{8})*\frac{R}{8})$

$+ ((75 -\frac{6*75}{8})*\frac{R}{8})\ + ((75 -\frac{5*75}{8})*\frac{R}{8})\qquad + ((75 -\frac{4*75}{8})*\frac{R}{8})$

$+ ((75 -\frac{8*75}{8})*\frac{R}{8})\qquad + ((75 -\frac{7*75}{8})*\frac{R}{8})$

$\Delta V = (75 * \frac{R}{8}) + (65.6 * \frac{R}{8}) + (56.25 * \frac{R}{8}) + (46.87 * \frac{R}{8}) + (37.5 * \frac{R}{8})$

$+(28.12 * \frac{R}{8}) + (18.75 * \frac{R}{8}) + (9.37 * \frac{R}{8})$

$$\Delta V = \frac{337.46\ R}{8} = 230 - 220 = 10$$

R = 0.237 ohm

Power Losses in Phase C

$P_{loss} = \sum_{n=1}^{8}((Ic - \frac{nIc}{8})^2 * \frac{R}{8})$

$P_{loss} = (\frac{337.46}{8})^2 * 0.237 = 0.421\ Kw$

Now the 3 phases will be balanced by changing the number of houses on each phase :

I_{total} = 75 + 34.6 + 36.3 = 145.9 A

$I_c = \frac{I\ total}{3} = \frac{145.9}{3} = 48.6$

New number of houses on phase C = $\frac{15}{3} \approx 5$

Consumption per house = $\frac{current\ of\ phase\ c}{number\ oh\ houses} = \frac{48.6}{5} = 9.72\ A$

Figure 4

Sketch for phase C after the improvement of Wad Transformer

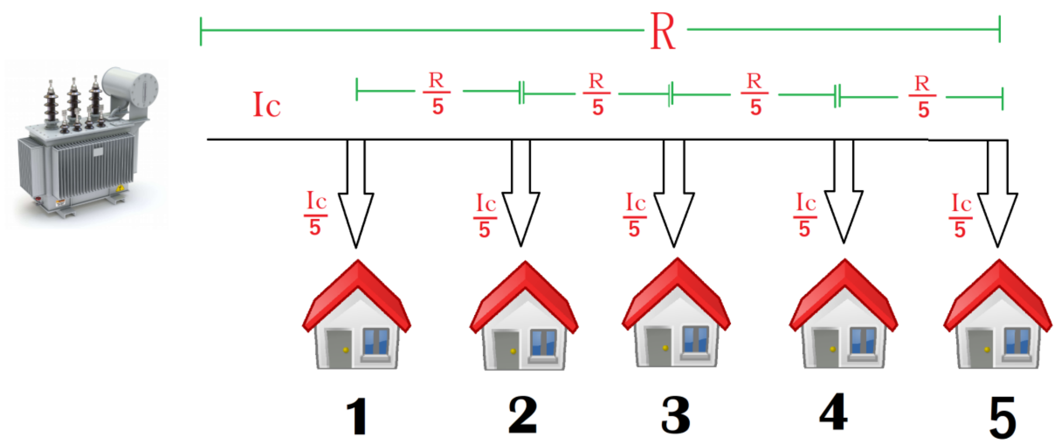


Figure 4 shows that all loads are redistributed to the phases So, Figure 4 shows balanced current in Phase C.

New voltage drop

$\Delta \boldsymbol{V} = \sum_{\boldsymbol{n}=\mathbf{1}}^{\mathbf{5}} \left(\left(\boldsymbol{Ic} - \frac{\boldsymbol{nIc}}{\mathbf{5}}\right) * \frac{\boldsymbol{R}}{\mathbf{5}}\right)$)

= (48.6* $\frac{R}{5}$) + ((48.6 -$\frac{48.6}{5}$)*$\frac{R}{5}$) + ((48.6-$\frac{2*48.6}{5}$)*$\frac{R}{5}$)

+ ((48.6-$\frac{3*48.6}{5}$)*$\frac{R}{5}$) + ((48.6-$\frac{4*48.6}{5}$)*$\frac{R}{5}$) + ((48.6-$\frac{5*48.6}{5}$)*$\frac{R}{5}$)

= (48.6* $\frac{R}{5}$) + (38.88* $\frac{R}{5}$) + (29.16* $\frac{R}{5}$) + (19.44* $\frac{R}{5}$) + (9.72* $\frac{R}{5}$)

= $\frac{145.8\ R}{5}$ = $\frac{145.8}{5} * 0.237 = 6.9\ V$

$V_{receiving} = V_{sending} - \Delta V$

$V_{receiving}$ = 230 – 6.9 = 223.1V

New Power losses in phase C

$P_{loss} = \sum_{n=1}^{5}(\left(Ic - \frac{nIc}{5}\right)^2 * \frac{R}{5})$

$P_{loss} = \left(\frac{145.8}{5}\right)^2 * 0.237 = 0.201\ Kw$

Table 6

Compare between before and after the improvement of MesraraTransformer

	Before	After
ΔV	10	6.9
$V_{receiving\ end}$	220	223.1
P_{loss}	0.421	0.201

This comparison chart is provided in pairs. Table 6 gives a before improvement scenario value and after improvement resultant value. Based on this table, and the performance of a given transformer can be analyzed. The drastic change in load balancing has been improved and transformed all these before values to after balanced values, and this is what makes their considerable difference.

2.4 The Etap Simulation

When the system is done by the Etap and makes the simulation, it is noticed that the results before and after the correction is very huge.

The system consists a main transformer which feeds many houses and low voltage transition lines called ABC cables and the distances between houses is almost equals .

The power of each house is 5.22 KVA and houses take the electricity from three phase source. and the number of houses on each phase is different, so the three phase currents is non-equal so the system is unbalanced.

Even making the number of houses on each phase equal, It is not sure that the all houses will consume the same power, so the three phase currents will not be equal.

Case 1: Before Improvement Without PV

Etap of the grid without PV before the improvement is Shown in Figure B.5

Table 7

Etap Results of the grid without PV before the improvement

Phase	MW	Mvar	MVA	% PF
Source (Swing Buses):				
A	0.079	0.059	0.098	79.99 Lagging
B	0.045	0.024	0.051	87.86 Lagging
C	0.112	0.000	0.112	100.00 Leading
Source (Non-Swing Buses):				
A	0.000	0.000	0.000	
B	0.000	0.000	0.000	
C	0.000	0.000	0.000	
Total Demand:				
A	0.127	0.037	0.133	96.11 Lagging
B	0.054	0.016	0.056	95.78 Lagging
C	0.035	0.009	0.036	96.61 Lagging
Apparent Losses:				
A	0.049	0.022		
B	0.009	0.000		
C	0.077	0.009		
System Mismatch:	0.000	0.000		
Number of Iterations:	3			

As it is seen, the losses in the system before is very large.

Receiving end of the grid without PV before the improvement is Shown in Figure B.6

As seen in Figure B.6 the voltage drop is very high so the voltage on the phase with high loud is 180 V and this is very bad value .

Case 2: Before Improvement With PV

And after change is made out in the houses and add PV to some houses As Shown in Figure B.7, this will decrease the voltage drop and losses in the cables.

Table 8

Etap results of the grid with PV before the improvement

Phase	MW	Mvar	MVA	% PF
Source (Swing Busses):				
A	0.141	0.056	0.152	92.92 Lagging
B	0.037	0.025	0.045	82.35 Lagging
C	0.072	0.004	0.073	99.84 Lagging
Source (Non-Swing Busses):				
A	0.000	0.000	0.000	
B	0.000	0.000	0.000	
C	0.000	0.000	0.000	
Total Demand:				
A	0.163	0.049	0.170	95.73 Lagging
B	0.054	0.016	0.057	95.78 Lagging
C	0.022	0.007	0.023	95.78 Lagging
Apparent Losses:				
A	0.021	0.007		
B	0.018	0.009		
C	0.051	0.002		
System Mismatch:	0.000	0.000		
Number of Iterations:	3			

As it is seen in Table 8, the losses in the system with PV but without improve is lower than before PV.

The Etap of Receiving end of the grid with PV before the improvement is Shown in Figure B.8.

As seen in Figure B.8 the voltage drop is lower so the voltage on the phase with high loud is 206 V and this is still bad value but its better than the system without PV.

Case 3: After Improvement without PV

And after change in the houses is made out on each phase, the current will be almost equal without taking PV systems As Shown in Figure B.9 , which mean a balanced system is achieved, and this will decrease the voltage drop and losses in the cables.

Table 9

Etap results of the grid without PV after the improvement

Phase	MW	Mvar	MVA	% PF
Source (Swing Busses):				
A	0.088	0.028	0.092	95.19 Lagging
B	0.084	0.027	0.088	95.05 Lagging
C	0.086	0.024	0.090	96.24 Lagging
Source (Non-Swing Busses):				
A	0.000	0.000	0.000	
B	0.000	0.000	0.000	
C	0.000	0.000	0.000	
Total Demand:				
A	0.084	0.025	0.088	95.78 Lagging
B	0.084	0.025	0.088	95.78 Lagging
C	0.079	0.021	0.082	96.72 Lagging
Apparent Losses:				
A	0.003		0.003	
B	0.000		0.002	
C	0.007		0.004	
System Mismatch:	0.000		0.000	
Number of Iterations:	2			

As it is seen in Table 9, the losses in the system will be improved improve, but without PV is lower than before with huge difference.

The Etap of Receiving end of the grid without PV after the improvement is Shown in Figure B.10

As seen in Figure B.10, the voltage drop is lower so the voltage on the phase with high loud is 220 V and this is very good value.

Case 4: After Improvement with PV

And after change in the houses on each phase is made out, the current will be almost equal with take PV systems As Shown in Figure B.11, which means that balanced system is achieved, and this will decrease the voltage drop and losses in the cables.

Table 10

Etap results of the grid with PV after the improvement

Phase	MW	Mvar	MVA	% PF
Source (Swing Busses):				
A	0.129	0.043	0.136	94.76 Lagging
B	0.075	0.026	0.080	94.61 Lagging
C	0.080	0.022	0.083	96.48 Lagging
Source (Non-Swing Busses):				
A	0.000	0.000	0.000	
B	0.000	0.000	0.000	
C	0.000	0.000	0.000	
Total Demand:				
A	0.130	0.039	0.135	95.78 Lagging
B	0.075	0.023	0.079	95.78 Lagging
C	0.071	0.021	0.075	95.78 Lagging
Apparent Losses:				
A	-0.001	0.004		
B	0.000	0.003		
C	0.009	0.000		
System Mismatch:	0.000	0.000		
Number of Iterations:	2			

And the Etap of Receiving end of the grid with PV after the improvement is Shown in Figure B.12

As seen in Figure B.12, the voltage drop is lower so the voltage on the phase with high loud is 221 V and this is the best value.

In Appendix A there is a Compare between four cases in the P losses and receiving end voltages in table A.1 .

2.5 Power Circuit

Figure 5

Power circuit of the project

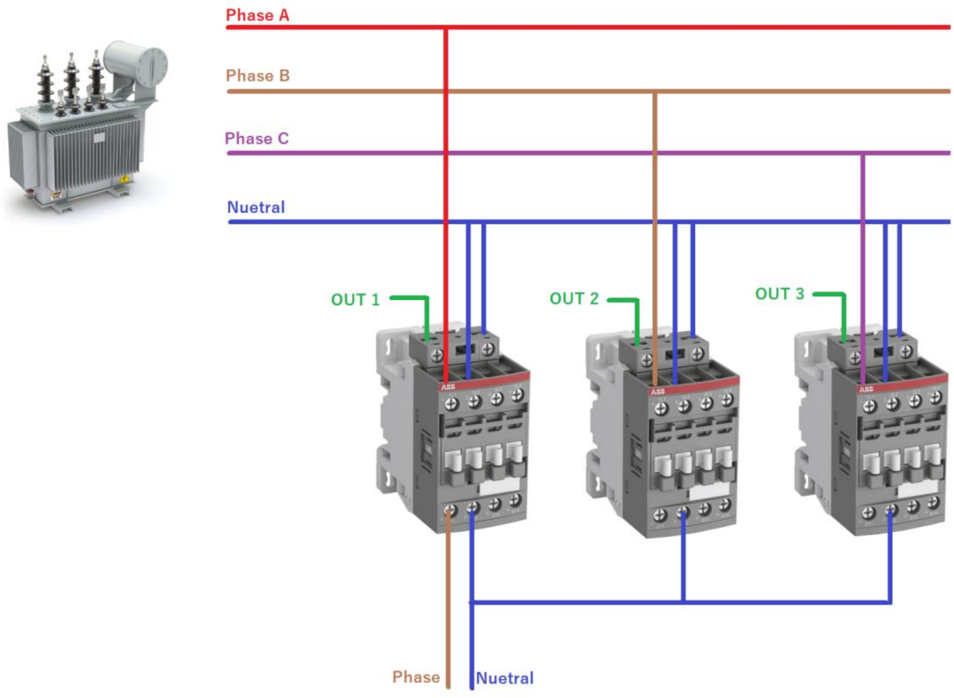


Figure 5 provides the layout of the main electrical circuit used for controlling and dynamically redistributing loads among phases which are three contactors for the three phase , each contactor for one phase.

This circuit will be behind each house and it will choose the Phase which will be connected to the house:

1. If K1 (contactor 1) is on:

Phase A and neutral will be connected to the house

2. If K2 (contactor 2) in on:

Phase B and neutral will be connected to the house

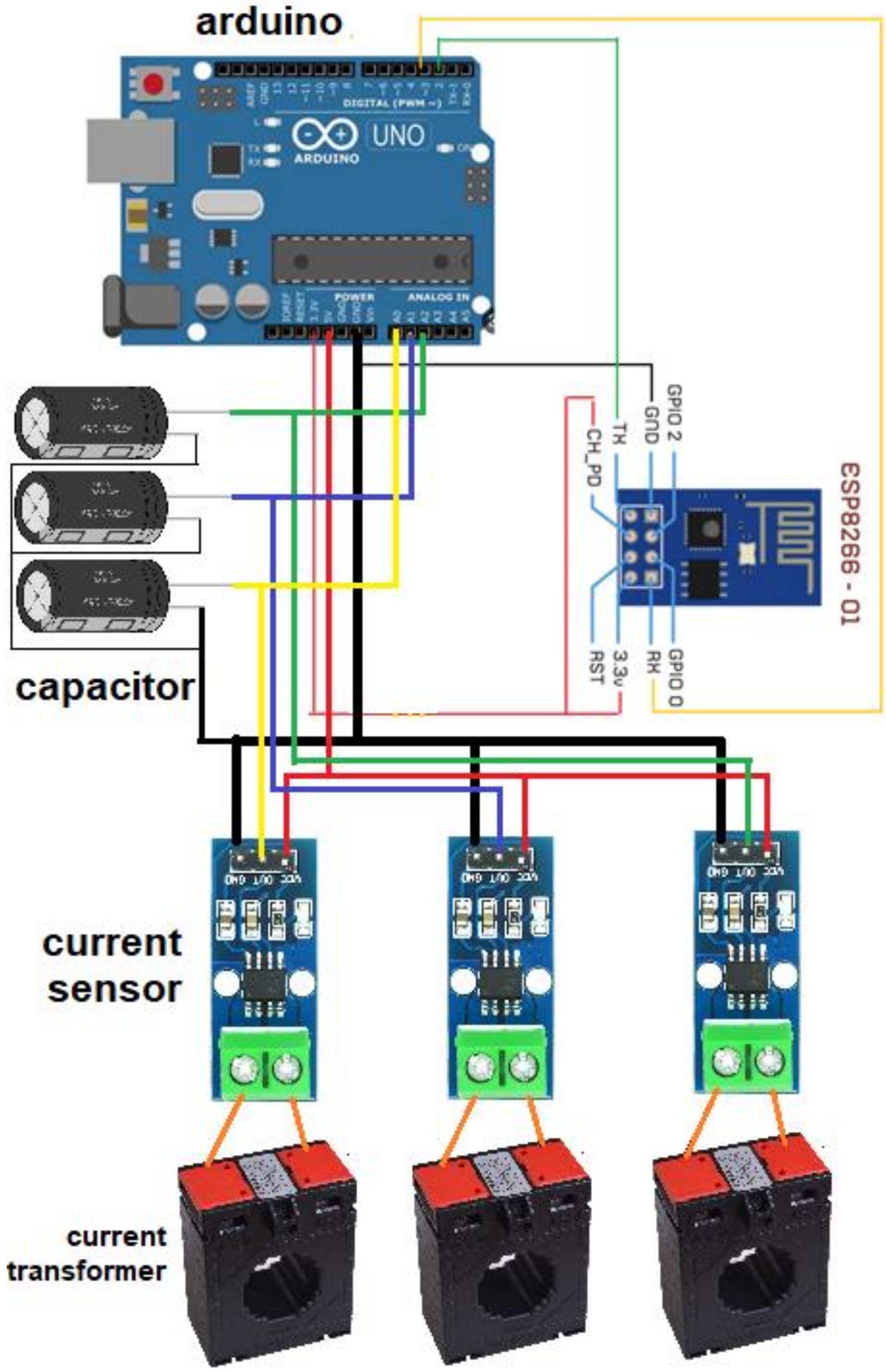
3. If K3 (contactor 3) in on:

Phase C and neutral will be connected to the house

2.6 Control Circuit of Master Panel

Figure 6

Control circuit of master panel of the project



This is designed to measure the current of a three-phase system using current transformers (CTs), process the data using Arduino UNO, and then transmit the data wirelessly to another Arduino using ESP8266 WiFi module. It contains the following components and follows the below-given connections:

Current Measurement: In order to measure the current, the CTs connected in the three phases continuing to measure the current of the respective phase.

An analog signal is obtained at the output after reading the current and this analog signal is proportional to the phase current.

The CT output is read through the analog pins of the Arduino UNO. This Arduino converted the analog voltage to the current value with the corresponding calibration factor of the CTs.

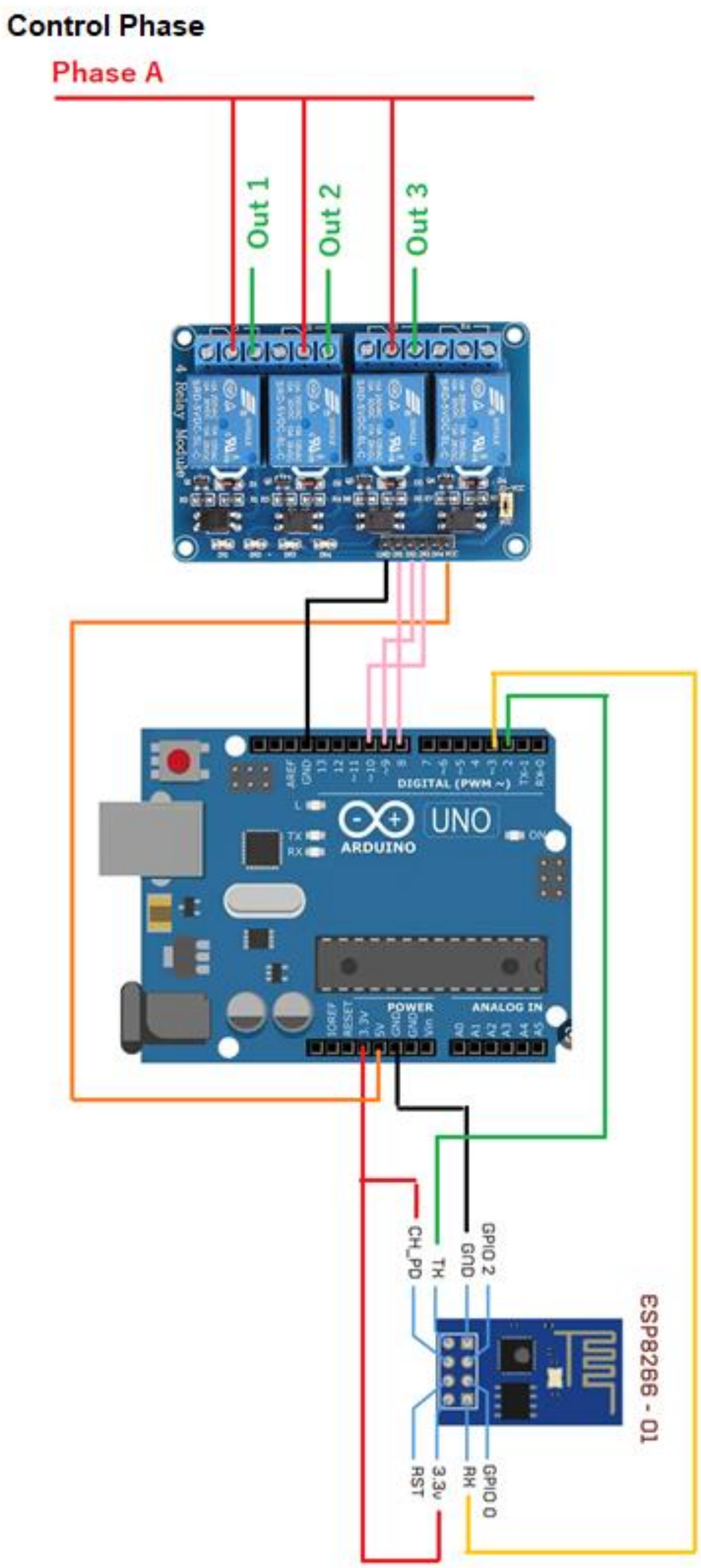
Data Processing: The three-phase current values are processed in the Arduino to make it into a packet to be transmitted.

Wireless Transmission: The processed is sent through UART (Universal Asynchronous Receiver/Transmitter) to the ESP8266 module. ESP8266 then transmits the data using WiFi to another Arduino or any other receiving device By Blink website.

2.7 Control Circuit of Slave panel

Figure 7

Control circuit of slave panel of the project



Circuit (Shown in Figure 7) involves the ability to obtain current data transmitted through the wireless transmission process by the previous circuit in order to operate a set of relays accordingly. The relays are used to determine that all these three outputs (Out1, Out2, Out3) are the Phase A.

Data Reception: ESP8266 WiFi module obtains real-time that the current data using wireless transmission process from the previous circuit. The obtained current data is something which is already available in analog values. This changes the data to the digital values and transferred to the device Arduino UNO using the TX and RX pins.

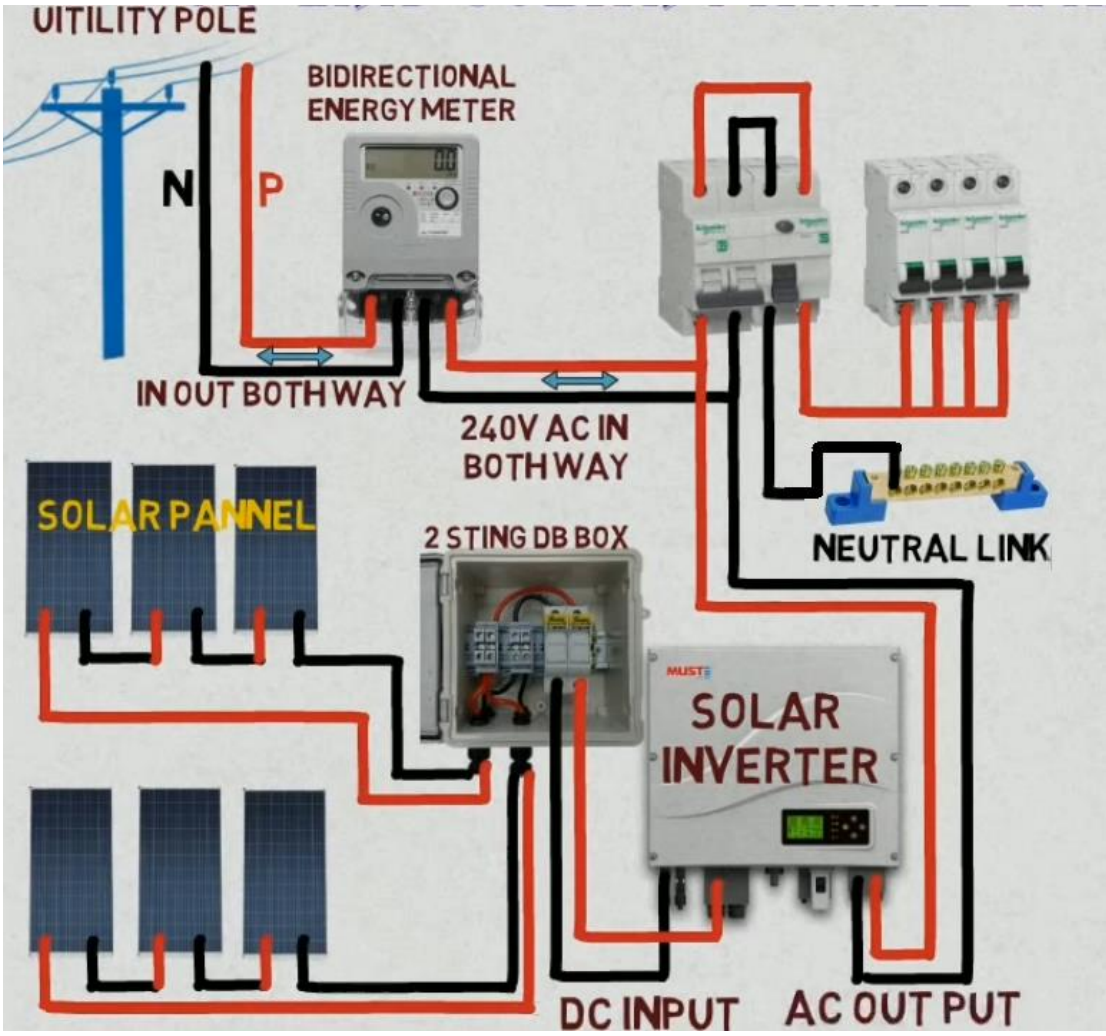
Decision Making: The current data here shows the current measurements in the Phase A which reaches any particular values like the load status. By observing these received data, the device and the program logic written in the Arduino device activate or deactivate the relays.

Relays Control: As per the final results of the programed values, the Arduino sends the respective digital HIGH or LOW signals to the relay module in order to open or close the required circuits for out 1, out 2 and out 3.

2.8 Power circuit of PV system of the houses

Figure 8

Power circuit of PV system of the houses



A diagram of a grid-connected solar photovoltaic (PV) system is shown in Figure 8. The following is a list of the components of the grid-connected PV system and their function:

Solar Panels: It converts sunlight into DC electricity.

There are several solar panels. Panels are connected in parallel or series in order to achieve the required voltage and current.

2 String DB Box: String DB Box combines the output of many solar panel strings. It contains fuses, SPD, and DC isolators are provided to protect and control the DC side of the system.

Solar Inverter: Solar Inverter converts the DC power from solar panels into AC power which is used for household appliances and supplied to the utility grid. This is the way electricity is being generated from the solar panels.

AC distribution: Inverters have DC input terminals in order to connect to the PV array and AC output terminals to connect to the AC distribution.

Bidirectional Meter Connection: Bidirectional meter connection measures the power consumed from the grid and the surplus power exported to the grid. It allows tracking energy flow in two ways, but it may also become the main component to introduce net metering.

Neutral Link: All circuits use neutral to terminate. It provides a stable return path for the current. It establishes a common neutral connection to all points. It plays a vital role while considering human safety on electrical circuits.

Utility Pole Connection: Utility Pole connects the system to the utility grid through the pole. This pole can also support the transformer to steps down power before it is sent to the consumer.

It is a mechanical and electrical structure which allows energy exchange. It supports any number of circuits and any layout of the PV system.

Working:

During the Day: At the time of sunlight and brightness, the solar panels generate electrical power in the form of DC power. This power is converted into electrical power by the solar inverter in the form of AC power.

During the day, this AC power can be used by the loads i.e. household loads and if this power is more than the household loads, then Net meter allows to send the generated power to the grid.

Night or Low Sunlight: If the solar power is less than the household loads, at this time, the power is drawn from the utility grid to the system where the power is supplied to the household loads. This system works only with the help of sunlight, but when it is cloudy day or in the night times, it works by absorbing the power from the utility grid.

This system supports both using power to self and also supply power to the grid. This system optimizes energy use and reduces electricity bills.

2.9 The components

2.9.1 ESP8266-01

The ESP8266-01 has a low retail price and gives WiFi ability to microcontroller-based projects. It has a low number of I/O pins since it's a small module. Also, the ESP8266-01 module has a small form factor and with an in-built antenna can be interfaced easily with other devices of the Arduino IDE, which comes with Wi-Fi libraries to simplify the process of connecting your microcontroller to any WiFi networks and also send and receive data through it [19].

It's been a popular choice for the Internet of Things (LoT) and also home automation projects because of its low price and the above mentioned is the easier way of use [20]. It can be used in two ways; either it can be connected to another microcontroller-based board in order to connect that board to the internet and communicate with sending or receiving data or can also act as a standalone device that can be connected to house router or network to work as a Web Server, creating a web page or can also hit it on a web-page and have processed the commands or the data [21].

The ESP-01 module is used AT commands in order to control it, which is a list of instructions within which 'this' can be sent using the UART interface and AT commands is the one that is used to set the parameter of ESP8266.

Some common AT commands for the ESP-01 include:

AT: Check if the module is responding.

AT+GMR: Get the firmware version.

AT+CWMODE: Set the Wi-Fi mode (e.g., station, access point, or both.(

AT+CWJAP: Connect to a Wi-Fi network.

AT+CIFSR: Get the module's IP address.

The baud rate is the speed at which data is transmitted over the UART interface.

(The default baud rate for ESP-01 modules is usually 115200 bps) [22].

The baud rate using the AT+UART_DEF command can be changed. For example, to set the baud rate to 9600 bps, the command: AT+UART_DEF=9600,8,1,0,0 can be used.

2.9.2 Current Transformer (CT)

A current transformer (CT) is an example of a sensor. This sensor is used to measure current flow in an electrical circuit. When a CT is connected to Arduino microcontroller [23], current in a circuit can be monitored and controlled [24].

A current transformer is used in a power line which carries high electrical current. It transforms the current to a lower amount which is very easy to handle. It can be considered like changing a big sound to a small one [25].

Current transformers are very important and necessary for safety. They are so important because they save devices and people from the dangers of the high flow of currents. The way they work is by decreasing the amount they reduced to a safe level so that they can be measured.

2.9.3 4-Relay Module

A 4-Relay Module is an electronic device which can be used to control up to four electrical loads. This module usually consists of four relays and each relay is used to switch an electrical load (which can be a light, fan, motor or any other device) on or off.

The relays on the module are controlled by digital logic input signals, usually from a microcontroller such as the Arduino. The module typically has a set of input pins for each relay that are connected to the microcontroller and a set of output pins for each relay that are connected to the electrical load [26] [27].

When the relay receives signal from the microcontroller (in the form of a digital input), the load is switched on or off circuititly [28].

2.9.4 ACS712 Current Sensor

Allegro Microsystems developed a linear current sensor that depends on the Hall effect, known as ACS712. It measures alternating current and direct current with high accuracy. [29]

The ACS712 works on the principle of the Hall effect. The Hall effect gap will produce a voltage that is proportional to the current when the current flows through a conductor. For the ACS712, the gap produces the output voltage [30].

The ACS712 produces an output voltage that is proportional to the current that flows through it. The output voltage is analog. The output voltage can be fed into an analog-to-digital converter on a microcontroller for measuring the current with high accuracy. ACS712 sensor has an integrated hall effect transducer, as well as a signal conditioning circuitry, that makes it to accurately sense the current with minimal drift and noise [31].

The ACS712 is a current sensor that usually finds a place in many projects and systems involving current sensing.

Modern consumer electronics can consume both direct and alternating current. So current sensing is an essential aspect of monitoring the power in such devices. Measuring the electric power delivered to a load is the basic concept of power monitoring.So the ACS712 is used to monitor the power more effectively. [32]

The ACS712 is used to protect against the overcurrent. The load connected to the sensor outputs will be removed when the microcontroller receives the output of ACS712 exceeds the particular threshold value. [33]

By placing the ACS712 in series with a load and measuring the output voltage, the uniformity of the load can be measured. [34]

The ACS712 is used in a wide range of applications such as those in industrial automation, production and electric car charging stations [35].

The sensor has an in-built path to flow the current. Models of ACS712 can handle currents up to 30A.

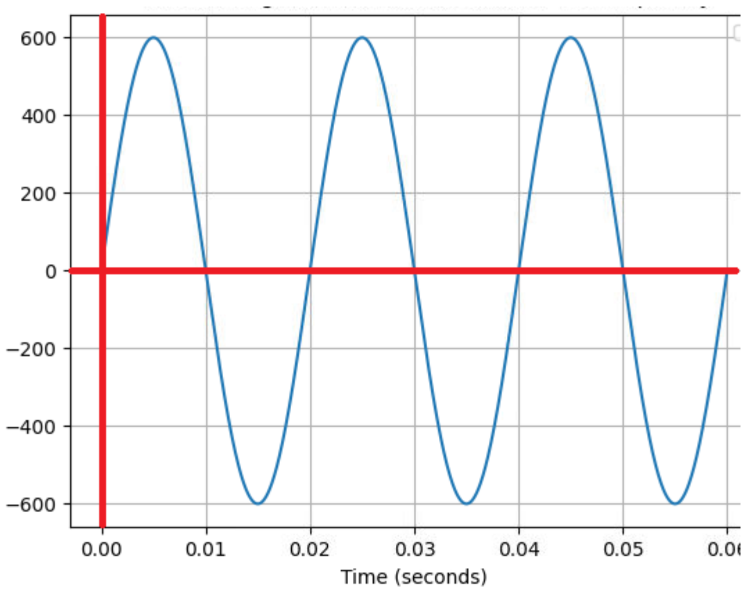
The ACS712 has very compact size.

If 600A cable into a CT (Current Transformer) with a ratio of 1000/5 is being placed:

Input Current (in the cable): The cable is carrying a current of 600A As in Figure 9.

Figure 9

Signal of the current of the cable



This ratio (shown in Figure 9) means that the CT is designed to scale down the current. For every 1000 units of current that go into the CT, it produces 5 units. So, it's like converting the current to a more manageable level. Output Current from CT: When passing the 600A through the CT with a ratio of 1000/5, it would be scaled down. In this case, the output current would be (600 / 1000) * 5 = 3A. So, the output current from the CT, in this case, would be 3A.

The ACS712 A5 current sensor is designed to measure current. In this case, it is connected to a circuit carrying an alternating current of 3 amperes AC (shown in Figure B.1).

The ACS712 A5 is a specific type of current sensor. The "A5" indicates a sensitivity of 416 mV/A. This means for every ampere of current passing through the sensor, the output voltage will increase by 416 millivolts. Output Voltage.

If 3A of AC passing through the ACS712 A5, the output voltage from the ACS712 A5 sensor would be a combination of the bias voltage and the voltage generated due to the current. In this case, it would be 2.5V (bias voltage) + 3A * 416 mV/A = 2.5V + 1250 mV = 3.75V. So, when a 3A AC current is applied, the output voltage from the ACS712 A5 sensor would be 3.75V AC (Shown in Figure B.2).

2.9.5 Capacitors

Capacitor is an electronic component that stores electrical energy in an electric field [36]. Capacitors can help regulate voltage in AC circuits. They store energy during the peaks of the AC waveform and release it during the lower points, helping to smooth out the voltage fluctuations(Shown in Figure B.3) [37].

Capacitors come in various types and configurations, including ceramic, electrolytic, and tantalum, each suited for different applications based on their characteristics [38].

Capacitors are versatile components in AC circuits, serving functions from smoothing out voltage fluctuations to storing and releasing energy [39].

2.10 Sketch for the All Steps

All of the project and the relation of the slaves and master panels is Shown in Figure B.4.

Shown in Figure B.4, the project involves a multi-Arduino system where a master Arduino communicates with multiple slave Arduinos, and the whole setup integrates with the Blynk platform for remote monitoring and control.

2.11 The Code of the Slaves

/**

/* Fill-in information from Blynk Device Info here */

#defineBLYNK_TEMPLATE_ID"TMPL63IdmODpK"

#defineBLYNK_TEMPLATE_NAME"ahmadkmail"

#defineBLYNK_AUTH_TOKEN"E3CaRbhY6sWHvvMJZpdYWtbOYl5PHQbf"

These are identifiers for connecting to a specific Blynk project in the Blynk Cloud.

#defineBLYNK_PRINT**Serial**

//Enables debug messages via the serial monitor for easier troubleshooting.

#include<ESP8266_Lib.h>

//Handles communication with the ESP8266 module.

#include<BlynkSimpleShieldEsp8266.h>

//Provides a Blynk interface for the ESP8266 shield.

char ssid[] ="Ahmad97";

char pass[] ="##ahmad1997";

//Stores the SSID and password of the WiFi network to connect the ESP8266 module.

#include<**SoftwareSerial**.h>

//Enables software-based serial communication for boards with limited hardware serial ports.

Software Serial Esp Serial (2, 3); // RX, TX

//Configures communication with the ESP8266 module on pins 2 (RX) and 3 (TX).

```
// Your ESP8266 baud rate:

#define ESP8266_BAUD 9600

//Sets the baud rate for ESP8266 communication to 9600.

ESP8266 wifi(&EspSerial);

intreceivedValue=0;

voidsetup()

{

// Debug console

 Serial.begin(115200);

//Starts the serial monitor for debugging.

 EspSerial.begin(ESP8266_BAUD);

//Sets up communication with the ESP8266.

delay(10);

pinMode(8,OUTPUT);

pinMode(9,OUTPUT);

pinMode(10,OUTPUT);

digitalWrite(8,HIGH);

digitalWrite(9,HIGH);

digitalWrite(10,HIGH);

//Blynk.begin(BLYNK_AUTH_TOKEN, wifi, ssid, pass);

// You can also specify server:
```

```
Blynk.begin(BLYNK_AUTH_TOKEN, wifi, ssid, pass,"blynk.cloud", 80);

//Blynk.begin(BLYNK_AUTH_TOKEN, wifi, ssid, pass, IPAddress(192,168,1,100), 8080);

}

voidloop()

{

Blynk.run();

// You can inject your own code or combine it with other sketches.

// Check other examples on how to communicate with Blynk. Remember

// to avoid delay() function!

if(receivedValue==1){

digitalWrite(8,LOW);

digitalWrite(9,HIGH);

digitalWrite(10,HIGH);

}

elseif (receivedValue==2){

digitalWrite(8,HIGH);

digitalWrite(9,LOW);

digitalWrite(10,HIGH);

}

elseif (receivedValue==3){

digitalWrite(8,HIGH);
```

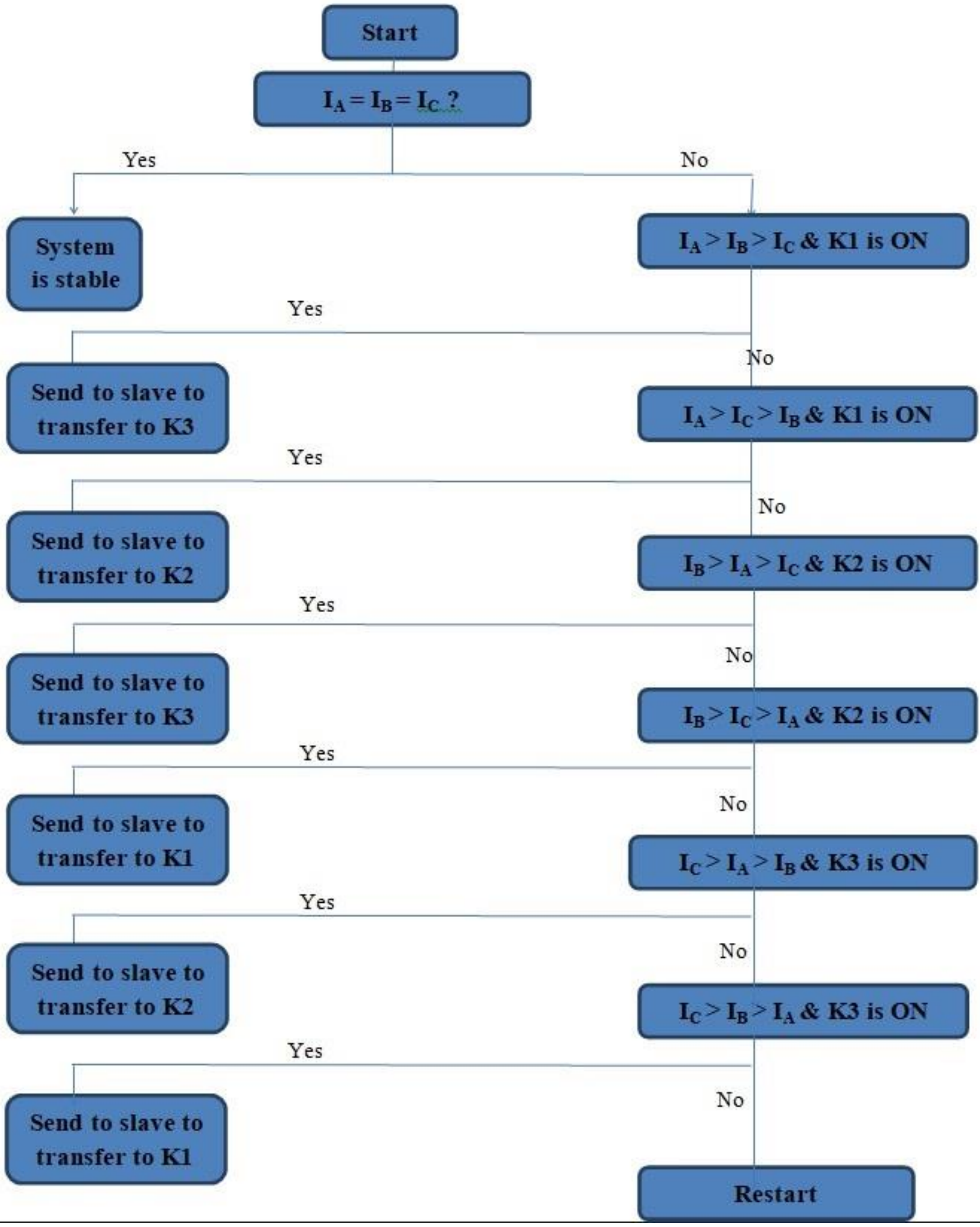
```
digitalWrite(9,HIGH);

digitalWrite(10,LOW);

}

elseif (receivedValue==0){

digitalWrite(8,HIGH);

digitalWrite(9,HIGH);

digitalWrite(10,HIGH);

 }

}

BLYNK_WRITE(V1) {

// This function is called whenever data is received on virtual pin V1

receivedValue=param.asInt();  // Get the value sent from the app

Serial.print("Received value on V1: ");

Serial.println(receivedValue);

}
```

2.12 Flow chart

Figure 10 is the flow chart that explain how the code will work, first the master Arduino read0 the three phases currents and compare them, if the three currents are equal then the system is stable, and if not equal the Arduino send command to the first house on the largest current phase to the smallest current phase.

Figure 10

The flow chart of the Arduino code



2.13 The Code of the Master Unit

```
#include<SoftwareSerial.h>

SoftwareSerial espSerial(2, 3); // RX, TX

int in1 = A0 ;

int in2 = A1 ;

int in3 = A2 ;

int house[7]={1,2,3,1,2,3,1};

String value[7]={"1","2","3","1","2","3","1"};

int i=0;

int sure=0;

int once=1;

unsignedlong startTime = 0;

unsignedlong elapsedTime = 0;

float max1=0.0;

float max2=0.0;

float max3=0.0;

int En=1;

voidsetup() {

Serial.begin(9600);

espSerial.begin(9600);

// Connect to Wi-Fi

sendATCommand("AT+CWJAP=\"Ahmad97\",\"##ahmad1997\"", 2000);
```

```
// Send HTTP GET request

String http[] =
{"E3CaRbhY6sWHvvMJZpdYWtbOYl5PHQbf&v1=","ucdIBBztz6y3medITb_DQI9y-
C3_5ozC&v2=","5gXjlGuZKUeDFqvNK1v08MW7dmkaXag1&v3=","wV66XHYVY
zQB5JXBgzimsj2c_ioUXOdx&v6=","JaAoimhnoSnFfGW3pD9bc1nqgTDlzX-
r&v7=","eZRLiA8UDAqHGrQpdEgrUvFSV-
GYtUj_&v8=","if1MnHEdqfTmC7zI72SMJUw6G2YG8INm&v9="};

delay(2000);

if(once==1){

for(int k=0;k<=6;k++){

sendHTTPRequest("sgp1.blynk.cloud",
80,"/external/api/update?token="+http[k]+value[k]);

}

once=0;

}

}

voidloop() {

String http[] =
{"E3CaRbhY6sWHvvMJZpdYWtbOYl5PHQbf&v1=","ucdIBBztz6y3medITb_DQI9y-
C3_5ozC&v2=","5gXjlGuZKUeDFqvNK1v08MW7dmkaXag1&v3=","wV66XHYVY
zQB5JXBgzimsj2c_ioUXOdx&v6=","JaAoimhnoSnFfGW3pD9bc1nqgTDlzX-
r&v7=","eZRLiA8UDAqHGrQpdEgrUvFSV-
GYtUj_&v8=","if1MnHEdqfTmC7zI72SMJUw6G2YG8INm&v9="};

int analog1=analogRead(in1);

int analog2=analogRead(in2);
```

```
int analog3=analogRead(in3);

delay(100);

Serial.println(analog1);

Serial.println(analog2);

Serial.println(analog3);

float voltage1 = 2.5-(analog1 * (5.0 / 1023.0)); // Convert the ADC reading to voltage

float current1 = voltage1*10.6; // Subtract the offset and divide by sensitivity to get current in Amperes

float voltage2 = 2.5-(analog2 * (5.0 / 1023.0)); // Convert the ADC reading to voltage

float current2 = voltage2*10.6; // Subtract the offset and divide by sensitivity to get current in Amperes

float voltage3 = 2.5-(analog3 * (5.0 / 1023.0)); // Convert the ADC reading to voltage

float current3 = voltage3*10.6; // Subtract the offset and divide by sensitivity to get current in Amperes

if(current1<0){

current1 = current1*(-1);

}

if(current2<0){

current2 = current2*(-1);

}

if(current3<0){

current3 = current3*(-1);
```

```
}
if(current1>max1){
delay(100);
int test1=analogRead(in1);
if((analog1-test1)<100 || (test1-analog1)<100){
max1=current1;
if(max1<0.4){
max1=0.0;
}
}
}
if(current2>max2){
delay(100);
int test2=analogRead(in2);
if((analog2-test2)<100 || (test2-analog2)<100){
max2=current2;
if(max2<0.4){
max2=0.0;
}
}
}
```

```
if(current3>max3){
delay(100);
int test3=analogRead(in3);
if((analog3-test3)<100 || (test3-analog3)<100){
max3=current3;
if(max3<0.4){
max3=0.0;
}
}
}
if(En==1){
startTime =millis();
elapsedTime = 2000 + startTime;
En=0;
}
for(int j=0;j<=6;j++){
Serial.print(house[j]);
}
Serial.print("\n");
Serial.println(i);
```

```
if(millis()>elapsedTime){

Serial.print(max1);

Serial.print("...");

Serial.print(max2);

Serial.print("...");

Serial.print(max3);

Serial.println("...");;

if(max1>max2 && max2>max3){

if( house[i]==2 || house[i]==3){

i++;

if(i==7){

i=0;

}

}

if(house[i]==1){

sendHTTPRequest("sgp1.blynk.cloud", 80,"/external/api/update?token="+http[i]+"3");

if(sure==1){

Serial.println("1to3");

house[i]= 3;

sure=0;

}
```

```
delay(1000);

i++;

if(i==7){

i=0;

}

}

}

if(max1>max3 && max3>max2){

if( house[i]==2 || house[i]==3){

i++;

if(i==7){

i=0;

}

}

if(house[i]==1){

sendHTTPRequest("sgp1.blynk.cloud", 80,"/external/api/update?token="+http[i]+"2");

if(sure==1){

Serial.println("1to2");

house[i]= 2;

sure=0;

}
```

```
delay(1000);

i++;

if(i==7){

i=0;

}

}

}

if(max2>max3 && max3>max1){

if( house[i]==1 || house[i]==3){

i++;

if(i==7){

i=0;

}

}

if(house[i]==2){

sendHTTPRequest("sgp1.blynk.cloud", 80,"/external/api/update?token="+http[i]+"1");

if(sure==1){

Serial.println("2to1");

house[i]= 1;

sure=0;

}
```

```
delay(1000);

i++;

if(i==7){

i=0;

}

}

}

if(max2>max1 && max1>max3){

if( house[i]==1 || house[i]==3){

i++;

if(i==7){

i=0;

}

}

if(house[i]==2) {

sendHTTPRequest("sgp1.blynk.cloud", 80,"/external/api/update?token="+http[i]+"3");

if(sure==1){

Serial.println("2to3");

house[i]= 3;

sure=0;

}
```

```
delay(1000);

i++;

if(i==7){

i=0;

}

}

}

if(max3>max1 && max1>max2){

if( house[i]==2 || house[i]==1){

i++;

if(i==7){

i=0;

}

}

if(house[i]==3){

sendHTTPRequest("sgp1.blynk.cloud", 80,"/external/api/update?token="+http[i]+"2");

if(sure==1){

Serial.println("3to2");

house[i]= 2;

sure=0;

}
```

```
delay(1000);

i++;

if(i==7){

i=0;

}

}

}

if(max3>max2 && max2>max1){

if( house[i]==2 || house[i]==1){

i++;

if(i==7){

i=0;

}

}

if(house[i]==3){

 sendHTTPRequest("sgp1.blynk.cloud", 80,"/external/api/update?token="+http[i]+"1");

if(sure==1){

Serial.println("3to1");

house[i]= 1;

sure=0;

}
```

```
delay(1000);
i++;
if(i==7){
i=0;
}
}
}
max1=0;
max2=0;
max3=0;
En=1;
}
}
void sendATCommand(String command,int timeout) {
espSerial.println(command);
delay(timeout);
while (espSerial.available()) {
Serial.write(espSerial.read());
}
}
```

```
void sendHTTPRequest(String server,int port,String path) {

String command ="AT+CIPSTART=\"TCP\",\""+ server +"\","+String(port);

sendATCommand(command, 2000);

String getRequest ="GET "+ path +" HTTP/1.0\r\n\r\n";

command ="AT+CIPSEND="+String(getRequest.length());

sendATCommand(command, 2000);

espSerial.print(getRequest);

delay(2000);

sendATCommand("AT+CIPCLOSE", 2000);

sure=1;

}
```

Chapter Three

Results

3.1 Voltage and Power Loss Calculations

The voltage drop and power losses have been calculated, and voltage levels have been measured for the Mesrara and Wad transformers. These losses and voltage drops were observed, measured, and minimized while observing the power and loads at the transformers for both the phases before and after load balancing at the receiving end. There was no balance in the loads and power losses at either of the three transformer phases. Therefore, non-uniform load distribution and power loss were recorded at each phase before balancing. Both cases, the power losses at the Mesrara and WAD transformer phases power losses were initially recorded.

The balancing of loads also caused a drastic reduction in power losses across different phases, while the final power losses were recorded in kW. The quality of power supplied by these transformers at the receiving end was improved. With the other two-phase slightly relaxed and more loaded, the voltage level also stabilized while power supply across different phases tend to reduce power loss. This indirectly reduced the costs of power supply by allowing the supplier to reduce or avoid power consumption.

3.2 Comparative Analysis Before and After Balancing

The performance between the systems before and after the transformer phases balancing were compared with calculate the difference in the power loss suffered by the systems as well as the voltage provided at the power station at the solutions comes to the load was unbalanced over different waves resulting in too high power losses and stress over the transformers. After the balancing of different phases, the total power loss also improved.

In comparative to the total power losses and voltage fluctuations at the transformer phases before registration, it has been observed that the power loss at the network was very high. At Case1 P_{loss} = 138 KW and At Case2 P_{loss} = 12 KW and At Case3 P_{loss} = 139 KW and At Case4 P_{loss} = 9 KW. This shows the major advantage of balancing power and energy dissipation with reduced overall power losses and increased power factor.

3.3 Proposed Control Circuit

The block diagram of phase distribution across all levels can be seen in the figure B4 explaining the block diagram of load balancing. The control load is centralized at Mains D. Trans., maintaining the loads equal among all three of these phases across different transformer locations. Hereby, a Wi-Fi enabled sensor has been embedded with the control provided at Mains D. Trans. Along with that, Arduino uno at the secondary end of it has been coupled, aiming at minimizing the power losses across each of these transformer phase.

The control unit at Mains D. Trans. Constantly monitors the current supplied and the amount of power consumed by each of the transformer units. It then transmits a message to the uno unit, which automatically shifts loads from the supply point to a more loaded phase of the transformer, causing an imbalance with the frequently used phase of the system. The power consumed during the shift is obtained from the standard deviation after considering the switching time of the system.

This causes a reduction in power losses and voltage sags so the overall resilience of the power distribution network is increased. The control circuit that is present inside the model 2 makes sure that the renewable energy sources such as photo-voltaic (PV) system are working great. The model adjusts with the change in the power output of the PV system.

3.4 Economic Benefits of Implementing the Master's Project

The profitability of the project was justified after examining the power loss minimization and load balancing aspects of the projected model. The proposed solution was executed on a transformer that supplied electricity to a community of 50 households. The primary focus of the project was to change the power losses from the original value of 138kW to 9kW. The financial benefits of investing in the project are as follows:

Project Description

- Number of Households Benefiting: 50
- Implementation Cost per Household: $75

- Total Project Cost: 50 households × $75 = $3,750
- Power Losses Before Implementation: 138 kW
- Power Losses After Implementation: 9 kW
- Electricity Price in Palestine: $0.1714 per kWh

3.4.1 Costs

Implementation Cost: The total cost of implementing the solution across all 50 households is calculated as follows:

- Total Implementation Cost=Cost per Household×Number of Households
- Total Implementation Cost=75 USD×50=3,750 USD

3.4.2 Benefit Analysis

Calculating the economic benefits derived from reducing power losses are:

- Calculate the Reduction in Power Losses:
- Losses Before Implementation: 138 kW
- Losses After Implementation: 9 kW
- Energy Savings: 138 kW - 9 kW = 129 kW
- Convert Power Losses to kWh (assuming continuous operation throughout the year):
- Total Hours in a Year: 8,760 hours
- Annual Energy Savings: 129 kW × 8,760 hours = 1,129,044 kWh
- Economic Value of Savings:
- Annual Savings in Dollars: 1,129,044 kWh × $0.1714 = $193,217
- Reduction in Power Losses: Reduction=135 kW/h−7 kW/h=128 kW/h

3.4.3 Economic Analysis

1. **Payback Period:**

- **Total Project Cost:** \$3,750
- **Annual Savings:** \$193,217
- **Payback Period:** \$3,750 / \$193,217 ≈ 0.02 years ≈ Less than a month

2. **Net Present Value (NPV):**

- **Assume a Discount Rate (e.g., 10%)**
- **NPV = (Annual Savings) / Discount Rate - Total Project Cost**
- **NPV = \$193,217 / 1.10 - \$3,750 = \$175,651 - \$3,750 = \$171,901**
- **Result:** The NPV is highly positive, indicating strong economic feasibility.

3. **Internal Rate of Return (IRR):**

- Given the short payback period and high NPV, the IRR would be very high, further confirming the project’s viability

3.4.4 Economic Conclusion

The study indicates that the project of improving the network through load distribution for a transformer serving 50 households is highly economically viable.

Project Benefits:

- Significant reduction in power losses.
- Substantial economic savings for consumers.
- Very short payback period and highly positive NPV.
- Extremely high IRR.

Chapter Four

Discussions and Conclusions

This research has emphasized the critical importance of maintaining current balance within power systems to ensure their stability and reliability. Through a comprehensive analysis of the Mesrara and Wad transformers in Merka – Jenin, it has been demonstrated that current imbalance can lead to significant issues such as voltage drops, overloading of transmission lines, and increased power losses. By redistributing the number of houses connected to each phase, the research successfully mitigated these imbalances, leading to more stable and efficient operation

Regularly monitor current and voltage levels across the network to detect and address imbalances promptly

Conducting periodic maintenance of transformers and other critical infrastructure to ensure they operate within their rated conditions and prevent overloads

By following these recommendations, power system operators and engineers can enhance the stability and reliability of their networks, ensuring a steady and secure supply of electricity to meet the growing demands of modern society.

This study addresses the issue of phase imbalance in residential networks sharing a three-phase power supply. Such imbalances occur when a disproportionate number of houses rely heavily on one or two phases, leading to power losses, overloaded lines, voltage drops, and potential blackouts. The increasing adoption of single-phase photovoltaic (PV) systems exacerbates this problem due to fluctuating solar energy production.

To mitigate these challenges, a smart system was developed using a microcontroller and WiFi technology to monitor and dynamically balance power distribution across the three phases. This system tracks real-time household power consumption and solar energy production, automatically reassigning houses to different phases to maintain balance.

Simulation and field testing on real transformers in Merka, Jenin, demonstrated the system's effectiveness. Results showed significant improvements in power reliability and efficiency, with network losses reduced from 138 kW to 9 kW—resulting in cost savings of $193.2, or $3.75 per house. The system achieved a simple payback period of less than one month. Furthermore, the lowest network voltage improved from 206 V under unbalanced conditions to 221 V after implementing the balancing solution.

References

[1] IEEE, IEEE Power and Energy Society: Power System Basics, IEEE, 2019.

[2] M. Singh and R. Sharma, Power System Stability and Control, 2 ed., Springer, 2017.

[3] P. Kundur, Power System Stability and Control, McGraw-Hill Education, 1994.

[4] M. Pidd, Energy and the Environment: A Systems Approach, Wile, 2003.

[5] M. Moulin, G. Bousquet and P. Maret, Modern Power System Analysis and Control, Elsevier, 2018.

[6] G. Boyle, Renewable Energy: Power for a Sustainable Future, 3 ed., Oxford University Press, 2012.

[7] J. Twidell and T. Weir, Renewable Energy Resources, 3 ed., Routledge, 2015.

[8] International Energy Agency (IEA), World Energy Outlook 2021, IEA, 2021.

[9] F. Vasilis and S. Kalogirou, Solar Energy Engineering: Processes and Systems, 2 ed., Academic Press, 2014.

[10] J. L. Sawin and E. Martinot, Renewables 2021 Global Status Report, REN21, 2021.

[11] REN21, Renewables 2022 Global Status Report, REN21, 2022.

[12] A. Kumar, P. Patel and R. Sharma, "Impact of High PV Penetration on Distribution Network Performance," *Journal of Electrical Engineering & Technology*, vol. 13, no. 4, pp. 1234-1246, 2018.

[13] H. Sian and N. Miller, "Challenges of High PV Penetration in Low-Voltage Distribution Networks," *International Journal of Electrical Power & Energy Systems*, vol. 104, pp. 146-156, 2019.

[14] J. García, D. López and E. Martínez, "Advanced Control Strategies for PV Integration in Distribution Networks," *IEEE Transactions on Smart Grid*, vol. 11, no. 1, pp. 58-70, 2020.

[15] T. Baker and M. Jones, "Enhancing Grid Stability with High PV Penetration: Current and Future Trends," *Renewable Energy Reviews*, vol. 46, pp. 102-115, 2021.

[16] N.A1, "Multifunctional Distributed MPPT Controller for 3P4W Grid-Connected PV Systems in Distribution Network with Unbalanced Loads]," https://www.mdpi.com/1996-1073/12/24/479, N.D.

[17] N.A.3, "[oai_citation:3,Energies | Free Full-Text | Multifunctional Distributed MPPT Controller for 3P4W Grid-Connected PV Systems in Distribution Network with Unbalanced Loads]," N.D. [Online]. Available: (https://www.mdpi.com/1996-1073/12/24/4799 .

[18] N.A2, "Power Quality Enhancement of Balanced/Unbalanced Distribution Systems Using Metaheuristic Optimizations," N.D.

[19] Espressif Systems, ESP8266EX Technical Reference Manual, Espressif Systems, 2015.

[20] H. Liu, Z. Zhang and J. Wang, "Exploring the ESP8266 for IoT Projects: A Practical Guide," *International Journal of Computer Applications,* vol. 168, no. 7, pp. 22-31, 2017.

[21] Y. Gao, Y. Zhou and M. Li, "Integrating the ESP8266 with Arduino: A Developer's Guide," *Journal of Embedded Systems and Applications,* vol. 12, no. 2, pp. 56-70, 2018.

[22] R. Miller, A. Smith and T. Johnson, "Low Power Consumption in WiFi Modules: Case Study of the ESP8266," *IEEE Transactions on Industrial Electronics,* vol. 66, no. 5, pp. 3456-3464, 2019.

[23] E. Hughes, Electrical and Electronic Technology, 11 ed., Pearson Education, 2015.

[24] R. Kuffel, J. Kuffel and J. Kuffel, High Voltage Engineering and Testing, 2 ed., Newnes, 2000.

[25] IEEE, IEEE Standard for Instrument Transformers, IEEE, 2012.

[26] R. Jain and V. Patel, "Microcontroller-Based Monitoring Systems: Integrating Current Transformers with Arduino," *Journal of Electrical Engineering and Automation,* vol. 6, no. 3, pp. 45-60, 2019.

[27] V. Vaidyanathan and S. Sontakke, Digital Electronics: Principles and Applications, McGraw-Hill Education, 2018.

[28] E. Hewlett, ractical Electronics for Inventors, 4 ed., McGraw-Hill Education, 2016.

[29] P. Kerr, Electronic Components and Systems, Wiley, 2015.

[30] M. Brown, Arduino Projects for Engineers, Springer, 2017.

[31] M. Allegro , ACS712 Current Sensor IC: Technical Datasheet, Allegro Microsystems, 2012.

[32] S. Tachibana, M. Suzuki and T. Kobayashi, "Advanced Current Sensing Techniques," *IEEE Transactions on Instrumentation and Measurement,* vol. 64, no. 6, pp. 1450-1460, 2015.

[33] K. Nakamura and X. Liu, "Linear Current Sensors for Power Monitoring Applications," *Journal of Power Electronics,* vol. 23, no. 2, pp. 341-352, 2017.

[34] H. Lee, Y. Kim and J. Park, "Current Measurement and Protection with Hall Effect Sensors," *International Journal of Electronics,* vol. 106, no. 5, pp. 684-695, 2019.

[35] "،"Practical Applications of Current Sensors in Electronics ،A. Smith و R. Johnson
Electronics Tutorials، المجلد 15، رقم 4، pp. 123-135، 2018.

[36] N. Khandelwal, Basic Electronics: A Comprehensive Guide, CRC Press, 2016.

[37] P. Horowitz and W. Hill, The Art of Electronics, 3 ed., Cambridge University Press, 2015.

[38] A. Sedra and K. Smith, Microelectronic Circuits, 8 ed., Oxford University Press, 2018.

[39] D. Morris, Capacitors in Electronic Circuits: Design and Application, Springer, 2017.

[40] N.A.4, " [oai_citation:2,Energies | Free Full-Text | Multifunctional Distributed MPPT Controller for 3P4W Grid-Connected PV Systems in Distribution Network with Unbalanced Loads]," [Online]. Available: (https://www.mdpi.com/1996-1073/12/24/4799.

[41] “A decentralized power injection-based approach for voltage imbalance mitigation in three-phase distribution networks” – Scientific Reports, 15: 16162. (2025)

[42] "On the Exact Formulation of the Optimal Phase-Balancing Problem in Three-Phase Unbalanced Networks: Two Alternative MINLP Models" – Electricity, 6(1): 9.

[43] Sciencedirect (2024) "Optimal conductor selection and phase balancing in three-phase distribution systems"

Appendices

Appendix A

Tables of Study

Table A.1

Compare between four cases in the P losses and receiving end voltages

	Total P losses	Va(receiving)	Vb(receiving)	Vc(receiving)
Case 1	138 KW	180V	210V	248V
Case 2	90 KW	206V	212V	243V
Case 3	14 KW	220V	222V	221V
Case 4	9 KW	221V	226V	228V

Appendix B

Figures of Study

Figure B.1

Signal of the output current of the CT

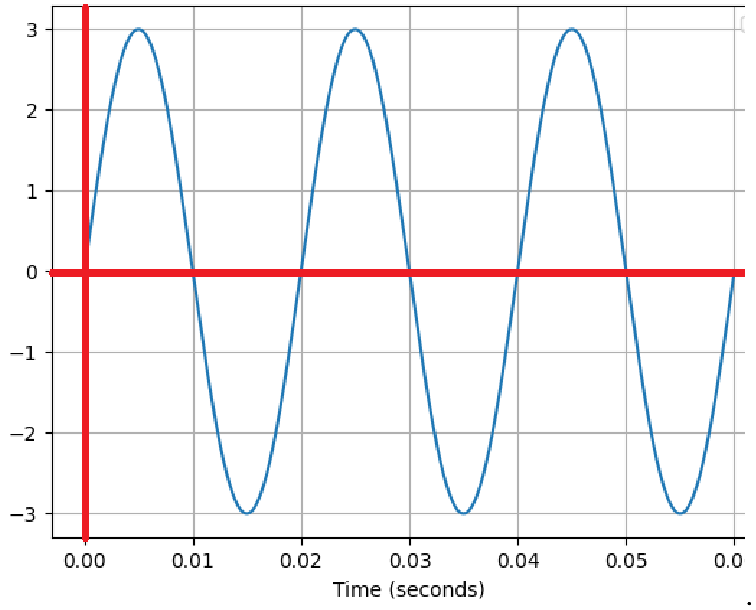


Figure B.2

Signal of the output voltage of the current sensor

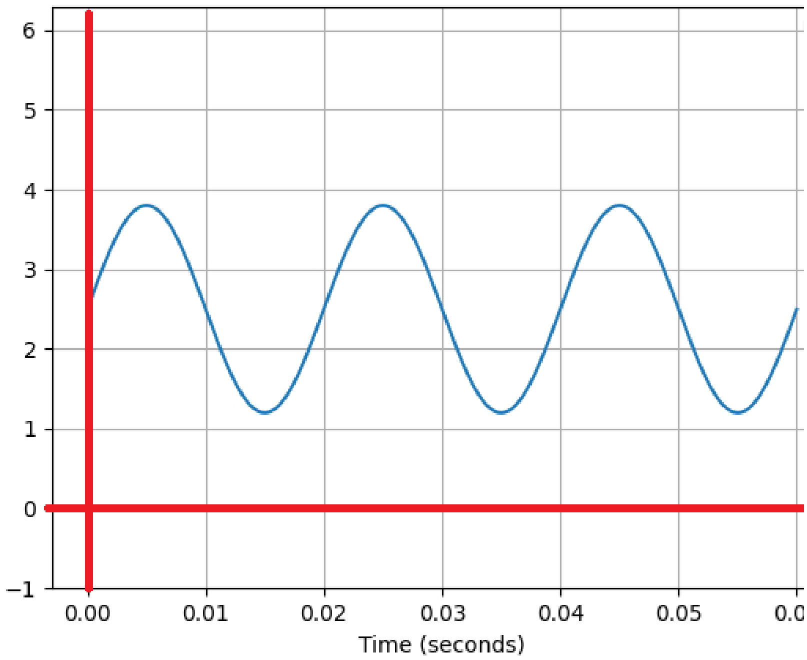


Figure B.3

Signal of the output voltage of the capacitor

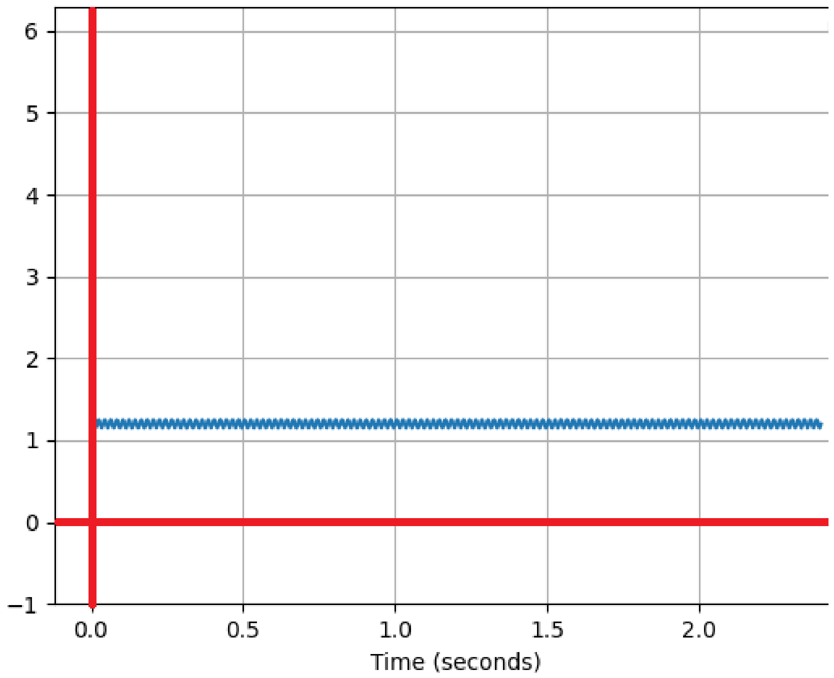


Figure B.4

All of the project and the relation of the slaves and master panels

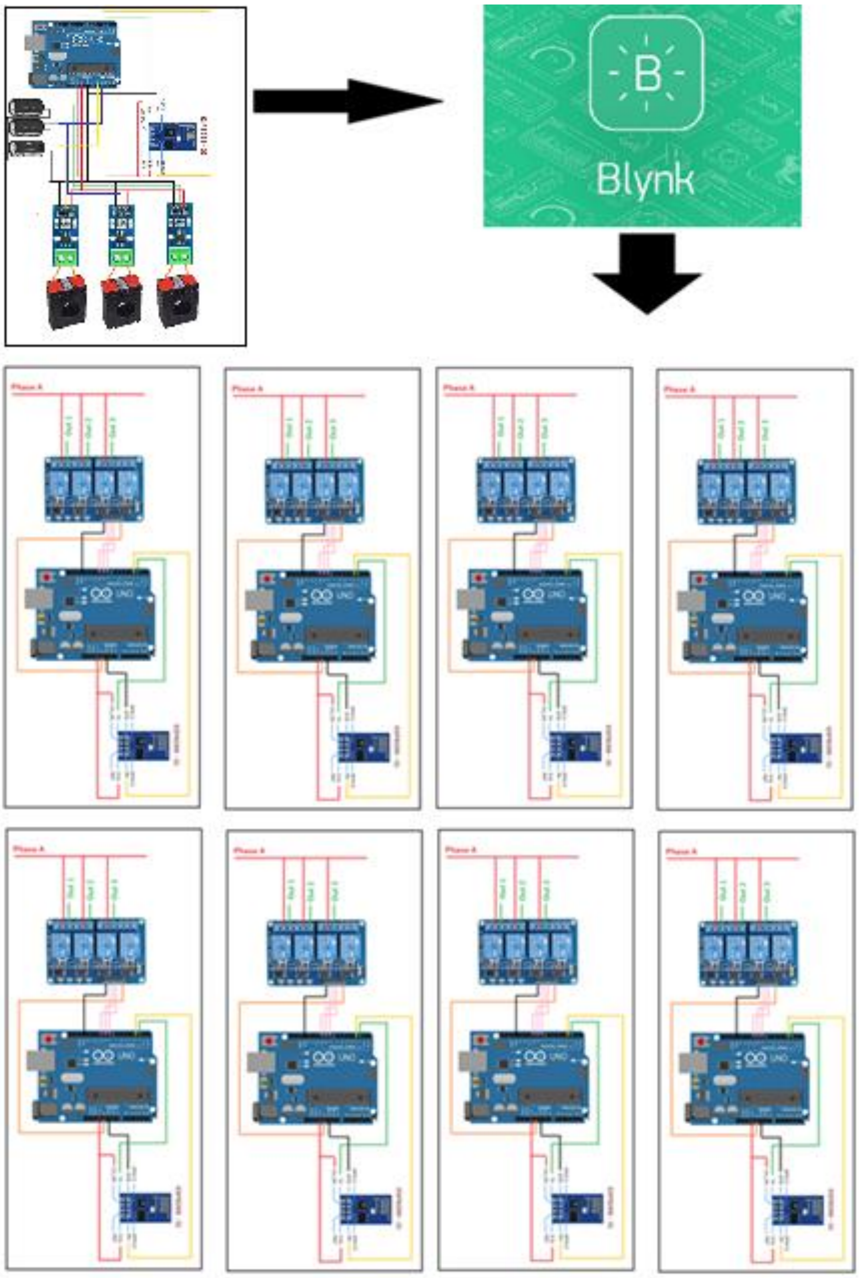


Figure B.5

Etap of the grid without PV before the improvement

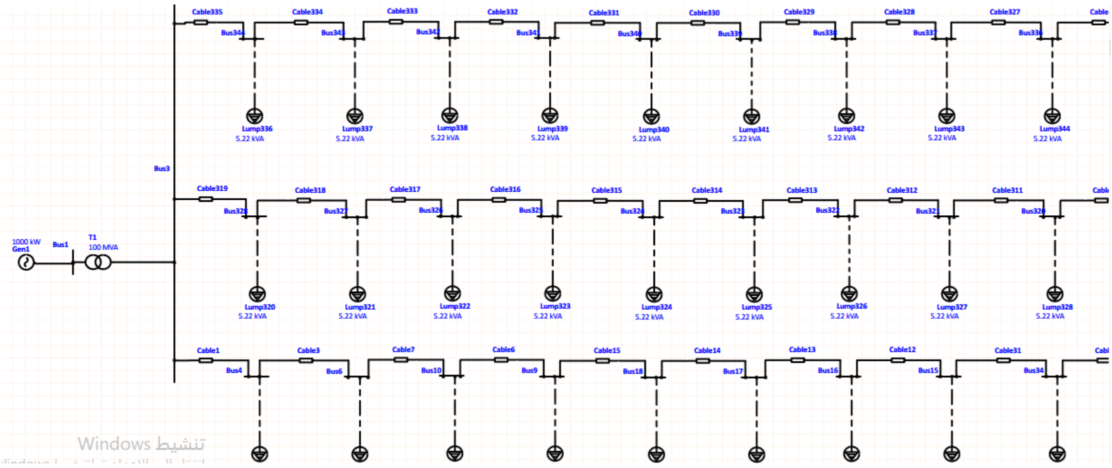


Figure B.6

Receiving end of the grid without PV before the improvement

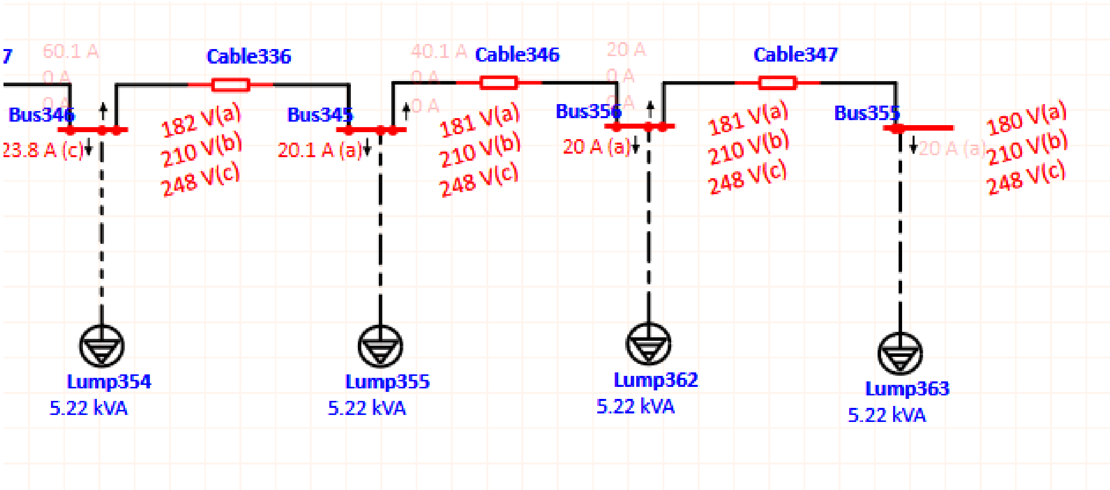


Figure B.7

Etap of the grid with PV before the improvement

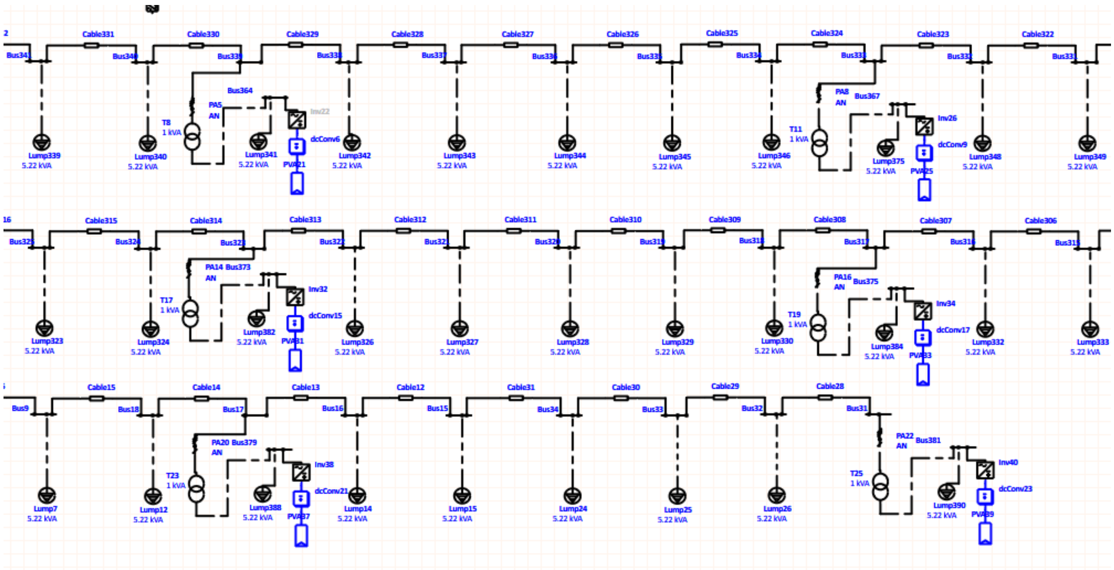


Figure B.8

Receiving end of the grid with PV before the improvement

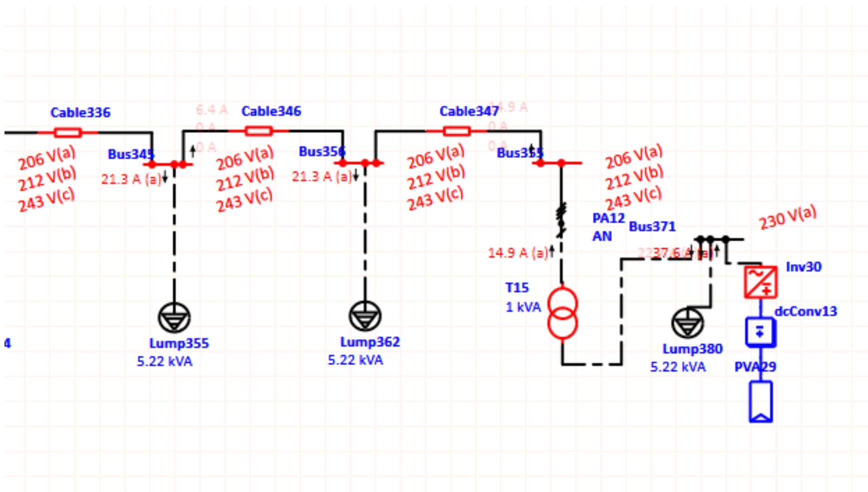


Figure B.9

Etap of the grid without PV after the improvement

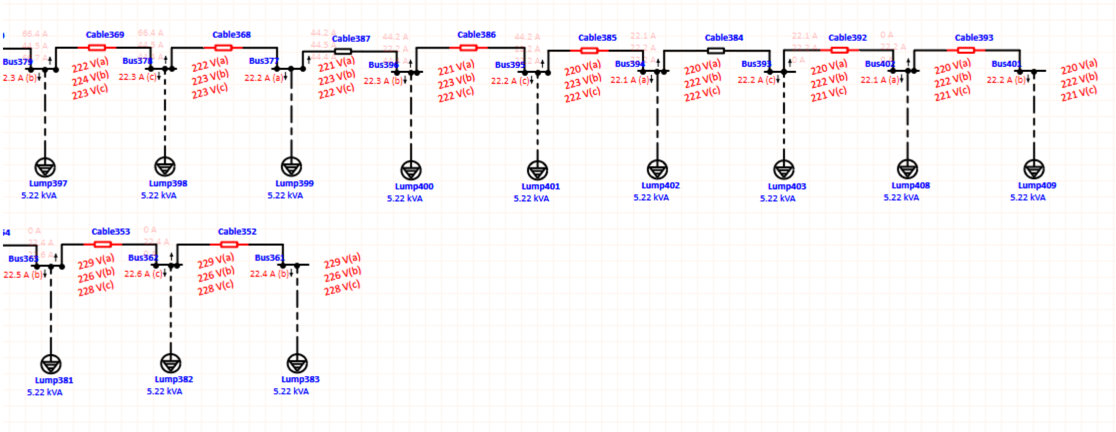


Figure B.10

Receiving end of the grid without PV after the improvement

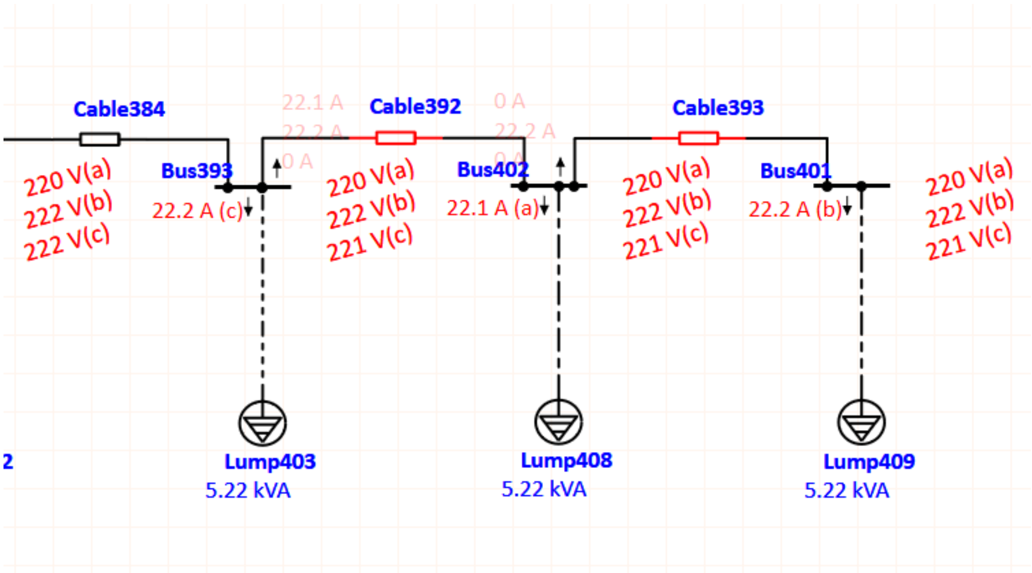


Figure B.11

Etap of the grid with PV after the improvement

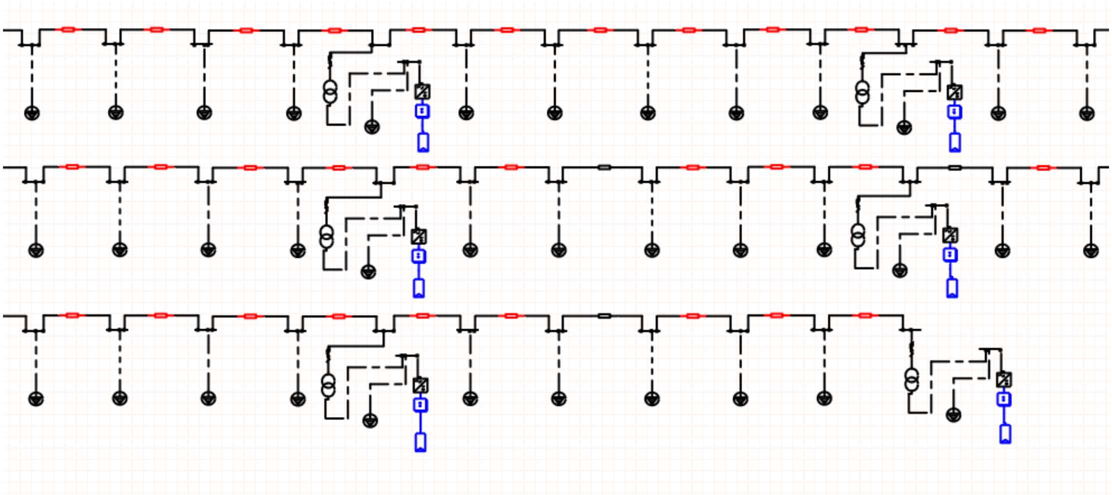
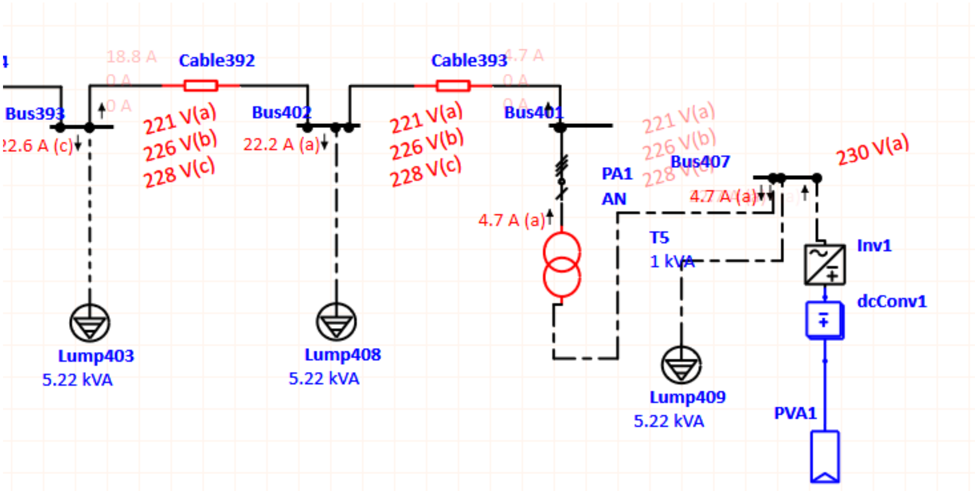


Figure B.12

Receiving end of the grid with PV after the improvement



جـامعـــة النجاح الوطنية

كليـــة الدراســـات العليـــا

طريقة مقترحة لتحسين اتزان التيارات الكهربائية الغير متوازنة في شبكات التوزيع الكهربائية مع وجود الأنظمة الكهروضوئية

إعداد

أحمد رائد عارف كميل

إشراف

د. معين عمر

قدمت هذه الرسالة استكمالا لمتطلبات الحصول على درجة الماجستير في هندسة القوى الكهربائية، من كلية الدراسات العليا، في جامعة النجاح الوطنية، نابلس– فلسطين.

2025

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إعداد

أحمد رائد عارف كميل

إشراف

د. معين عمر

الملخص

تقترح هذه الرسالة نموذجا عمليًا لجهاز ذكي يهدف إلى معالجة مشكلة عدم توازن الأحمال في شبكات التوزيع الكهربائية ذات الجهد المنخفض. تحدث هذه المشكلة عادةً عندما تعتمد مجموعة كبيرة من المنازل على طور واحد أو طورين من أصل ثلاثة، مما يؤدي إلى زيادة الفاقد الكهربائي، وتحميل مفرط على بعض الخطوط، وانخفاض في الجهد، وقد يصل الأمر إلى انقطاعات في التيار الكهربائي. ومع التوسع في استخدام أنظمة الطاقة الشمسية المنزلية، تزداد حدة هذه المشكلة بسبب التوزيع غير المنتظم للطاقة المولدة من الألواح الشمسية على الأطوار الثلاثة، تبعًا لتفاوت كمية الإشعاع الشمسي بين المنازل.

ولمعالجة هذه التحديات، تم في هذه الدراسة تصميم وتنفيذ نظام ذكي يستخدم متحكمًا دقيقًا وتقنية WiFi لمراقبة تدفق الطاقة في الخطوط الثلاثة بشكل مستمر، مع تتبع استهلاك الكهرباء لكل منزل بالإضافة إلى الطاقة الشمسية المنتجة، ومن ثم إعادة توزيع المنازل بين الأطوار تلقائيًا بهدف تحقيق التوازن، وذلك دون أي انقطاع في التيار الكهربائي، حيث تفترض الدراسة استخدام أنظمة انفرتر هجينة مزوّدة ببطاريات تضمن استمرارية التغذية الكهربائية أثناء عمليات التحويل بين الأطوار.

في الوقت نفسه، يتميز النظام بقدرته على التكيف ديناميكيًا مع التغيرات اللحظية في الأحمال والإنتاج، مما يعزز من مرونته وكفاءته التشغيلية. أظهرت نتائج المحاكاة بعد تطبيق النظام المقترح انخفاضًا كبيرًا في الفواقد الكهربائية من 138 كيلوواط إلى 9 كيلوواط، أي ما يعادل توفيرًا ماليًا قدره 193.20 دولارًا، أو حوالي 3.75 دولارًا لكل منزل. كما أظهر النظام فترة استرداد بسيطة تقل عن شهر واحد، إلى جانب تحسن ملحوظ في أقل قيمة للجهد في الشبكة من 206 فولت في حالة عدم التوازن إلى 221 فولت بعد تنفيذ حل التوازن.

الكلمات المفتاحية: شبكة توزيع الكهرباء، عدم توازن التيار، موازنة الأحمال، أنظمة الطاقة الشمسية الكهروضوئية (PV)، استقرار الجهد، تقليل الفاقد في الطاقة، الشبكة الذكية، المراقبة اللحظية.