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Practical Approach to Enhance Energy Resilience in Manufacturing Facilities

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ABSTRACT

Both developed and developing countries are affected by the global energy problem. Over the last few decades, the industrial sector's electrical energy demand has grown exponentially, altering the supply-and-demand balance. The trend toward Industry 4.0 compliant production facilities necessitates a greater demand for high-reliability power. Because severe production losses caused by power outages cannot be tolerated, an increasing number of large vital industrial processes integrate centralized high-quality, online UPS technology onto their network to establish a grid-to-load link and continuously condition dirty electricity from the national grid. These facilities distribute electrical power using either an MV or LV system. Based on the integration design, investigating ways to quantify energy efficiency savings of MV versus LV UPS system is required. This paper proposes strategic and technical interventions for these systems and assesses their electrical losses and budgetary ramifications. The paper also aims to contribute to the implementation of an energy efficiency plan and help facilities close power efficiency gaps. From the results obtained, the MV UPS system offers a significant reduction in energy consumption. Compared to the LV UPS system, annual energy losses are reduced by 46% at a load factor of 65%. A significant energy improvement is expected at higher load factors and in larger facilities where longer distribution cables are used. Compared to the LV UPS system, MV UPS saves R221 509 per meter of cable length increase and R31 457 per percentage increase in load factor.

1 | Introduction

The trend towards energy supply security in any industrial facility nowadays necessitates a rising demand for high-reliability electricity. Critical industrial processes increasingly rely on power quality levels that the grid often cannot offer. The UPS system provides facility-wide power security and protection from all grid disturbances [1, 2]. The system conditions the incoming power and sustains the supply of power through periods of disturbances [3–5]. Often, facilities distribute power using either an MV or LV system [6, 7]. At low voltage system levels, the facility's notified maximum capacity is reached very soon [8, 9]. The higher current rating of the LV system causes high resistive losses and lets the costs and the dimensions of both the busbars and switchgear increase dramatically [10, 11]. A way to reduce the currents and enable a further increase of the power is to move to a medium voltage system level [4, 12].

Energy efficiency, on the other hand, can be considered one of the unsung heroes in the fight to create a resilient low-carbon economy, and this is an important lever [13, 14]. The energy crisis is becoming a global concern and is mainly accompanying the increase in energy costs and low energy availability [15, 16]. Manufacturing facilities are responsible for 51% of Eskom-produced energy in South Africa and targeting their efficient use of energy significantly contributes to the reduction of power crisis in the Country. For energy efficiency potential that exists, almost half of the reduction can be done through energy efficiency alone [13, 17]. Energy Efficiency often translates into economic benefits over and above its ability to impact the environment positively [18–20]. It holds a vital position in achieving a reduction of carbon emissions [21–23]. Reduction in energy consumption trims down facility electricity costs, shrinks dependence on fossil fuels, and contributes to overall energy security [24, 25].

While the government has made strong commitments to supporting the uptake of energy-efficiency initiatives, there are several interruptions and a lack of commitment and execution. Although energy-efficiency practices are advancing worldwide, their optimal acceptance is still of major concern [13, 14]. The extent to which facility managers analyze data-driven statistical and equipment learning techniques to understand implementable energy-saving strategies remains unknown [6]. Knowledge oversight can be considered as the key barrier to why facilities are unable to use tools to improve energy efficiency [22, 23, 26]. This partial response to energy efficiency drives the current situation of load shedding [27, 28].

Several articles have elaborated on the benefits of assessing energy efficiency in various sectors [6, 21, 29]. Some have evaluated the efficacy of energy utilization and efficiency techniques in reducing energy demand in various industries [30–32]. Others have also discussed tactics and behaviors to promote sustainable energy consumption [33–35]. These researchers dug into the sustainability imperatives of energy interventions [36], studying the economic factors that drive retrofit decisions, as well as the delicate relationship between advanced technological solutions and the behavioral patterns of building operators and users [23, 37, 38]. Other research has found that external factors such as weather changes, government legislation, and behavioral interventions are important in influencing energy use in these structures [7, 26]. Unfortunately, all these studies are unable to fit elements from all facilities since they are subject to the constraints imposed by a specific facility [39–41]. Specific data-driven technical solutions are becoming a more prominent and straightforward strategy, with the potential to save significant energy and reduce environmental impact [6, 19, 42].

This study presents a data-driven energy-saving baseline to assist facilities in accelerating their energy efficiency plans and achieving sustainability. The quantitative benefits of integrating the UPS system into the MV distribution compared to the LV distribution are studied. The study employs two scenarios to analyze the topic. The first scenario examines the integration of the UPS system into an MV power distribution network. The second scenario integrates the UPS system into an LV power distribution network. Copper losses at specified cable lengths between primary components and loads are used to determine the energy optimization potential of each scenario. The analysis is based on the electricity consumption trends of a typical facility.

2 | UPS System Overview

The UPS system consists of three three-phase, online or double conversion unit. Every load is deemed essential or critical. Each UPS unit consists of a rectifier, battery converter, and inverter. Figure 1 depicts these key components. The system employs a backup battery supply to deliver uninterruptible power to the load if grid power is interrupted or falls outside of the predefined specifications. A bypass switch transfers power straight from the grid to the load during system repair. The presented concept is based on a notified maximum demand (NMD) of 5MVA supplied directly from the local electricity supply authority, and the average consumption of the facility is defined as 100% load. The static UPS and batteries are sized based primarily on full facility energy requirements to maximize the overall efficiency of the facility energy. The energy system concept aims to provide UPS functionality to ensure power conditioning and compliance with the Power Quality Standard [8, 43]. The Energy Management System (EMS) is set to monitor and control energy flow from all sources (SUPS, BESS, and Grid) to the facility's load.

Numerous LIB-SUPS versions can communicate with the facility's network. These versions include the Eaton Power Xpert9395P modular UPS, HiPerGuard MV ABB SUPS, Delta UPS - Ultron Family (DPS Series, DPS-1000K or DPS-1200K), Liebert EXL S1 1000 or 1200 kVA, Toshiba G9400 Series UPS 1050 kVA, and Legrand Keor XPE IOBM 1000 or IOBM 1200. All of these types are compatible with lithium-ion batteries. In this study, an appropriately sized UPS system is chosen to match the facility's notified maximum demand (5MVA) while eliminating implementation and operational costs when compared to a low-voltage power reticulation system. For the Medium Voltage system, the HiPerGuard MV, ABB SUPS brand is selected. HiPerGuard is the next generation of MV SUPS designed for multi-megawatt power protection. The HiPerGuard MV UPS, based on the impedance-isolated static converter (ZISC) architecture, provides a versatile solution with high reliability and efficiency for critical power installations [12]. The HiPerGuard is ABB's most recent addition to the Power Protection product portfolio, providing a comprehensive power protection solution [1]. This enhanced flexibility eliminates the need for sophisticated power distribution infrastructures.

For the Low Voltage system, the Eaton Power Xpert9395P modular UPS brand is selected [44, 45]. The unit uses double-conversion technology conducted on three levels. This topology reduces stress and thermal losses on its major converting components (rectifier and inverter) by reducing the current flowing through them in normal operation. The three-level converter topology operates at less than 50% of the stress endured in traditional converters, thus improving the overall SUPS system efficiency. Other electronic components have also been miniaturized and become less inefficient than in the case of traditional topology. Both systems are popular and well-known brands with a track record of success and a strong support structure in the country and around the world. Their modularity characteristic reduces maintenance expenses, allowing the facility to operate more affordably. Both technologies are simple to use and do not require highly skilled individuals.

3 | Problem Description

The design of a UPS system and its integration into an LV and MV power supply system is investigated. The copper loss

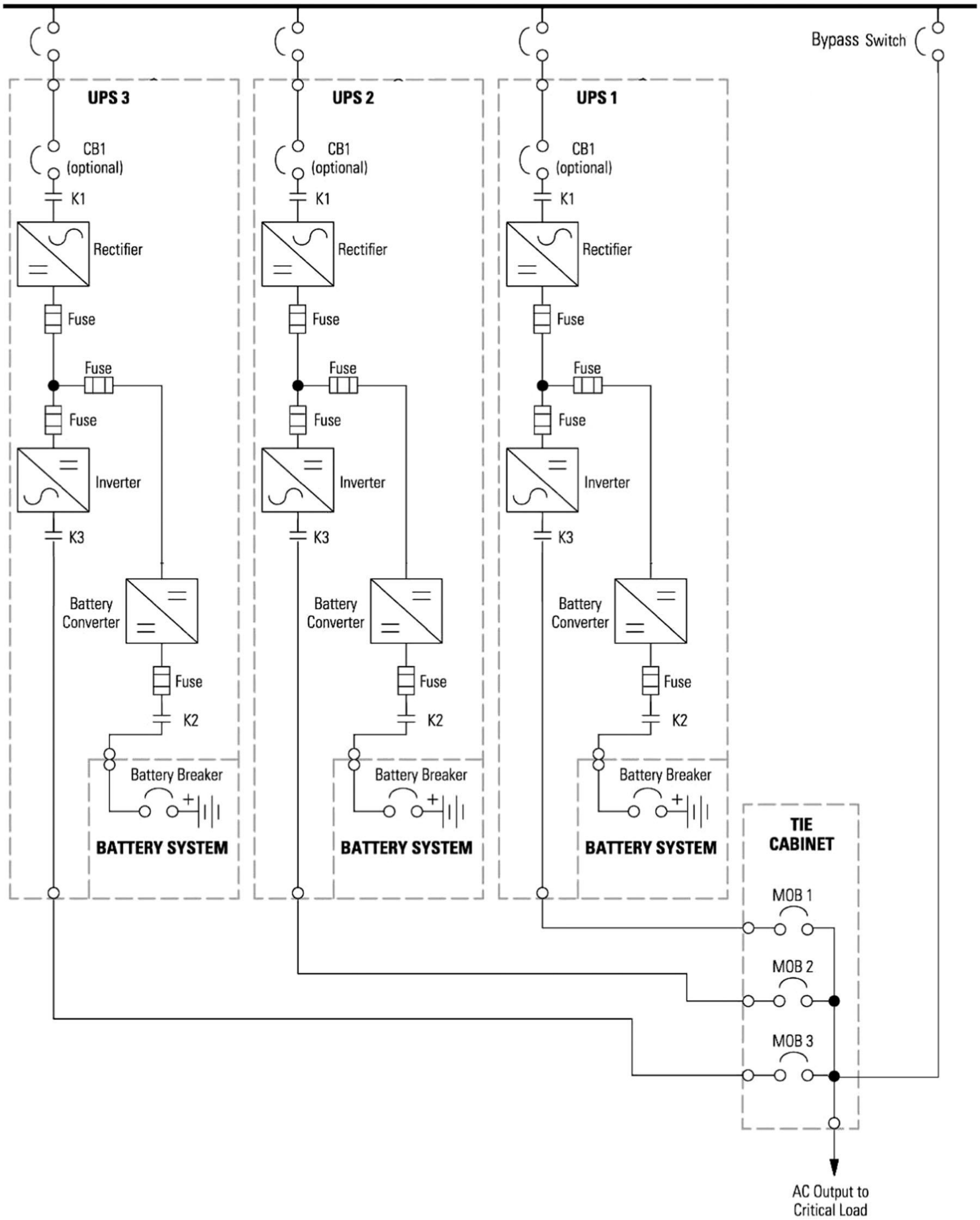

FIGURE 1 | Online, double conversion, battery backed up UPS system. This is a redundant UPS system with a centralized maintenance bypass. The three UPS units are configured to feed critical loads through a single tie cabinet. The system output bus is constantly monitored for abnormalities. If an abnormal condition is detected, critical loads are automatically transferred to the bypass line.

implications of integrating a UPS system into an MV power system versus an LV power system are analyzed and discussed. At an LV system (400 V), increasing the current drawn helps to sustain the load requirement. High currents need large copper cross sections and significant resistive losses. When switching to an MV system (11 kV), minimal current is required to maintain the same power demand. Low current minimizes copper cross sections and resistive losses, leading to increased efficiency. The nature of cable losses considered in these scenarios is based on a linear load where the power losses in cable lines are Joule's or Copper losses. The three-phase Copper loss is defined as per Equation (1):

$$P_{\text{Loss}} = (I^2 \times R)/1000, \tag{1}$$

where P_{Loss} is the Joule's or Copper Loss expressed in kW, I the linear current expressed in Ampere, and R the resistance of the conductor expressed in Ω.

The Energy dissipated through this loss of power is given as per Equation (2):

$$E_{\text{Loss}} = P_{\text{Loss}} \times t, \tag{2}$$

where E_{Loss} is the energy lost in kWh, P_{Loss} the Joule's or Copper Loss expressed in kW, and t the time in hours.

Inductive loads consume both real and reactive powers, and when combined, it is known as apparent power measured in Volt-amps (VA). Apparent power is the total power in an AC system, and it is used to rate measure components of the system (transformers and UPS). It is expressed as per Equation (3):

$$S = V \times I, \tag{3}$$

where S the apparent power expressed in kVA or MVA, V the rated supply voltage expressed in kV, and I the linear current expressed in Ampere.

4 | Assessment of Copper Losses in LV/MV UPS Distribution System

Mainly, there are two UPS systems available nowadays, namely LV and MV. The energy efficiency benefits in this section are conceived through both LV and MV UPS systems as per the layout specified in Figures 2–4 and 5. With global power shortage concerns looming, the obvious decision of what UPS system to select must mainly reside on their technological expertise toward energy efficiency. The selection must also include the UPS system's power, safety, availability, maintainability, cost, scalability, design performance, and ability to condition all NRS-048-stated defects. These standards help the system achieve its optimum integrity and performance level.

4.1 | Assumptions

All calculations are based on the following assumptions. Energy loss comparison between the LV and MV UPS system configurations is conducted at various cable lengths between main components (UPSs, transformers, busbars) and load. The cable parameters are taken from the cable data specification in CBI African Cables, 2024a and b. The losses for the cable have been calculated by using an adequate type of cable suitable for the current flowing through each specific branch of the network [10, 11].

The accumulated cable losses calculations per year are based on 24/7 and 365 days of operations. The accumulated cost of cable losses is based on the chosen facility's 2024/2025 electricity tariff structure and average cost deduced from the consumption behavior (R1.4377/kWh excluding all network charges). The facility uses the "Miniflex" electricity tariff structure from the power utility. This tariff structure is one of the time-of-use (TOU) electricity tariffs for urban customers with an NMD from 25 kVA up to 5 MVA. In view of the energy loss calculation, the AC resistance is used [10, 11]. The resistance of the conductor is inversely proportional to the cross-section area through which the current flows. The skin effect is the tendency of an AC current passing through a conductor to concentrate on its surface or skin rather than disperse equally across its cross-section. This means that the inner part of the conductor carries less current than the outer part, resulting in higher effective AC resistance relative to DC resistance. When the DC flows through the conductor, the total cross-section area of the conductor is utilized, and thus, DC resistance is less. The load is assumed to be completely balanced, with no current flowing through the neutral conductor, thus no energy losses are generated by the neutral conductor. Energy losses from equipment (UPS and Transformers) and busbars are omitted from the calculation [46].

4.2 | Design Scenarios

4.2.1 | Scenario 1: MV UPS System

The energy efficiency evaluation is conducted only on the supply cables between the main components of the MV UPS system comprising three (3) MV-to-MV, 1700 kVA, and two (2) 2500 kVA MV-to-LV transformers configured as modeled in Figure 2. Figures 2 and 3 depict the MV UPS system layout. The facility is assumed to be supplied by the local authority from an 11 kV, 50 Hz. The MV UPS system comprises three (3) 1.7 MVA, 11 kV, ABB HiPerGuard static UPSs. The system is parallel connected to the single 11 kV Main utility supply via the main intake switch gear and three (3) dedicated input switch gears. All three static UPS units feed a common busbar through dedicated switch gears. Two (2) parallel-connected oil-immersed, step-down, 2.5 MVA transformers assist in dropping voltages from the 11 kV to 400 V usable by various loads. The notified maximum demand in the facility supply agreement is set to be 5MVA. The Grid/Bus2-to-UPS and UPS-to-Bus3 supplies are made via three 15-m long 3-core, 35 mm^2 XLPE 11 kV copper cables. The Bus3-to-transformers primary windings supply is made via two 15-m, 3-core, 35 mm^2 XLPE 11 kV copper cables, and the Transformers secondary Windings-to-Loads supply is made via two, 8-paralleled 4 core, 300 mm^2 PVC copper cables. Each transformer supply facility loads through dedicated switch gears. The system is equipped with an external bypass switchgear, which automatically bypasses the entire system for maintenance operations. All loads are considered essential.

4.2.2 | Scenario 2: LV UPS System

The LV UPS system, on the other hand, comprises two (2) 2500 kVA MV-to-LV transformers and three (3) LV-to-LV, 1700 kVA configured as modeled in Figure 4. Figures 4 and 5 illustrate the LV UPS system layout. The facility is assumed to be supplied by the local authority from an 11 kV, 50 Hz. The LV UPS system comprises three (3) 1.7 MVA, 400 V static UPSs. The UPS system is parallel connected to the common 400 V Bus3. The main utility supplies the main intake switch gear and two (2) dedicated transformers input switch gears. These two

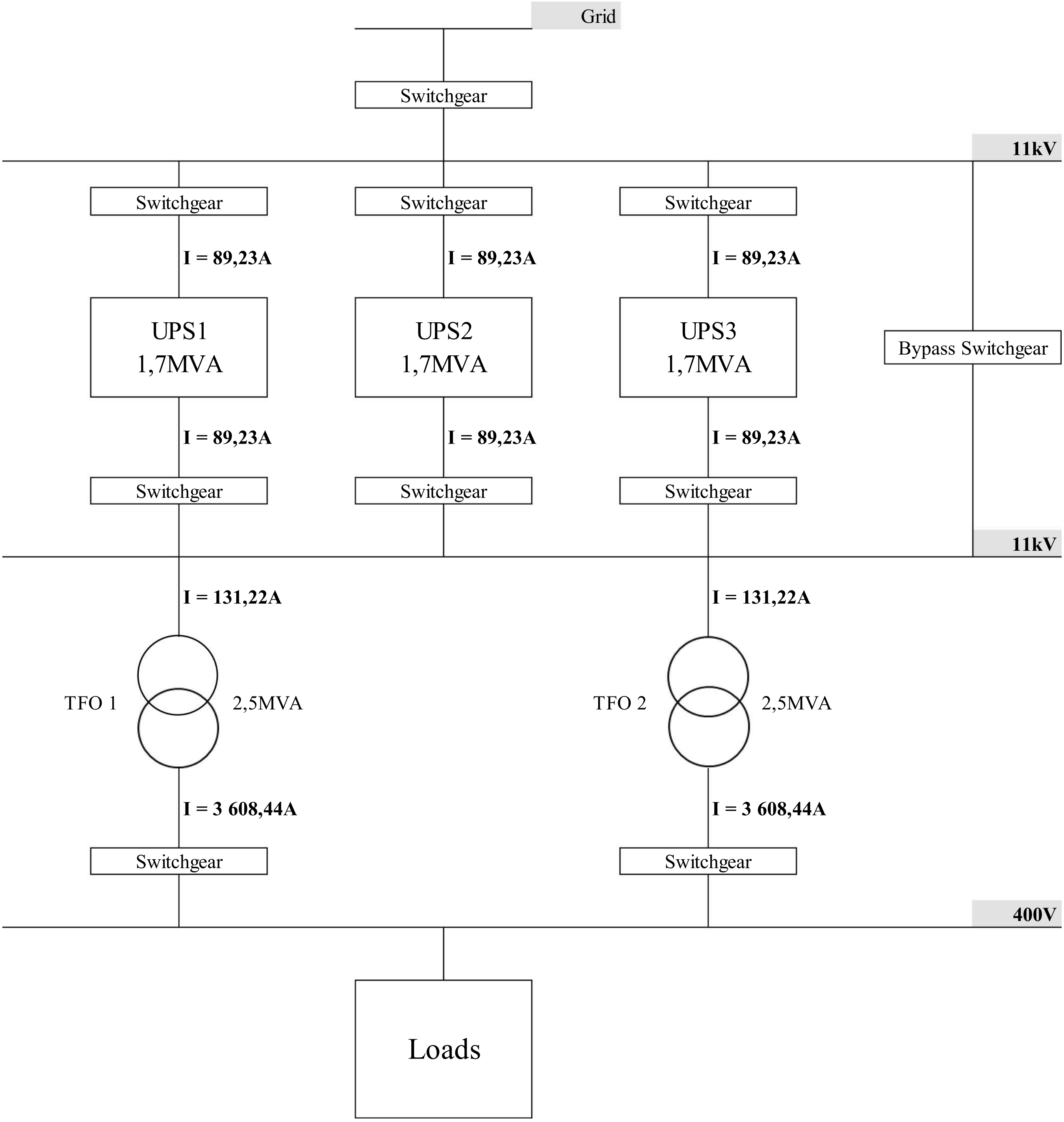

FIGURE 2 | MV UPS system layout. The system is parallel connected to the single 11 kV utility supply. All three medium voltage UPS units feed a common busbar. Two parallel-connected step-down transformers drop voltages to a usable level. An external bypass switchgear can automatically bypass the system. I, line current expressed in Ampere (A); TFO 1 and 2, step-down Transformers expressed in Megavolt Ampere (MVA); UPS 1, 2, and 3, uninterrupted power supply 1, 2, and 3.

transformers are parallel connected oil-immersed, step-down, 2.5 MVA, assisting in dropping the voltage from the 11 kV to 400 V usable by the UPS system. All three static UPS units then feed the common busbar 4 through dedicated switch gears. The notified maximum demand in the facility supply agreement is set to be 5MVA. The Grid/Bus2-to-Transformers primary windings supply, is made via two 15-m long 3-core, 35 mm^2 XLPE 11 kV copper cables. The transformer secondary windings-to-Bus3 supply is made through two, 8-paralleled, 4-core, 300 mm^2 PVC copper cables. The Bus3-to-UPS and UPS-to-Load (Bus4) supply is made through three, 5-paralleled, 4-core, 300 mm^2 PVC copper cables. Each UPS supply facility loads through dedicated switch gears. The system is equipped with an external bypass switchgear, which automatically bypasses the entire system for maintenance operations. All loads are considered essential.

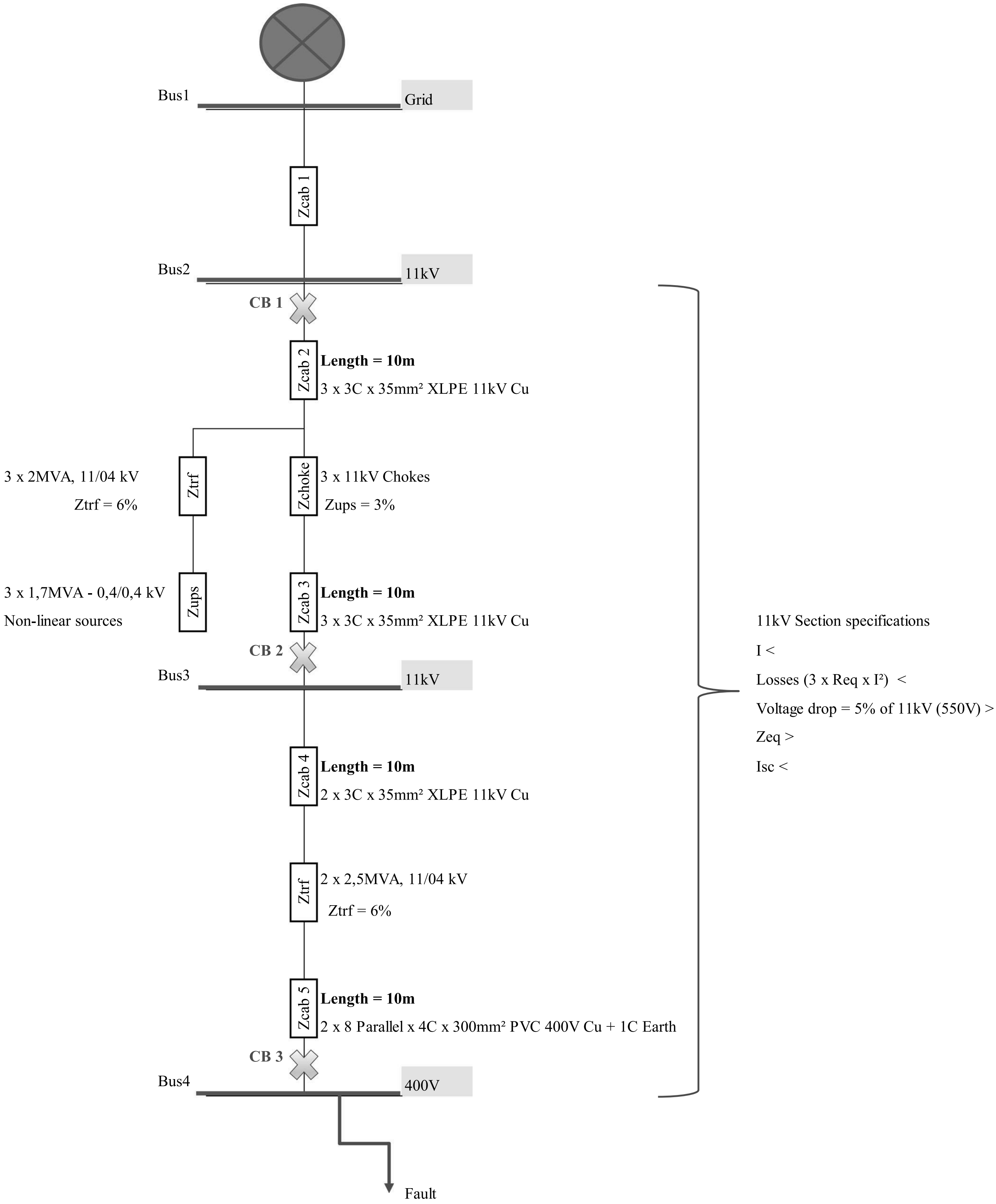

FIGURE 3 | MV UPS system modeling. 1C/3C/4C, single, three or four cores cable. CB, circuit breaker; Cu, copper cable; Isc, short-circuit current; PVC, polyvinyl chloride cable; XLPE, cross-linked polyethylene cable; Zcab, cable Impedance; Zeq, equivalent impedance; Zups, UPS impedance; Ztrf, transformer impedance.

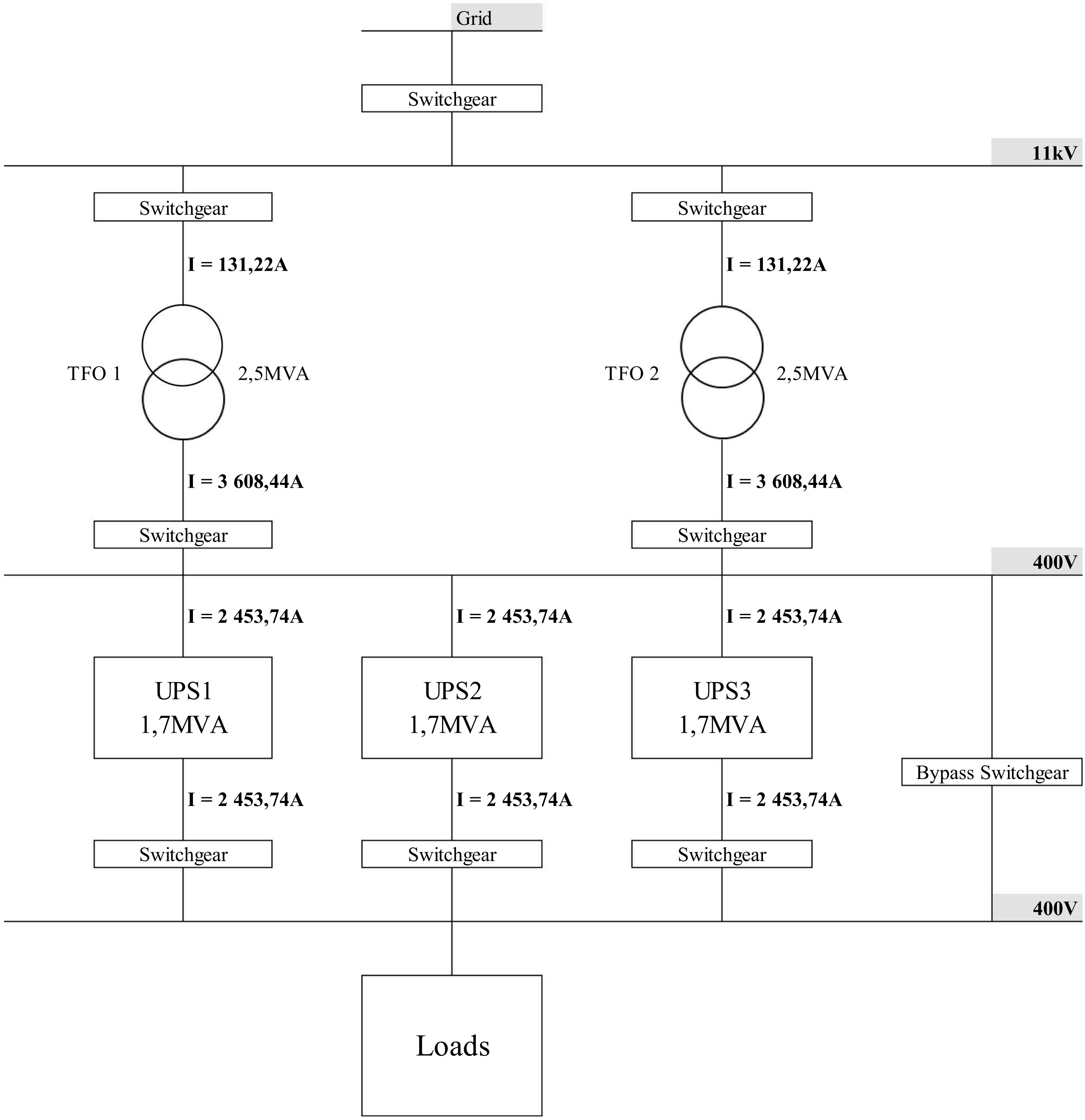

FIGURE 4 | LV UPS system layout. The step-down transformers are parallel connected to the single 11 kV utility supply and drop voltages to a usable level. All three low voltage UPS units feed a common busbar. An external bypass switchgear can automatically bypass the system. I, line current expressed in Ampere (A); TFO 1 and 2, step-down transformers expressed in Megavolt Ampere (MVA); UPS 1, 2, and 3, uninterrupted power supply 1, 2, and 3.

5 | Results and Discussions

The summary of the savings in energy losses between the MV and LV UPS systems is as in Tables 1 and 2. The initial calculation in these tables is based on the 10 m cable length and at 65% load factor. Electrical energy losses are an important consideration when selecting a UPS system, particularly at long distribution distances and at various load factors.

Table 1 analyses the cable losses in each section of the MV UPS System's power reticulation. Cable manufacturers' specifications provide information on cable type, size, and AC resistance (Ω/km). The number of cables required for the planned current carrying capacity and section voltage is stated. For comparing purposes, each section's cable length is considered to be 10 m. Given that the system does not always run at its maximum capacity, a load factor of 65% is assumed. The power loss ($R \times I^2$) and energy losses are calculated, together with their accompanying costs.

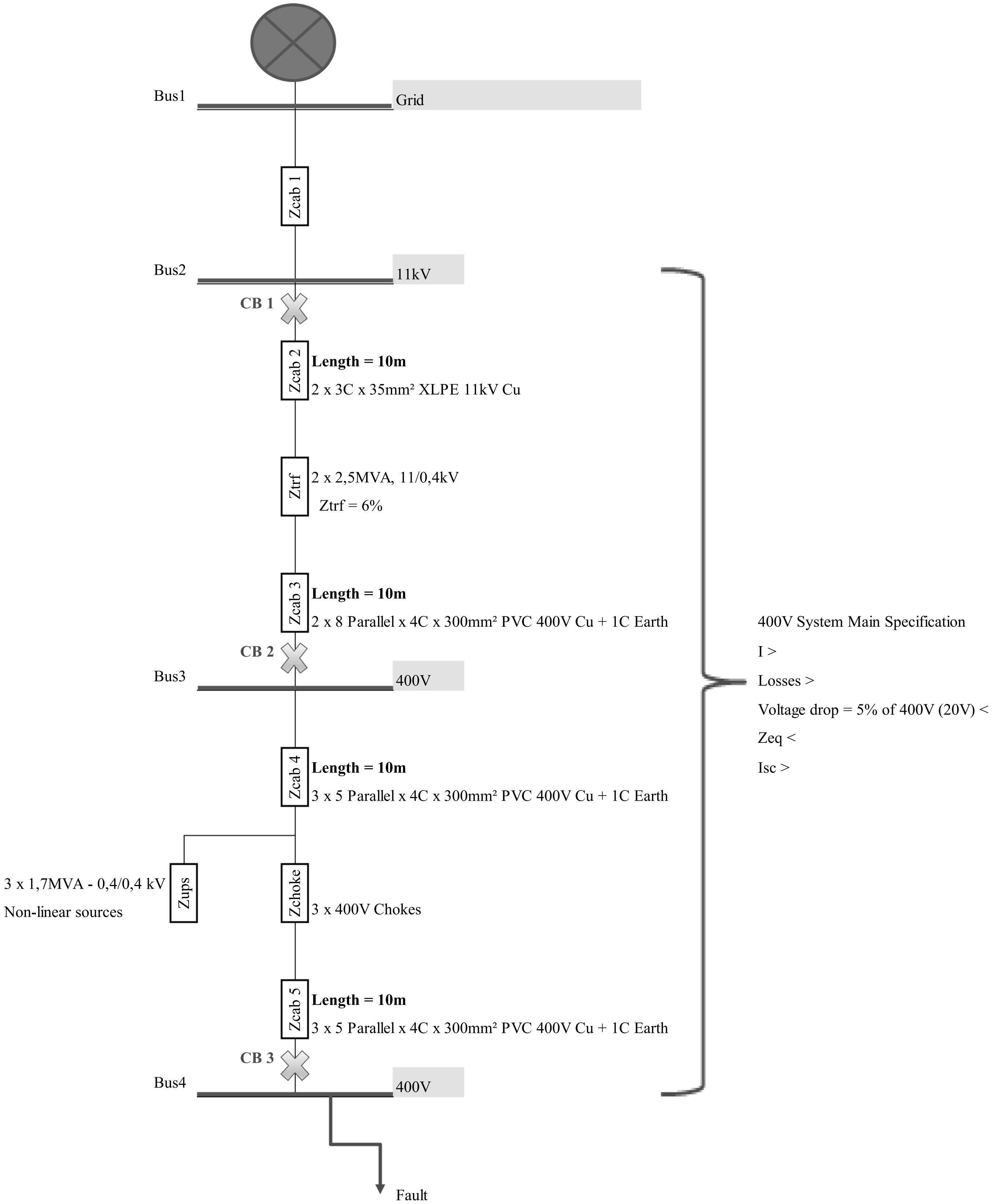

FIGURE 5 | LV UPS system modeling. 1C/3C/4C, single, three or four cores cable; CB, circuit breaker; Cu, copper cable; Isc, short-circuit current; PVC, polyvinyl chloride cable; XLPE, cross-linked polyethylene cable; Zcab, cable impedance; Zeq, equivalent impedance; Ztrf, transformer impedance; Zups, UPS impedance.

TABLE 1 | MV UPS system cables losses.

MV UPS system cables losses											
Impedance	**Cable type and size**	**Qty**	**Parallel cable**	**Length (m)**	**Total copper length (km)**	**Section voltage (kV)**	**Current @ 65% load factor (A)**	**AC resistance (Ω/km)**	**Power loss = R x I^2 (kW)**	**Energy loss per year (kWh)**	**Annual cost of lost energy @ R1.4377/ kWh**
Zcab2	3 C × 35 mm^2 XLPE 11 kV Cu	3	1	10	0.090	11	57.99	0.668	0.202	1 771.23	R2 546
Zcab3	3 C × 35 mm^2 XLPE 11 kV Cu	3	1	10	0.090	11	57.99	0.668	0.202	1 771.23	R2 546
Zcab4	3 C × 35 mm^2 XLPE 11 kV Cu	2	1	10	0.060	11	85.29	0.668	0.292	2 554.22	R3 672
Zcab5	4 C × 300 mm^2 PVC 400 V Cu + 1 C Earth	2	8	10	0.480	0,4	2 345.49	0.077	203.328	1 781 155.18	R2 560 767
										Total cost	**R2 569 532**

Note: Table 1 analyzes the cable losses in each section of the Medium Voltage UPS System. The number of cables required for the planned current carrying capacity and section voltage is stated. For comparing purposes, each section's cable length is 10 m. Given that the system does not always run at its maximum capacity, a load factor of 65% is assumed. Energy losses and corresponding costs are calculated.
Abbreviations: 1 C/3 C/4 C, single, three or four cores cable; Cu, copper cable; PVC, polyvinyl chloride cable; R, South African Rand; XLPE, cross-linked polyethylene Cable; Zcab, cable Impedance.

The power loss on cable Zcab2 is estimated as follows. Each UPS is fed by three 10-m-long, single-parallel, $3\,C \times 35\,mm^2$ XLPE 11 kV Cu cables. The total length of all cable cores carrying current is $(3 \times 3 \times 1 \times 10) = 90$ m, or 0.09 km. The cable's current carrying capacity at 65% load factor is $89.22 \times 0.65 = 57.99$ A. The AC resistance of Zcab2 is 0.668 Ω/km. According to Equation (1), the power loss is calculated as $P_{Loss\text{-}Zcab2} = [0.09 \times 0.668 \times (57.99)^2]/1000 = 0.202$ kW.

Similarly,

$$P_{Loss\text{-}Zcab3} = [(3 \times 3 \times 1 \times 10)/1000 \times 0.668 \times (57.99)^2] \\ = 202, 174\,W = 0.202\,kW,$$

$$P_{Loss\text{-}Zcab4} = [(3 \times 2 \times 1 \times 10)/1000 \times 0.668 \times (85.21)^2] \\ = 292\,W = 0.292\,kW,$$

$$P_{Loss\text{-}Zcab5} = [(3 \times 2 \times 8 \times 10)/1000 \times 0.077 \times (2345.49)^2] \\ = 203\ 328\,W = 203, 328\,kW.$$

The annual cost of cable losses is calculated using an average cost based on consumption behavior of R1.4377/kWh. Equation (2) calculates the annual cost of lost energy.

$$E_{Loss\text{-}Zcab3} = 0.202 \times 365 \times 24 \times 1.4377 = R2\ \ 546,$$

$$E_{Loss\text{-}Zcab3} = 0.202 \times 365 \times 24 \times 1.4377 = R2\ \ 546,$$

$$E_{Loss\text{-}Zcab4} = 0.292 \times 365 \times 24 \times 1.4377 = R3\ \ 672,$$

$$E_{Loss\text{-}Zcab5} = 203.328 \times 365 \times 24 \times 1.4377 = R2\ \ 560\ \ 767.$$

Table 2 analyses the cable losses in each section of the LV UPS System's power reticulation. Cable manufacturers' specifications provide information on cable type, size, and AC resistance (Ω/km). The number of cables required for the planned current carrying capacity and section voltage is stated. For comparing purposes, each section's cable length is considered to be 10 m. Given that the system does not always run at its maximum capacity, a load factor of 65% is assumed. The power loss ($R \times I^2$) and energy losses are calculated, together with their accompanying costs.

The power loss on the Zcab2 cable is calculated as follows. Each step-down transformer is fed by two 10-m-long, single (parallel = 1), $3\,C \times 35\,mm^2$ XLPE 11 kV Cu cables. The total length of all cable cores carrying current is $(3 \times 2 \times 1 \times 10) = 60$ m, or 0.06 km. The cable's current carrying capacity at 65% load factor is $131.22 \times 0.65 = 85.29$ A. Zcab2's AC resistance is 0.668 Ω/km. According to Equation (1), the power loss equals $P_{Loss-Zcab2} = [0.06 \times 0.668 \times (85.29)^2]/1000 = 0.292$ kW.

Similarly,

$$P_{Loss\text{-}Zcab3} = [(3 \times 2 \times 8 \times 10)/1000 \times 0.077 \times (2\,345.49)^2] \\ = 203\ \ 328\,W = 203.328\,kW,$$

$$P_{Loss\text{-}Zcab4} = [(3 \times 3 \times 5 \times 10)/1000 \times 0.077 \times (1\,594.93)^2] \\ = 88\ \ 143\,W = 88.143\,kW,$$

$$P_{Loss\text{-}Zcab5} = [(3 \times 3 \times 5 \times 10)/1000 \times 0.077 \times (1\ \ 594.93)^2] \\ = 88\ \ 143\,W = 88.143\,kW.$$

The annual cost of cable losses is calculated using an average cost based on consumption behavior of R1.4377/kWh. Equation (2) calculates the annual cost of lost energy.

$$E_{Loss\text{-}Zcab3} = 0.292 \times 365 \times 24 \times 1.4377 = R3\ \ 672,$$

$$E_{Loss\text{-}Zcab3} = 203.328 \times 365 \times 24 \times 1.4377 = R2\ \ 560\ \ 767,$$

$$E_{Loss\text{-}Zcab4} = 88.143 \times 365 \times 24 \times 1.4377 = R1\ \ 110\ \ 093,$$

$$E_{Loss\text{-}Zcab5} = 88.143 \times 365 \times 24 \times 1.4377 = R1\ \ 110\ \ 093.$$

Figures 6 and 7 show how the length of the distribution cable and the demand factor affect system energy losses. The two Figures depict the net difference in total annual cable loss expenses between the MV and LV UPS systems. The Figures demonstrate that the distant load is located from the UPS supply system, and the closer the system is to operating at full capacity, the more an MV system appears to be the ideal choice due to the exponential increase in cost savings it provides over the LV system.

The MV UPS system has the following advantages over the LV UPS system. There is an increase in the reliability and reduction of costs of the critical power facility build and operation. The MV UPS system increases the flexibility of the network for future upgrades while being more fault tolerant due to lower fault levels. LV switch gears must withstand high fault currents. The MV UPS system provides an energy-efficient configuration as the lower currents at 11 kV result in smaller cables and lower losses. The MV UPS system offers physical cost savings. The MV UPS system does not have higher heat dissipation associated with a lower voltage system (higher current).

As elaborated, losses can become significant in large industry facilities. The longer the distribution lengths, the more cables influence energy losses. In the same way, the demand factor impacts proportionally the system energy losses. By integrating the UPS system into the MV network, both transformers can be omitted. MV UPS technology reduces distribution losses downstream and reduces space due to the lower number of transformers required. This increased reliability derives from the reduced number and size of components, cabling, and footprint, which keeps its complexity within manageable limits compared to LV design. Short circuit currents are limited to a manageable value, while the reliability of the power distribution is kept at a high level when using a high-quality UPS system.

TABLE 2 | LV UPS system cables losses.

LV UPS system cables losses											
Impedance	**Cable type and size**	**Qty**	**Parallel cable**	**Length (m)**	**Total copper length (km)**	**Section voltage (kV)**	**Current @ 65% load factor (A)**	**AC resistance (Ω/km)**	**Power Loss = $R \times I^2$ (kW)**	**Energy loss per year (kWh)**	**Annual cost of lost energy @ R1.4377/ kWh**
Zcab2	3 C × 35 mm^2 XLPE 11 kV Cu	2	1	10	0,060	11	85.29	0.668	0.292	2 554.22	R3 672
Zcab3	4 C × 300 mm^2 PVC 400 V Cu + 1 C Earth	2	8	10	0,480	0.4	2 345.49	0.077	203.328	1 781 155.18	R2 560 767
Zcab4	4 C × 300 mm^2 PVC 400 V Cu + 1 C Earth	3	5	10	0,450	0.4	1 594.93	0.077	88.143	772 131.27	R1 110 093
Zcab5	4 C × 300 mm^2 PVC 400 V Cu + 1 C Earth	3	5	10	0,450	0.4	1 594.93	0.077	88.143	772 131.27	R1 110 093
										Total cost	R4 784 625

Note: Table 2 analyses the cable losses in each section of the Low Voltage UPS System. The number of cables required for the planned current carrying capacity and section voltage is stated. For comparing purposes, each section's cable length is 10 meters. Given that the system does not always run at its maximum capacity, a load factor of 65% is assumed. Energy losses and corresponding costs are calculated.
Abbreviations: 1 C/3 C/4 C, single, three or four cores cable; Cu, copper cable; PVC, polyvinyl chloride cable; R, South African Rand; XLPE, cross-linked polyethylene Cable; Zcab, cable Impedance.

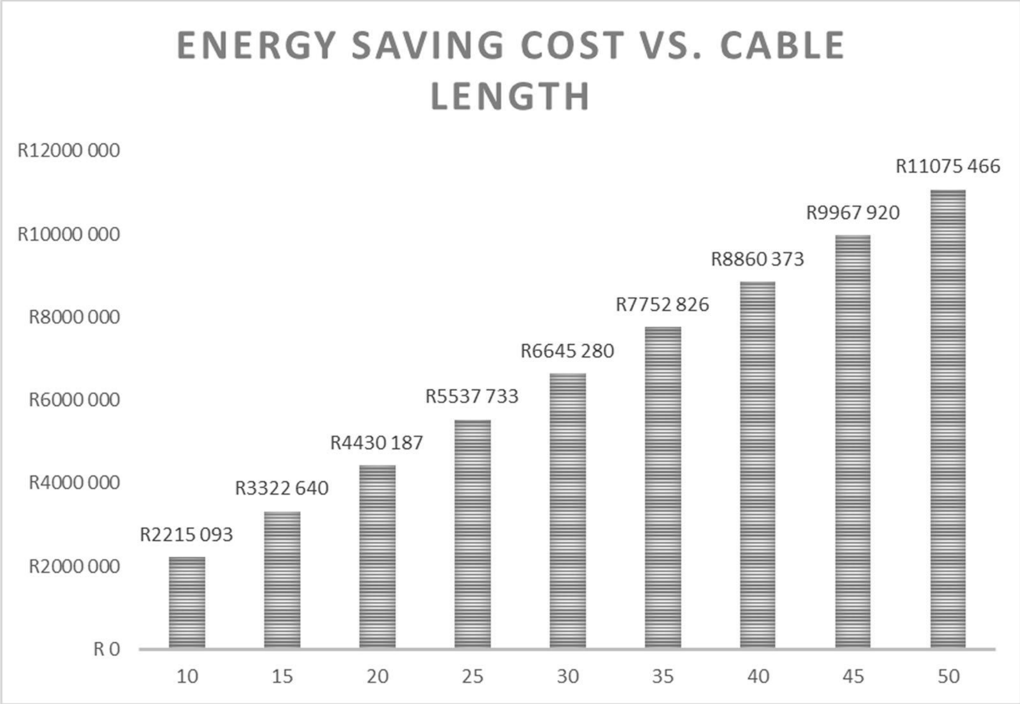

FIGURE 6 | Energy saving cost versus cable length. The figure demonstrates how the length of the distribution cable influences system energy losses. It shows the net difference in yearly cable loss expenses between MV and LV UPS systems. The further the load is from the UPS system, the more an MV system appears to be the better option. R, South African Rand.

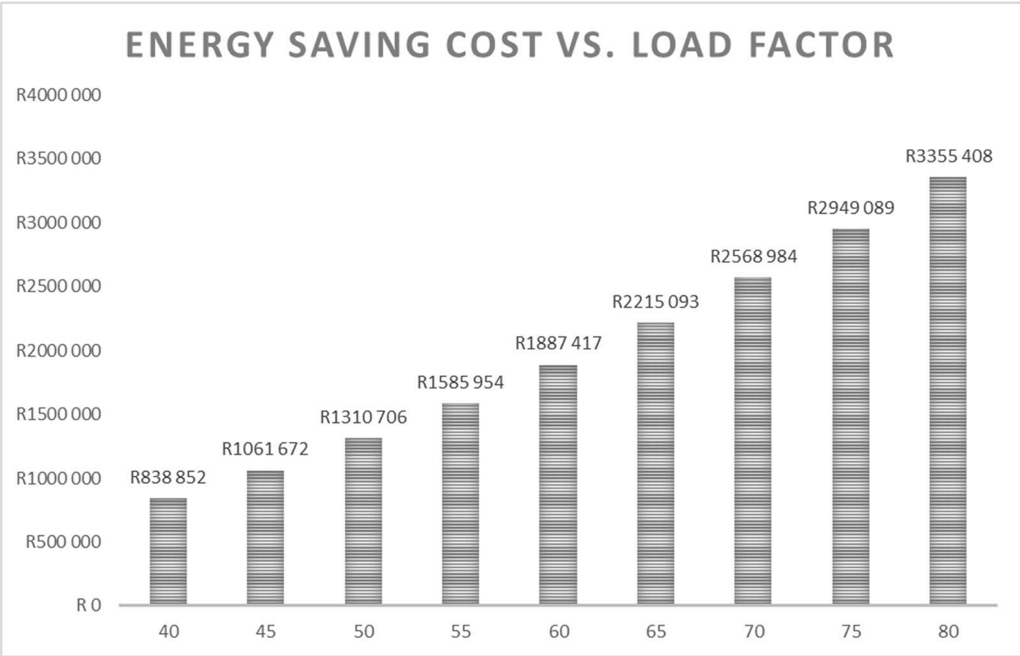

FIGURE 7 | Energy saving cost versus load factor. This figure illustrates how the demand factor influences system energy losses. The graph shows the net difference in annual cable loss expenses between the MV and LV UPS systems. It is evident that when the system approaches full capacity, an MV system appears to be the better option. R, South African Rand.

6 | Conclusion

Facilities aim to show their contribution to climate change and increase their resilience to power. The move from LV UPS to MV UPS systems is well-suited to achieving significant energy efficiency. To maximize the potential of any UPS technology for energy savings, it is necessary, among other things, to switch to a higher voltage operating system. LV systems operate at higher currents, resulting in dangerously high fault currents. A rise in operating voltage reduces operational current, and, thus, fault currents. This voltage increase minimizes cable size, heat dissipation, multiple cable runs, subsequent exposure to everincreasing energy tariffs and carbon footprint, and increases competitiveness in energy management and savings.

Integrating the UPS system into the MV network significantly reduces energy consumption. The system annually reduces energy losses by up to 46% at a load factor of 65% when compared to the LV UPS system. It also saves R221 509 per meter of cable length increase and R31 457 per percentage increase in load factor. This fiscal return is substantial and can easily justify the system upgrade and allow the facility to pay back the invested capital into the MV SUPS system much more quickly. The analysis of the two scenarios demonstrated that the closer the system is to operating at full capacity or the larger the facility is where longer distribution cables are used, the more an MV UPS system appears to be the ideal choice due to the exponential increase in cost savings it provides over the LV UPS system.

Aside from the numerous benefits of switching to MV UPS, the following are the primary drawbacks that necessitate further examination. A total cost of ownership analysis is required, given that MV UPS semiconductors are more expensive than LV UPS semiconductors, in addition to the related switching losses. To evaluate energy savings, a simple generic formula for cable heat dissipation is presented. Future studies should address the derating factor of cables. Profitability must be calculated by changing the current-carrying capability of cables based on factors such as ambient temperature, installation method, depth of installation, and the presence of other cables nearby.

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