Power Distribution Network Restoration using Mobile Electrical Power Transport Architecture (MEPTA) Based on Energy Storage System with µ-Grid Approach for Electrical Disaster Management

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Abstract: *Electricity is essential for our way of life. It provides all the comforts of life. Generated power is transferred to consumers through transmission lines and distribution networks. Natural disasters can cause severe damage to the distribution network, which leads to power outages. During this period, the restoration of the power distribution networkis a major challenge. µ- Grids play a vital task in the restoration of power after disruptions like blackouts or natural disasters. They provide localized energy generation and distribution, ensuring critical facilities like hospitals, emergency services, and communication networks can operate independently of the main grid. In this research, some of the centralized methods are discussed, which are used to restore the power distribution network however, have some challenges. This paper presents a novel approach for restoring power distribution networks in the event of electrical disasters using Mobile Electrical Power Transport Architecture (MEPTA) based on energy storage systems with a µ-grid approach. The proposed system aims to efficiently manage and distribute electrical power to restore functionality to affected areas quickly and effectively. The use of MEPTA and energy storage systems allows for a flexible and mobile solution, while the µ-grid approach ensures reliable and stable power distribution. This research suggests the field of electrical disaster management by providing a comprehensive and innovative idea for restoring power distribution networks in emergencies. The MATLAB/SIMULINK results for the proposed system are formulated.*

Keywords: *Electricity, Distribution Network, Disasters, outage, µ-Grid, restoration, MEPTA, Matlab/Simulink.*

I.INTRODUCTION

Electricity is the most significant invention in the world. Electric power travels from power plants to a commercial building through the power distribution grid [1]. The plant transmits electricity most efficiently at very high voltages. The purpose of the Distribution System is to deliver energy to homes and commercial environments with safety and quality as shown in Figure 1. Because of this greater population density and increased business activity, metropolitan regions often experience greater power consumption. [2]

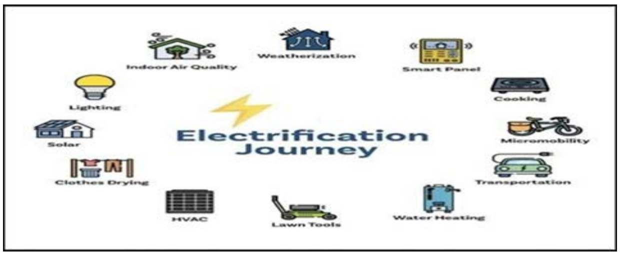

Figure 1.Represents the Journey of electrification.

Power distribution networks are complex systems that deliver electricity from transmission substations to consumers. They consist of a hierarchical structure of substations, transformers, and distribution lines. At the top of the hierarchy are high-voltage transmission substations that receive electricity from power plants or transmission lines [3, 4]. Disasters like earthquakes or floods can cause widespread power outages by damaging power lines, transformers, and substations. Natural disasters can damage roads, bridges, and railways [5]. Distribution infrastructure such as pipelines, cables, and towers can be damaged by natural disasters and require extensive repairs and replacements Conventional Methods like the Design of µ- Grid-connected solar PV system, µ- Grid-connected wind energy system, µ- Grid connected system with Nuclear power, µ- Grid connected system with fossil fuels are discussed and major challenges are formulated. In the case of an emergency, a decentralized electrical network may utilize µ- grids to segregate residential areas while using local generation and storage infrastructure to support important systems and structures including campuses, hospital communities, and data centers.[6]. In the case of an emergency, a decentralized electrical network may utilize µ- grids to segregate residential areas while using local

generation and storage infrastructure to support important systems and structures including campuses, hospital communities, and data centers. This paper proposes a MATLAB/SIMULATION-based restoration of power distribution with the Mobile Electrical Power Transport Architecture (MEPTA) requires the use of all available resources, including distributed generation, to restore the distribution network's essential loads as much as feasible.

II. EFFECTS OF DISASTERS ON POWER DISTRIBUTION NETWORKS

Power distribution networks refer to the infrastructure used to deliver electrical power from power plants or other sources to consumers. [7]. Utilizing distributed energy resources like solar and wind energy, present distribution networks are closely connected with non-conventional energy sources at the distribution level of the power systems. Distribution systems are thus growing increasingly separate from the transmission networks daily. It is quite difficult to balance the generation-demand connection at these present distribution networks, and doing so calls for a variety of operational and technical strategies. These tools include data analytics, battery storage power plants, optimization tools, and so on. [8].The power distribution systems can include a range of information about the components and operation of the system. In present distribution systems, µ-Grids are recognized as dependable substitutes for conventional techniques in reinstating de-energized regions of distribution networks and furnishing safe sources of electricity. Table 1. Shows the Differences between Traditional Distribution Networks and Modern Distribution Networks.

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Traditional distribution Network	**Modern Distribution Network**
1.Typically centralized, with large warehouses and distribution centers.	More Decentralized, utilizing smaller Warehouses and fulfillment centers closer to consumers.
2. Inventory is stored in bulk at central locations, leading to longer lead times.	Utilizes real inventory tracking and management systems for better stock control and quicker replenishment.
3. Limited scalability due to fixed infrastructure and processes.	More adaptable and scalable, able to adjust Quickly to changing demand and market conditions.
4. Can be less efficient due to longer transportation routes and higher inventoryholding costs.	Generally more efficient due to optimized logistics, and shorter delivery times
5. Communication channels limited, often through phone or fax	Utilizes digital platforms for seamless communication among suppliers.

Although the electrical system is an essential part of modern civilization, blackouts, cascade failures, and natural disasters are the main threats to it. [6]. There is a fundamental anticipation regarding the security of a grid of electricity. Currently, as the grid's significance grows daily, malicious threats are increasingly aiming their attacks at it.

III. CONVENTIONAL METHODS

The previous methods used to restore the power distribution with µ- Grid are; 1. Design of µ- Grid-connected solar PV system, µ- Grid-connected wind energy system, µ- Grid-connected system with Nuclear power, µ- Grid-connected system with fossil fuels.

1. Design of µ- Grid-connected solar PV system

A Battery Energy Storage System (BESS) linked with a photovoltaic solar power plant connected to the µ- grid offers an efficient and sustainable solution for both residential and commercial energy needs. This design typically involves photovoltaic panels installed on rooftops or open spaces to harness solar energy [9]. [10]. µ- Grid with a solar PV system shown in Figure 2 typically works by generating electricity from solar panels, which is then used to power local loads within the µ- Grid. Surplus power can be sent to the main electrical grid or stored in batteries to be utilized during cloud cover.

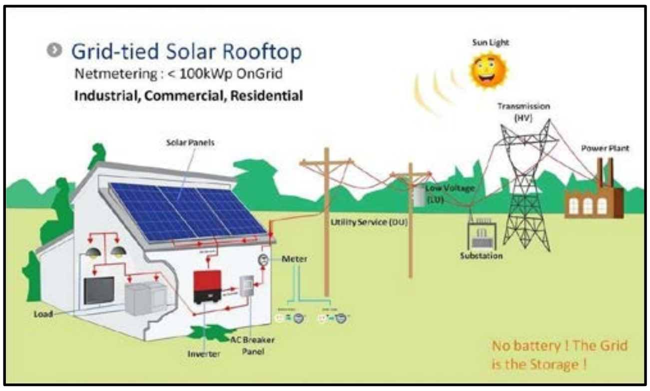

Figure 2. µ- Grid-connected solar PV system.

2.µ- Grid-connected wind energy system

Wind energy is integrated into the electrical grid through a multi-step process. Onshore or offshore, wind turbines use generators to transform the kinetic energy of the wind into electrical energy.[11-15]. As seen in Figure 3, overall, this networked system makes it easier to integrate wind energy dependably and effectively, resulting in a more robust and sustainable energy system.

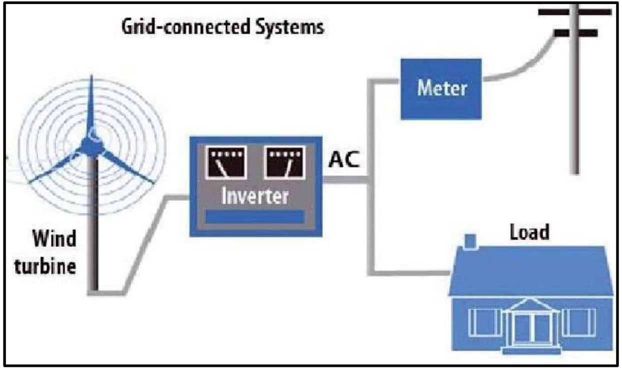

Figure 3. µ- Grid-connected wind system

3.µ- Grid-connected system with Nuclear power

Nuclear power plays a crucial part in the grid's energy supply through a methodical procedure. The energy generated during nuclear fission reactions—in which uranium atoms split and release a lot of heat is captured by nuclear reactors.[16, 17]. After being transformed into steam, this heat drives turbines that are coupled to generators to provide electricity. Within nuclear stations, stringent safety measures and containment systems ensure the controlled release of energy and prevent radiation leaks. [18]. µ- Grid-connected system with a nuclear power system is shown in Figure 4.

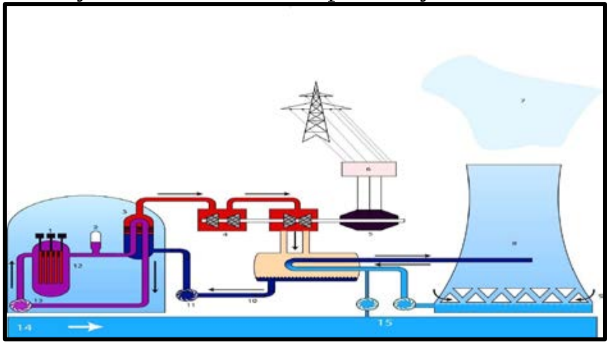

Figure 4. µ- Grid connected system with nuclear power system

4.µ- Grid-connected systems with fossil fuels energy

Fuel plants play a pivotal role in supplying energy to the grid through a process that involves several steps. To begin with, these plants produce heat by flaming fossil fuels like coal, natural gas, or oil. By water being heated in a boiler, steam is created utilizing this heat. After that, the steam runs a turbine that spins a generator that is attached to it.[19]. As the generator spins, it produces electricity through electromagnetic induction, converting mechanical energy into electrical energy. µ- Grid-connected system with fossil fuels is shown in Figure 5.

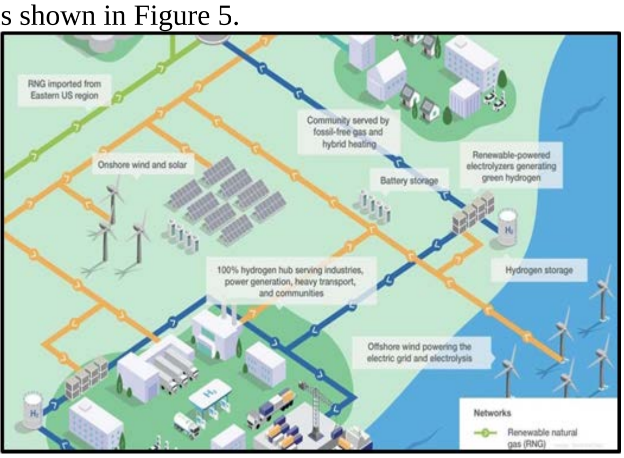

Figure .5. µ- Grid connected system with fossil fuels

Table 2 shows Differences between µ- Grid connected with Solar, Wind, Nuclear, and Fossil Fuels energy systems.

Table 2. Differences between µ- Grid connected with Solar, Wind, Nuclear, and Fossil Fuels energy systems.

µ- Grid-connected solar PV system	**µ-Grid-connected wind system**	**µ- Grid-connected system with nuclear power system**	**µ-Grid-connected system with fossil fuels**
1. The source of energy is Solar	1. The source of energy iswind	1. The source of energy isUranium	1. Sources of energy are Coal, natural gas, oil
2. Unlimited (sunlight) availability	2. Variable (wind) availability	2. Limited (uranium) availability	2. Finite availability
3. Reliability dependenton sunlight	3. Reliability dependent on wind	3. High Reliability	3. High Reliability
4. Grid Integration Variable	4. Grid Integration Variable	4. Grid Integration Steady	4. Grid Integration Steady
5. Highly scalable	5. Highly scalable	5. Limited scalable	5. Limited scalable

From the above methods following are the major Problems.

- The production of solar energy depends on weather conditions and daylight hours, leading to intermittency in power supply.
- Large-scale solar farms require a lot of area, which might lead to issues with habitat damage and land utilization.
- Like solar, wind energy generation is variable and dependent on weather conditions, leading tointermittency in power supply.
- In certain environments, wind turbines might be viewed as eyesores due to their noise production, which raises aesthetic and social problems.
- Fossil fuel extraction, transportation, and burning can result in habitat destruction and water pollution, among other forms of environmental degradation.
- The production of radioactive waste from nuclear power presents issues for long-term storage and environmental effect, necessitating careful management and disposal.

- Fossil fuel burning produces greenhouse gasses, which worsen air pollution and contribute to climate change.

5.µ- Grid Resources

The restoration of power distribution networks using µ- Grid resources in electrical disaster management involves utilizing small-scale, localized energy systems to supply electricity during times of grid outages or disruptions. [20-21]. µ-grid includes non-conventional energy sources, such as solar arrays or windmills, energy storage options, and smart grid technologies to efficiently distribute power to critical facilities or communities presented in Figure 6. During an electrical disaster, such as a storm or cyber-attack that causes widespread power outages, µ- Grid can provide a reliable source of electricity to keep essential services running, such as hospitals, emergency services, or communication networks. By decentralizing power generation and distribution, µ- Grid can enhance the resilience of the overall electrical infrastructure and reduce the impact of disruptions on the larger grid system. [22].Overall, the restoration of power distribution networks using µ- Grid resources in electrical disaster management offers a flexible and sustainable solution to safeguard against the effects of unforeseen events and ensure the continuity of essential services in times of crisis [23-24].

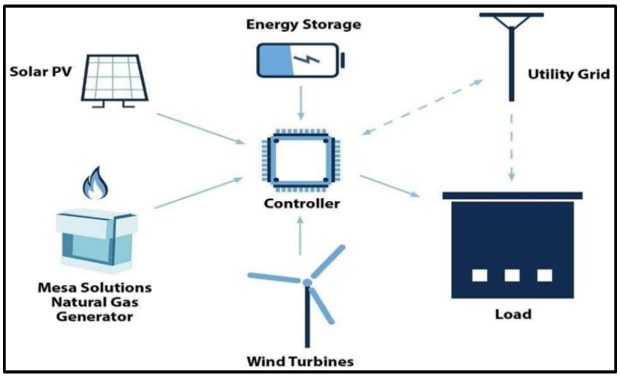

Figure 6. Represents a µ- Grid Resources.

IV.PROPOSED METHOD

The main Objectives of the proposed method are: To increase µ-Grid stability, reduce infrastructure cost Increase the µ-Grid efficiency, restore the power in the grid, Reduce the load management problems, reduce environmental impact due to fossil fuels, To enhance µ-Grid resilience**.** The above-mentioned objectives are met by the proposed method of Mobile Electrical Power Transport Architecture (MEPTA). **[25].** Figure 7 illustrates the MEPTA Block diagram.

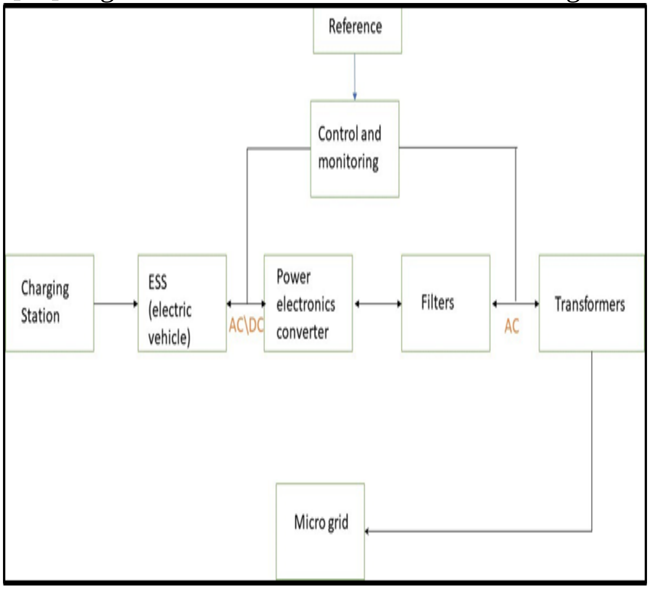

Figure 7. Block diagram of MEPTA

Figure 8 depicts the circuit diagram for the MEPTA to µ-Grid and µ-Grid to MEPTA.

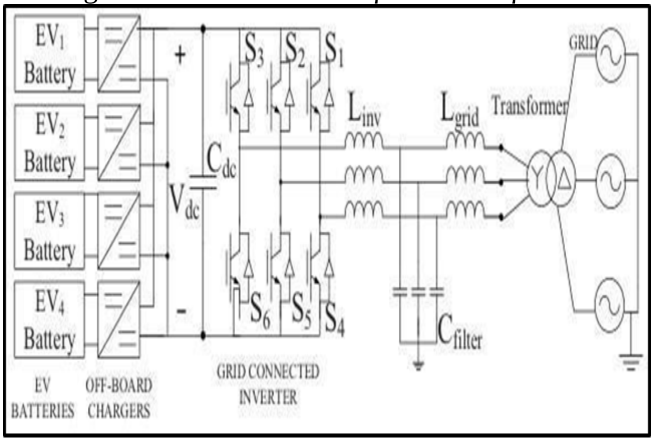

Figure 8. Circuit diagram of MEPTA to µ-Grid and µ-Grid to MEPTA

1. Calculations for the Design of MEPTA

Suppose an MEPTA with a battery capacity of 60 kWh. It can charge at a rate of 6 kW. The µ- Grid it's connected to has a capacity of 100 kW. Calculate:

I. The charging time of the vehicle.
II. The power contribution of the vehicle to the µ- Grid during charging.
III. The backup time provided by the vehicle's battery to the µ- Grid in case of an outage, assumingthe µ- Grid consumes an average power of 50 kW.

Solution

I. **Charging Time of Vehicle**

Charging Time = Vehicle Battery Capacity / Charging RateCharging Time = 60 kWh / 6 kW = 10 hours

II. **Power Contribution to µ- Grid**

Power Contribution = Charging Rate * Charging TimePower Contribution = 6 kW * 10 hours = 60 kWh

III. **Backup Time Provided by Vehicle's Battery**

Backup Time = Vehicle Battery Capacity / Average Power Consumption of µ- Grid Back up Time = 60 kWh / 50 kW = 1.2 hours

V. RESULTS

Simulink is an architectural schematic framework that is utilized for multi-domain simulation and model-based design. It facilitates continuous testing and verification of embedded systems, automated code creation, simulation, and system-level design. Simulink provides a graphical editor, solver settings, and changeable block libraries for modeling and simulating dynamic systems. Its interface with MATLAB allows it to integrate MATLAB algorithms into models and export simulation results to MATLAB for further analysis. Figure 9 displays the Simulation diagram of MEPTA to µ- Grid and µ- Grid to MEPTA.

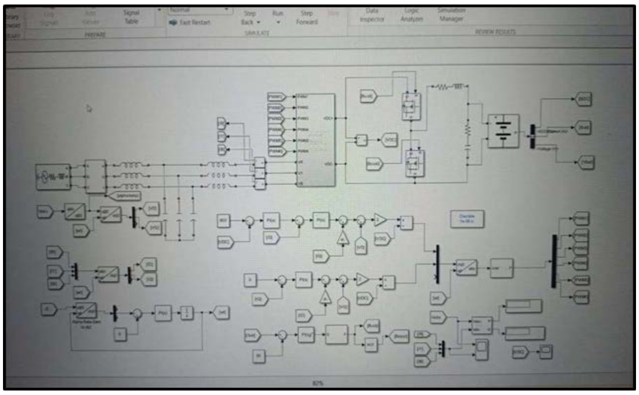

Figure 9. Simulation Diagram of MEPTA to µ- Grid and µ- Grid to MEPTA

The Current and Voltage waveforms of MEPTA to µ- Grid shown in Figure 10 are in phase i.e., the phase difference is zero. Therefore, the power is injected into the µ-grid through MEPTA since the power demand is high. As a result, the µ-grid receives power transfer from the MEPTA..**[26]** Therefore, the µ-grid restores the power in it.

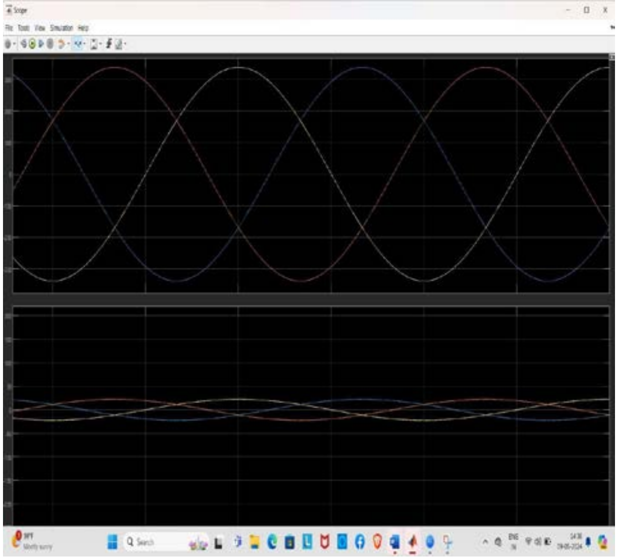

Figure 10. Current and voltage waveforms from MEPTA to µ- Grid.

The DC Bus output voltage shown in Figure 11 firstly increases with time then after it reaches maximum voltage it decreases with time and constant voltage supply to the µ- Grid.

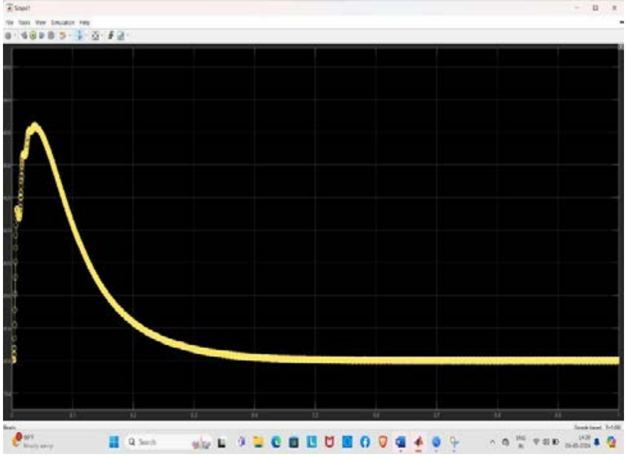

Figure 11. DC Bus output voltage waveform from MEPTA to µ- Grid.

The current and voltage waveforms are out of phase presented in Figure 12 from µ- Grid to MEPTA i.e., there is a phase difference. Therefore, the power is transferred from the µ-Grid to MEPTA. In this, the active power is negative which is used to charge the battery of MEPTA.

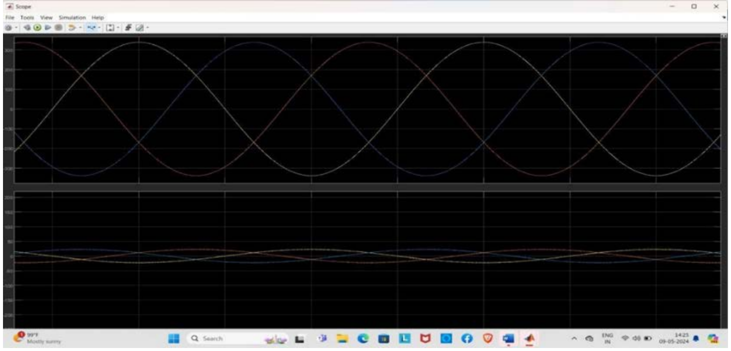

Figure 12.Current and voltage waveforms from µ- Grid to MEPTA

The Bus output voltage waveform from µ- Grid to MEPTA is shown in Figure 13.It is the reverse waveform of the DC bus voltage from µ- Grid to MEPTA

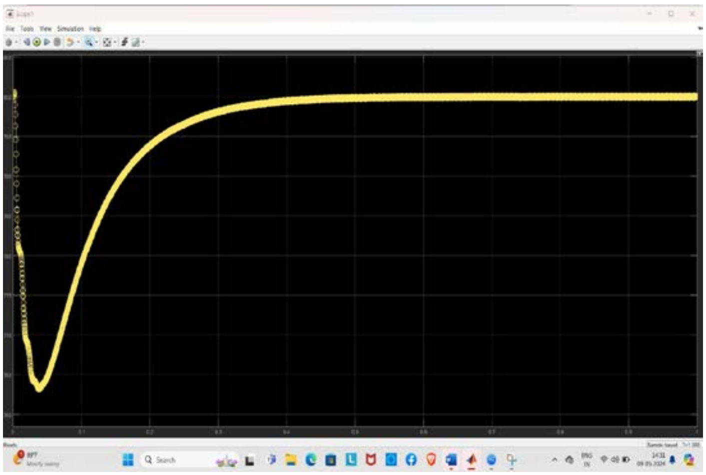

Figure 13.DC Bus output voltage waveform from µ- Grid to MEPTA

VI. CONCLUSION

The Mobile Energy Power Transport Architecture (MEPTA) to the µ- Grid represents a transformative approach to managing energy distribution and consumption. By utilizing mobile energy storage units, such as electric vehicles (EVs) and portable batteries, surplus energy can be efficiently stored and transported to where it's needed most. This architecture offers significant benefits, including enhanced grid flexibility, better integration of non-conventional energy sources, and improved resilience against disruptions. The Mobile Electrical Power Transport Architecture (MEPTA) based on an energy storage system with a µ-grid approach provides an innovative solution for restoring power distribution networks in the event of electrical disasters. By utilizing this technology, emergency response teams can quickly and efficiently deploy resources to restore power to affected areas, minimizing downtime and ensuring the safety and well-being of communities. The integration of MEPTA into electrical disaster management strategies has the potential to revolutionize the way power distribution networks are restored in the face of emergencies, ultimately leading to more resilient and reliable electrical infrastructure.

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