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Improved Design of 1.5KVA/24VDC Uninterruptible Power Supply (Case study: FIPL Omoku)

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ABSTRACT*: The interruption of power supply is a source of concern in both residential and industrial settings, as power disruptions can lead to significant inconveniences and financial losses. This emphasizes the need for robust and reliable backup power solutions. This paper presents an improved design of a 1.5KVA/24VDC Uninterruptible Power Supply (UPS) system, using the First Independent Power Limited (FIPL), Omoku Uninterruptible Power Supply facility as a case study. Applying the parallel redundant power supply design technique to the existing design incorporates an alarm system to signal power source failures and a redundant power supply for added reliability, facilitated by a contactor serving as an automatic transfer switch between the power sources. AutoCAD and Electrical Transient Analyzer Program (ETAP) were utilized in the design process. The simulation and load flow test done to determine the voltage levels, current distribution, and power losses on the introduced redundant and existing power sources showed a seamless transition between the two power sources, a stable 24VDC output, and a total current of 4.392A drawn by the loads when on the existing power source and 4.192A when on the introduced redundant power source, resulting in a backup time of 38 hours. This indicates the compatibility of the introduced redundant power source with the loads powered by the existing power source. Consequently, the improved design will not only enhance the robustness and reliability of the existing uninterruptible power supply system but also effectively reduce the downtime of critical loads.*

KEYWORDS: *Uninterruptible Power Suppy, Battery, Rectifier, Alarm, Load flow, Contactor*

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I. INTRODUCTION

Power losses have always posed significant challenges for individuals and organizations that rely on delicate electronic equipment requiring a stable power supply; therefore, stability of such a main power supply is a subject of concern [1]. Such interruptions have resulted in significant inconveniences, particularly for highly sensitive systems like computers, medical equipment, and industrial control systems where a power outage could be dangerous [2].

Uninterruptible Power Supply (UPS) is an energy storage application used to prevent losses due to power outage or low power quality conditions [3]. In 1934, John Hanley completed the first Uninterruptible Power Supply in the USA. He patented it as an "Apparatus for Maintaining an Unfailing and Uninterrupted Supply of Electrical Energy" [4]. An Uninterruptible Power Supply (UPS) supplies emergency power to critical loads, as well as preventing delicate systems from losing data or malfunctioning during a power outage [5].

An Uninterruptible Power Supply differs from an auxiliary emergency power system or standby generator, which provides instantaneous or near-instantaneous protection from power interruptions, utilizing one or more attached batteries and associated electronic circuitry for low power users or using diesel generators and flywheels for high power users [6].

Over time, UPS topology has changed because of technological advancements that have produced devices that are more effective and dependable. There are different varieties of UPS topologies, each with specific characteristics and capacities. These types can be grouped into offline, line-interactive, and online UPS topologies [7, 8].

Semiconductor power devices are vulnerable to failures, which challenge the reliability of power conversion systems. One of the most effective methods to enhance system reliability is the parallel redundant approach, which is considered a highly fault-tolerant method. [9]. In designing an Uninterruptible Power Supply system, factors such as the load size, the required backup time, the level of protection required, and the topology of the UPS are considered. The standby, line-interactive, and online UPS topologies are the most popular, and each has benefits and drawbacks. The UPS system involves the conversion of power from one form to the other based on the types of load that require an Uninterruptible Power Supply. DC load(s) requires an uninterruptible DC power supply system; AC load(s) also requires an uninterruptible AC power supply system [7].

Therefore, lack of use of reliable UPS in the power supply systems of critical loads may lead to serious consequences in the form of distortion of the proper functioning of the electrical or electronic components, damages or the change of technical parameters and the performance of the loads, formation of costly downtimes of the equipment, accelerated aging of the hardware, the loss of processed information, formation of additional power losses, prevention of the proper functioning of the systems [10].

1.1 Aim of the Study

The goal of this work is to improve the design of 1.5KVA/24VDC Uninterruptible Power Supply using FIPL Omoku as a case study.

1.2 Objectives of the Study

To achieve improved design of 1.5KVA/24Vdc uninterruptible power supply the following objectives were considered, which are

i. To identify the components of the UPS system in FIPL.
ii. To assess the existing UPS system design at FIPL Omoku.
iii. To determine the topology of the Uninterruptible Power Supply System.
iv. To design an improved UPS circuit using AutoCAD.
v. To conduct load flow analysis on the existing and improved UPS design using ETAP.
vi. Determine an estimated backup time of the improved design.

II. MATERIALS AND METHODS

2.1 Materials Used

The materials used in this research work include circuit diagram of existing UPS, data of UPS components, data obtained during UPS operation tests, AutoCAD, and Electrical Transient Analyzer Program (ETAP)

2.2 Circuit Diagram and Operation of ExisitingUPS

The circuit diagram in Fig. 3.1 shows the connection and arrangement of the existing series Uninterruptible Power Supply System. It consists of an inverter/battery charger, rectifier, batteries, and circuit breakers. The battery charger built into the inverter rectifies the 220VAC from the mains to DC; this charges the 24V battery and supplies 24VDC to the inverter when there is power in the mains. The 1.5KVA inverter inverts the 24VDC from the battery when there is power failure and converts DC from the battery charger when there is power in the mains to 220VAC. A rectifier is connected at the output of the inverter to rectify the 220VAC to 24VDC used to power the MESD load. Circuit breakers are placed at different points in the circuit to provide protection against overcurrent and overloading.

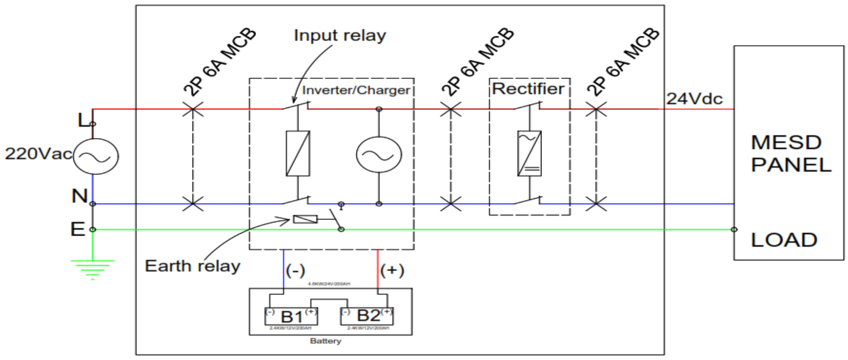


Fig 3.1: Circuit diagram of existing UPS of FIPL Omoku UPS Facility

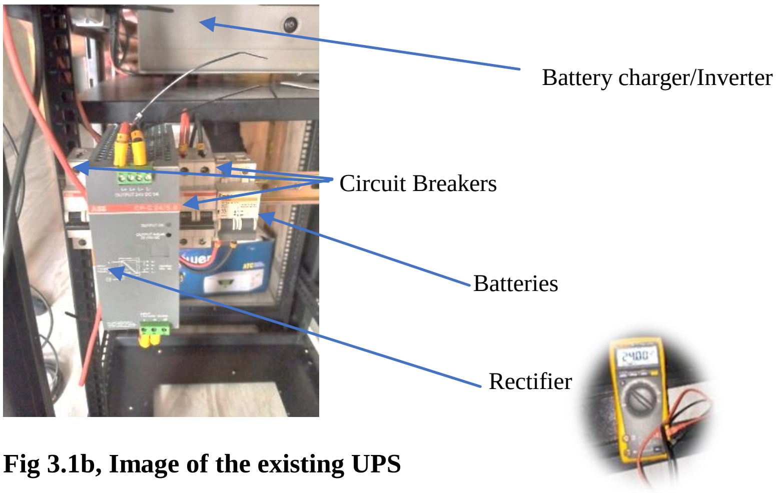


Fig 3.1b, Image of the existing UPS

2.3 Improved Design Using The Parallel Redundant Power System Design Technique

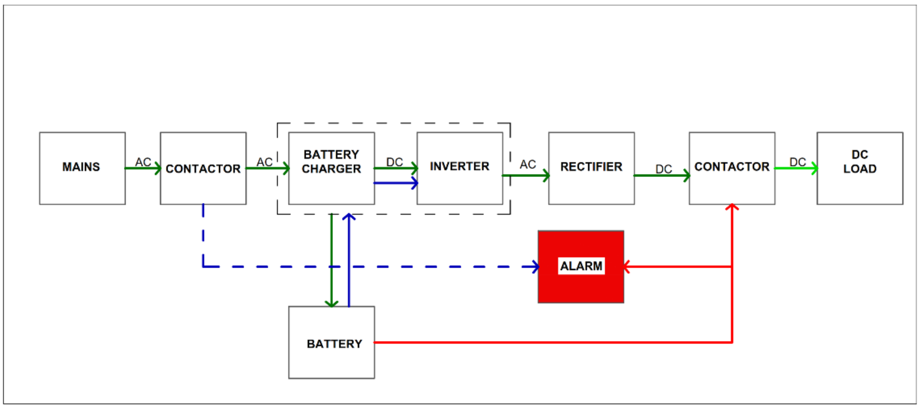


Figure 3.2: Block diagram of improved design UPS System

The parallel redundant method has the configuration (N+1) in parallel with the Load. With this configuration, uninterruptible power is supplied to the load as shown in Fig 3.3b. This design technique provides redundant power sources, automatic switch over, fault tolerance and enhances the reliability of the Uninterruptible Power Supply system [10, 11]. The technique is used to improve the existing design, such that in the event of the failure of power supply from the rectifier (primary power source to the load), as shown in Fig. 3.3a the contactor will automatically switch to the power supply from the battery bypass [12], still providing full coverage of the required power.

The circuit diagram in Fig 3.3a shows how the outputs of the inverter, rectifier, and battery are connected to the contactors. Contactor B provides the switching of the power supply in the event of rectifier failure to the battery bypass. The output of the rectifier is connected to the normally open contacts and the coil of contactor B. The battery output is connected to the normally closed contacts of contactor B. A buzzer is connected to the auxiliary normally closed contacts of the contactors A and B. Fig 3.3b shows the overall improved circuit diagram of the UPS system, indicating the position of the two contactors, battery bypass conductor, and alarm components in the system. The three modes of the UPS system are Normal Mode (green), Stored Energy Mode (blue), and Redundant Mode (red), as shown in Fig 3.2. Table 4.3 shows the result of the status of the components in each of themodes

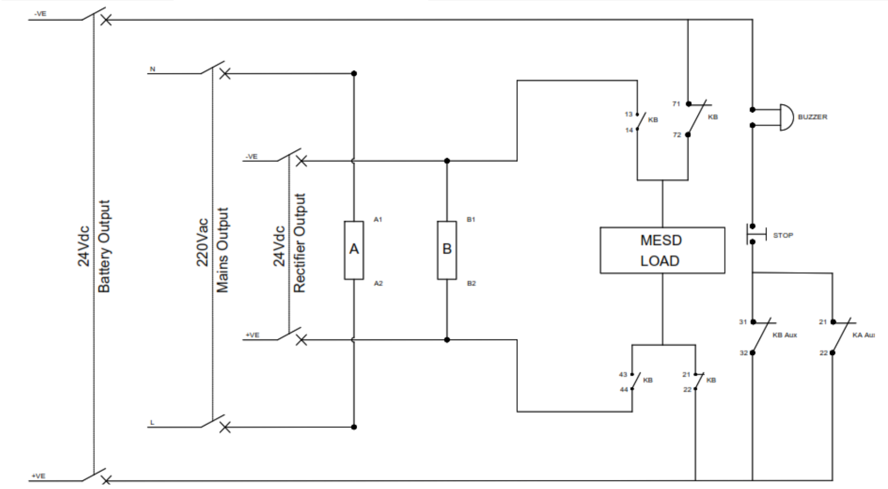


Figure 3.3(a) contactors and alarm connection

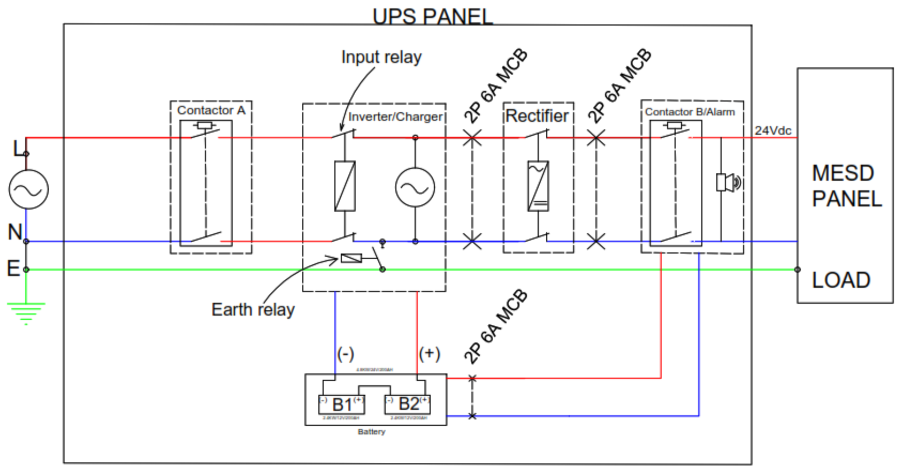


Figure 3.3(b) improve Circuit Diagram of the UPS system

2.4 ETAP Model of the UPS outputs to the Load

Fig 3.4 below shows the graphical representation of the ETAP model used in simulating and performing the Load flow test on the UPS two outputs power sources in parallel with the load, with the use of a DC Contactor.

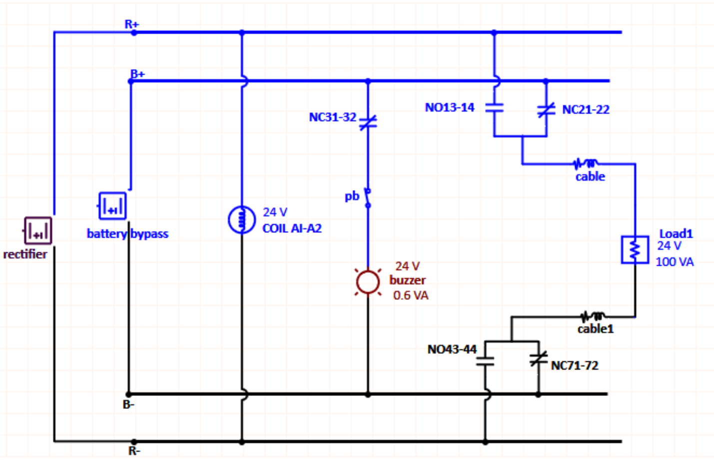


Figure 3.4 ETAP Model

2.5 Determination of Contactor Rating,Battery Backup Time and Battery Connection Scheme

Determination of Contactor rating

$I_r = \frac{P_{max}}{V}$

Where

I_r = Rated load Current

P_{max} = Maximum Power Output

V_{max} = Output Voltage

From the rectifier specification sheet

Maximum rated power = 120W

Output Voltage = 24Volts

From equation 3.2 Rated Current $(I_r) = \frac{120}{24}$

I_r= 5A

I_r = 5 x 1.5= 7.5A (1.5 is used from IEC 60947-4)

For availability and close range, 10A Contactor is used.

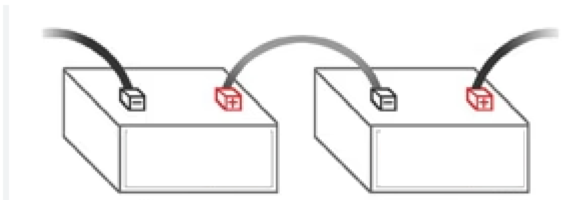
Battery Backup time (T_b)

$$T_B = \frac{\text{Battery Capacity (C in Ah)} \times \text{Battery rating (in V)} \times \text{Number of Batteries} \times \text{Battery Efficiency}}{Loads\ (W)} = \frac{\text{Battery rating (in Ah)} \times \text{Number of Batteries} \times \text{Battery Efficiency}}{Total\ Load\ Current\ (l_L)}$$

$$T_B = \frac{C\ x\ V\ x\ N\ x\ \mu}{P} = \frac{C\ x\ N\ x\ \mu}{l_L} \qquad 3.1$$

BatteryConnectionScheme

There are two primary ways to successfully connect two or more batteries: they are series or parallel connections. In this work, parallel connection is used. In a Series connections the output voltage is the summation of the voltage of each battery, but the Amperage will remain the same. In Fig 3.5 below, the two 12-volt batteries are joined in Series, the voltage will double to 24volts but the total capacity will remain 200Ah.



Therefore, in a SeriesConnection

Capacity of Battery (Ah) = 200Ah

Total Voltage $V_T = V_1 + V_2$ = 12V + 12V = 24VDC

III. RESULTS AND DISCUSSION

3.1 RESULTS

Table 4.1: Result when the rectifier powers the load

Voltage Drop and Power Flow Report

CSD1

Time (Sec.)	Step	ID	Device Type	Rated V	Voltage Drop Volt	Voltage Drop %	Power Flow Watt	Power Flow Amp	Power Consumed Watt
0.000	1	cable	Cable		0.00		100.00	4.167	0.00
0.000	1	cable1	Cable		0.00		0.00	4.167	0.00
0.000	1	NO13-14	Tie PD		0.00		100.00	4.167	0.00
0.000	1	NO43-44	Tie PD		0.00		0.00	4.167	0.00
0.000	1	COIL AI-A2	Control Relay	24.00	24.00	100.00	5.40	0.225	5.40
0.000	1	Load1	General Load	24.00	24.00	100.00	100.00	4.167	100.00
0.000	1	battery bypass	CSD Source	24.00	24.00	100.00	0.00	0.000	0.00
0.000	1	rectifier	CSD Source	24.00	24.00	100.00	105.40	4.392	105.40

Table 4.2: Result when the contactor switch to battery bypass to power the Load

Voltage Drop and Power Flow Report

CSD1

Time (Sec.)	Step	ID	Device Type	Rated V	Voltage Drop Volt	Voltage Drop %	Power Flow Watt	Power Flow Amp	Power Consumed Watt
0.000	1	cable	Cable		0.00		100.00	4.167	0.00
0.000	1	cable1	Cable		0.00		0.00	4.167	0.00
0.000	1	NC21-22	Tie PD		0.00		100.00	4.167	0.00
0.000	1	NC71-72	Tie PD		0.00		0.00	4.167	0.00
0.000	1	buzzer	Light	24.00	24.00	100.00	0.60	0.025	0.60
0.000	1	Load1	General Load	24.00	24.00	100.00	100.00	4.167	100.00
0.000	1	battery bypass	CSD Source	24.00	24.00	100.00	100.60	4.192	100.60
0.000	1	rectifier	CSD Source	24.00	24.00	100.00	0.00	0.000	0.00

Table 4.3: Expected components status in each mode

Modes	Battery	Inverter	Rectifier	Contactor A	Contactor B	Alarm	Load
Normal Mode (Green)	Charging	On	On	On	On	Off	On
Stored energy Mode (Blue)	Discharging	On	On	Off	On	On	On
Redundant Mode (Red)	Discharging	Off	Off	Off	Off	On	On

3.2 DISCUSSION

Normal Mode

In this mode of the UPS, there is power in the mains. Such that, as the battery is charging, inverter, rectifier, contactor A and B will be On, the Alarm will be Off and the load will be continuously powered.

Stored Energy Mode

In this mode of the UPS, there is no power supply from the mains, the Load is continuously powered by the energy stored in batteries during the normal mode. The inverter is On, rectifier is On, Contactor A is Off, Contactor B is On. Since Contactor A is Off, the buzzer will notify the users of blackout and can be switched Off with the double throw switch. Both the normal and stored energy mode power the rectifier that supply the primary power to the Load.

Redundant Mode

In this mode of the UPS, there is no power supply from the mains, the Load is continuously powered through the battery bypass by the energy stored in batteries. The inverter, rectifier, Contactor A and Contactor B are Off. Since Contactors A and B are Off, indicating absence of power in the mains and failure of the rectifier, the Buzzer will notify the user of an emergency. The buzzer can be switched Off with the stop button.

Load flow Analysis of the Power Sources

The load flow test results, as shown in Tables 4.1 and 4.2, determine the voltage levels, current distribution, and power losses of the 24VDC rectifier and 24VDC battery bypass power sources connected in parallel to a 100-watt load with the use of a contactor. Table 4.1 shows the result obtained from the simulation: when the contactor B coil A_1 –A_2 is energized, all normally open contacts (NO $_{13-14}$, NO $_{43-44}$) switch to closed contact, and as such, the rectifier continuously powers the load. The voltage is 24VDC and the 100-watt load draws an average current of 4.167A, the contactor coil draws an average current of 0.227A. The total current drawn from the rectifier is 4.392A, which is less than 5A the maximum current rating of the rectifier from the manufacturer. Table 4.2 shows the result obtained from the simulation when the contactor B coil A_1 –A_2 is de-energized, all normally closed contacts (NC $_{21-22}$, NC$_{71-72,}$ NC$_{31-32}$) switch back to closed contact, as such the load is continuously powered by the battery bypass. The voltage is approximately 24VDC and the 100-watt load draws an average current of 4.167A, the Buzzer draws an average current of 0.025A, which shows that the buzzer will be on the moment the contactor switches to the battery bypass. The total current drawn is 4.192A. Therefore, the rectifier output serves as the primary power source to the Load, and the battery bypass serve as the secondary power source to the Load. The 24VDC, 100-watt load draws a current of 4.167A in both the existing and improved design. Hence, the design can be implemented to improve the reliability of the existing Uninterruptible Power Supply system.

Redundant Mode Backup Time

An ideal backup time can be estimated for the UPS system when on the redundant mode

I_L =4.192A, N=1, C=200AH from the equation 3.1

$$T_b = \frac{200x1x0.8}{4.192} \approx 38hours$$

The factor 0.8 is used to account for battery efficiency and other losses. Therefore the estimated backup time$T_b \approx 38hours$.

The backup duration depends on the capacity of the battery, State of charge of the battery (SOC) and the wattage of the load.

IV. CONCLUSION AND RECOMMENDATION

4.1 Conclusion

From the load flow test, the improved system operates at the load-compatible current and voltage level of 24VDC, and the buzzer notifies the users of a blackout or failure of the rectifier as it draws an equivalent current of 0.025A. This shows that the improved design using the parallel redundant power supply can be implemented in any application demanding such continuous, reliable power, demonstrating a substantial contribution to improving the performance and resilience of UPS systems in diverse settings. Thus, examplifying the practical implementation of innovative solutions to address power continuity challenges and underlining the importance of such advancements in today's technology-driven world.

4.2 Recommendation

This research gives an innovative solutions to address power continuity challenges, however UPS components should be properly maintianed to increase their reliability and lifespan.

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