Photovoltaic, Emergency Auxiliary Communications, and Electronics (PEACE) Amateur Radio Station for Disaster Relief

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***Abstract*—In the aftermath of natural disasters such as tornadoes or hurricanes, modern infrastructure—especially the electrical grid—often sustains significant damage, leading to widespread communication failures. Reliable communication systems are critical for effective disaster relief, yet the absence of power exacerbates these challenges for citizens, emergency services, and government entities. This paper presents a Photovoltaic Emergency Auxiliary Communications and Electronics (PEACE) Station, a portable solar-battery-powered solution designed to meet critical communication needs during emergencies. The PEACE station features a 100W solar panel array, a battery pack, a reconfigurable open-source power electronics converter, and an ICOM 2720 Transceiver for amateur radio communication. Field tests have been conducted to evaluate the system's performance, demonstrating its potential as a deployable solution in disaster relief operations.**

***Index Terms*—Power Electronics, Control, Disaster Relief, Emergency Communication, Amateur Radio, Solar Battery System**

I. Introduction

In 2023, the US had the most disasters in the country's history. According to Climate.gov, damages from the 28 disasters totaled $92.9 billion [1]. In the wake of a devastating event such as a natural disaster, power and telecommunication infrastructure may be damaged or destroyed leaving people stranded and disconnected from the rest of the world. One of the most important yet often overlooked humanitarian field activities and aspects of disaster response is emergency relief communications [2]. When a tornado or hurricane tears down a cell tower or power pole leaving only a single cellular provider available, many people's devices become incapable of communication; and in a city-wide blackout, a cellphone running out of battery would render the electronic device useless. In recent decades, the amount of natural disasters has increased over the years from five in the year 2000 to twenty-eight in the year 2023 [3]. Currently in Fall 2024, Hurricane Helene and Hurricane Milton have wreaked havoc on the East Coast killing at least two hundred people and leaving many more missing and stranded. A news article in North Carolina titled "Forget cell phones – amateur radio shines in the wake of Helene" discusses the vital role amateur (HAM) radio is currently playing in ensuring that relief and recovery come as soon as possible [4]. Without Google Maps or a working messenger app, local HAM operators find themselves giving directions to first responders over the air, sending messages to loved ones, requesting aid, and so much more [5]. This is why the Federal Emergency Management Agency (FEMA) has continued to partner with the Amateur Radio Relay League (ARRL) ensuring that HAM radio operators would be incorporated as an essential role in the National Incident Management System [6].

HAM radio operators are normal, everyday citizens who have been trained or, many times, have trained themselves to be knowledgeable in antennas, electronics, radio theory, communication engineering, off-grid power systems, and utilizing their personal equipment remotely [7]. Each radio operator attains a license by passing a test from the Federal Communications Commission (FCC) to ensure they have a sufficient knowledge base to operate their radios safely and professionally. HAM operators have been the pioneers of auxiliary communications for over 100 years in the United States partnering with FEMA, the Red Cross, local governments, and other organizations to innovate solutions and provide services such as emergency communications. For some, Amateur Radio is only a hobby where they can talk to friends hundreds or thousands of miles away without a power grid, Wi-Fi, or a cellphone. To others, it is also a means of providing a vital service to families, communities, and governments in their most vulnerable states. Organizations such as the Amateur Radio Emergency Service (ARES) or the Radio Amateur Civil Emergency Service (RACES) have been formed to support both federal and state response services during emergencies. Training for both groups occurs in settings "both formal and informal, and often in conjunction with local agencies where the team can meet agency personnel with whom they can expect to be operating during a true emergency" [8]. Over the years, these trained volunteers have become essential to emergency response in the United States and its territories.

Hurricane Maria, which devastated Puerto Rican power and telecommunication infrastructure in 2017, had 50 HAM operators respond in order to establish HAM radio stations to

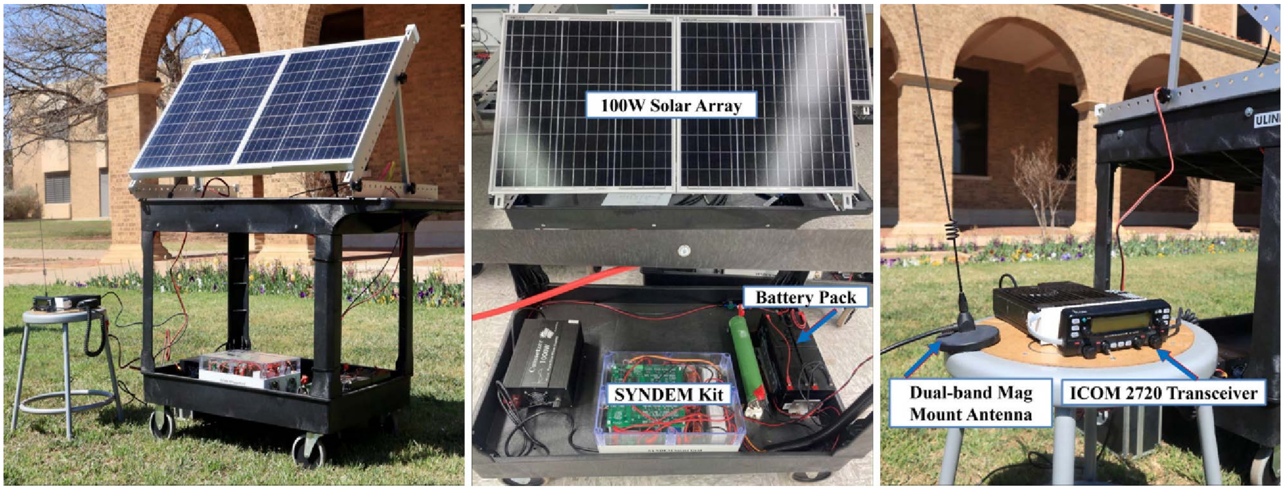


Fig. 1: The Proposed PEACE Station Setup

communicate with the Red Cross, police, and medical personnel [7]. Additionally, Hurricane Katrina relief, in 2005, heavily relied on ARES to maintain and manage communications of hospital operations across multiple cities as some hospitals were flooded or destroyed and others were overwhelmed with an influx of patients [7]. Another HAM radio organization, the Army Military Auxiliary Radio System, joined with Bethesda Hospitals' Emergency Preparedness Partnership in 2008 to create the BHEPP-MARS Emergency Radio Service (BMERS) and ensure communication within hospitals would be sustained during a disaster [9]. The BMERS solution incorporated Winlink 2000 (WL2K), an email messaging service using HAM radios, allowing emails to be sent from doctors or nurses to the recipient without the hassle of directly using a middleman. Instead, the HAM operator would let staff use their Winlink account and monitor email traffic to ensure that the communication went smoothly [9]. In Perryton, TX according to the After-Action Review (AAR) from State RACES District Radio Officer of Amarillo, Marci Rossiter, radio operators arrived the evening after a tornado destroyed a part of the town assisting the Red Cross and local first responders in establishing shelters and administering aid per request of the Texas Division of Emergency Management (TDEM). HAM operators in the city were able to report the weather updates to the National Weather Service (NWS) as part of SKYWARN, a service that trains citizens to spot and report up-to-date weather reports "to save lives and property through the use of observations" [10]. Furthermore, as some RACES operators were relaying communications from relief sites, an ARES operator arrived on the scene and set up AW Broadband, a high-speed internet service, to each site providing more communication with surrounding cities that could send aid [11]. FEMA provides recommendations for community members to follow in case they find themselves in a power outage with no communication. Their suggestions include memorizing family contact information, choosing familiar meeting spots, and more; but it is the responsibility of the individual cities, neighborhoods, and families to utilize the expert advice and create their own plan [12]. Given that FEMA, TDEM, and other emergency management organizations realize the essential role HAM radio plays in maintaining communications during a crisis, cities across the United States and the world need to ensure they are equipped with HAM radio gear in case disaster strikes. This work proposes the Photovoltaic, Emergency Auxiliary Communications, and Electronics (PEACE) station as a prototype "Go Kit" or "Go Box" solution that aims to be scalable, sustainable, portable, and practical for the average citizen's communication needs in an emergency and disaster.

- **Scalable—**The power converter is open-source and reconfigurable, with the ability to operate in coordination with multiple units, thereby increasing both the overall power capacity and communication capabilities.
- **Sustainable—**The system has off-grid capabilities, utilizing clean energy from solar power and battery storage, enabling it to operate at any time of day. However, optimal performance is achieved when the system is exposed to direct sunlight.
- **Portable—**The system is portable and can be easily transported short distances by a single person or loaded into a vehicle for longer trips.
- **Practical—**The radio is operable both day and night for extended periods, enabling it to transmit distress signals and support the coordination of initial emergency and disaster relief efforts.

II. PEACE Station System Description

The proposed PEACE station, shown in Figure 1, consists of an ICOM 2720 Dual-band amateur radio transceiver connected to a magnetic mount antenna for reliable transmission and reception of radio frequencies, a 100-watt photovoltaic array, a 384 Wh battery pack (comprising four 12V, 8Ah rechargeable lead-acid batteries) and a SYNDEM Smart Grid Research and Educational Kit (the "Kit") power electronics converter [13]. The system overview is depicted in Figure 2 with the converter configured as a DC-DC boost stage cascaded with a DC-DC buck converter, with a 100Ω-500W resistive load integrated to prevent overcharging of the battery pack. All components are mounted on a portable utility cart for easy relocation and transport. The system also includes a custom-made Human-Machine Interface (HMI) for real-time data acquisition and monitoring.

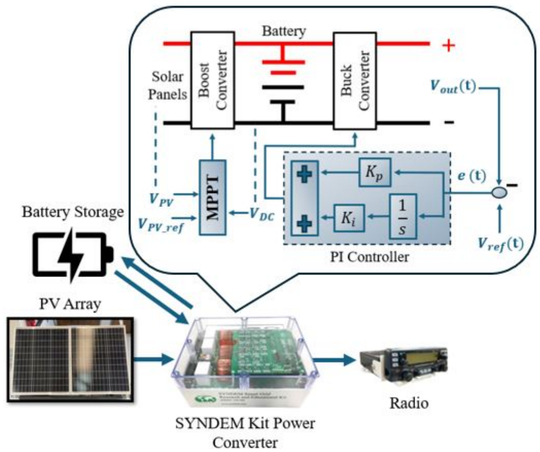


Fig. 2: System Overview

A. Radio Transceiver

The ICOM 2720 transceiver is incorporated with the PEACE station due to its dual-band capabilities and variable power modes. Dual-band transceivers can transmit and receive on both the Very High Frequency (VHF) 2m band (144-148MHz) and the Ultra High Frequency (UHF) 70cm band (430-450MHz). It also has various power modes ranging from a low-power mode of 5 watts up to a high-power mode of 50 watts. These specifications allow for multiple tests of the system's capabilities and functionality allowing us to determine whether it meets the criteria of practicality. The specifications for the IC2720 are in the Table I below.

TABLE I: ICOM 2720 Radio Specifications

Voltage Supply Requirement	13.8V DC
50W Transmit Drain	12A
Receive Drain	1.2A
Receive Drain at Max Adio	1.8A
Output Power VHF	50/15/5W
Output Power UHF	35/15/5W
VHF Frequencies	144-148MHz
UHF Frequencies	430-450MHz

The VHF band tends to allow for longer-distance communication; while the UHF band allows for more indoor communication as its short wavelengths penetrate through walls more easily. Both these capabilities are essential for emergency radio communication. The VHF band can increase the likelihood of communication with those outside of the affected area of a disaster enabling others to send help. Whereas, the UHF frequency can be used in an affected area of disaster to coordinate and provide relief for those inside as well as outside of buildings.

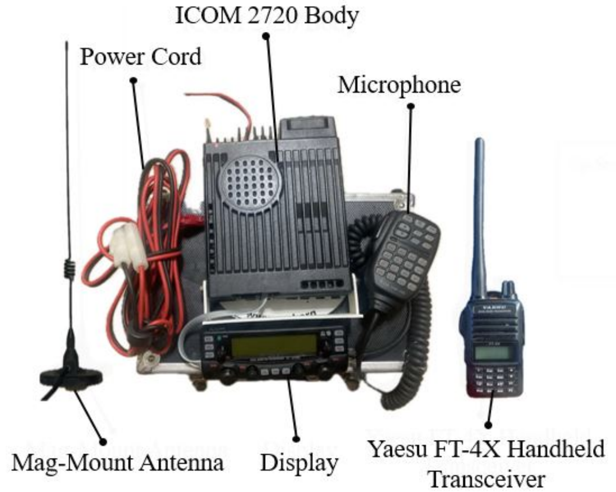


Fig. 3: ICOM 2720 Radio Components

As seen in Figure 3, the ICOM 2720 requires minimal setup with a plug-in display and microphone as well as a power cord for a DC connection. A magnetic-mounted antenna is one of many antenna options, but for an emergency setting, it provides great portability being able to attach to most metal surfaces from cars to refrigerators and even fire hydrants. To test for accurate transmission and reception on the ICOM 2720, the Yaesu FT-4X handheld transceiver is used as a secondary communications device.

B. Power Stage

The Kit used in this platform is an open-source, reconfigurable power electronic converter that supports more than ten topologies, including both DC–DC and AC–DC configurations, adaptable to off-grid and grid-connected modes. The Kit's control board features a Texas Instruments C2000 ControlCARD, which enables automatic code generation directly from MATLAB/Simulink. This allows users to engage with Simulink's graphical programming environment and apply pre-verified control algorithms from simulations. Additionally, the power board includes various pre-assembled components such as IGBTs, relays, current and voltage sensors, inductors, capacitors, and fuses, enhancing reconfigurability and providing access to test different topologies. In this work, the topology used is a DC-DC boost converter cascaded with a DC-DC buck converter, with the battery pack interfaced between the two stages, as shown in Figure 4, with component ratings listed in Table II.

TABLE II: SYNDEM Power Converter Component Ratings

Capacitors C_a, C_c	20 μF
Capacitors C_{dc}, C_{76}	470 μF
Inductors L_1, L_3	1.5 mH
Switching Frequency S1,S2	20 kHz

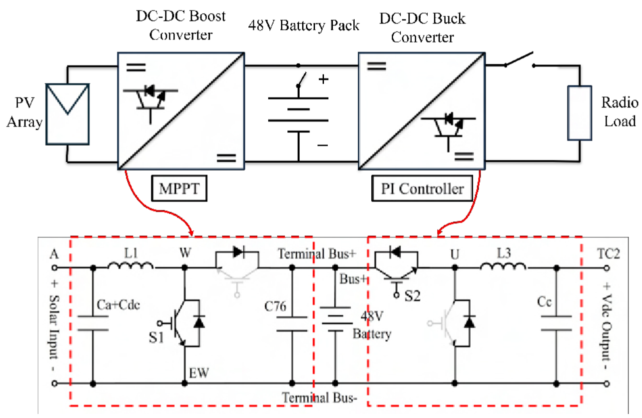


Fig. 4: System Topology

On the input side (Terminal A and Bus-), two Newpowa NPA50S-12H solar panels, each rated at 50W, are connected in series to create a 100W array. This input section includes capacitors C_a and C_{dc} and inductor L_1. The PWM control for the boost converter is applied to switch 1 (S1), with the output voltage reflected across capacitor C_{76}. The feedback signal for controlling S1 is measured across the input capacitors $(C_a + C_{dc})$ to match the optimal voltage setpoints of the solar panels. Simultaneously, the DC bus voltage (between Terminal Bus+ and Terminal Bus-) is continuously monitored to prevent overcharging of the battery pack. If overcharging conditions occur, the MPPT algorithm adjusts the solar panel voltage setpoint to reduce the output power directed towards the battery pack.

In the second stage, switch 2 (S2) is controlled to achieve the desired output voltage for the DC-DC buck converter, tailored to the specific requirements of the radio load. The buck converter uses the 48V battery pack as its input and includes an LC filter on the output side, consisting of inductor L_3 and capacitor C_c. The voltage across C_c is used as the feedback signal to regulate and stabilize the output voltage. The radio load is connected across Terminal TC2 and Bus- through a switch, ensuring proper power delivery.

By incorporating the SYNDEM Smart Grid Research and Educational Kit into the platform, the system becomes open-source at both the control and power stage levels, allowing users to modify components and configurations to meet the specific requirements of their communication systems. For instance, if a different radio requiring a voltage higher than the battery pack is to be used, the Kit's reconfigurable power board and control code enable easy adjustments. Designers can modify a few jumper-wire connections to change the topology to a dual-stage boost converter, stepping up the voltage on the radio load side to meet the specified requirements.

C. Control Stage

Low-level Pulse Width Modulation (PWM) control is used to drive the internal switches S1 and S2 of the Kit, allowing precise control within the aforementioned topology. The dual-stage topology serves two main objectives, as illustrated in Figure 2: (1) maximizing power input from the PV array while maintaining battery voltage, and (2) stepping down the voltage for radio load operation. The first control task is handled by a boost stage, which utilizes a fixed set-point Maximum Power Point Tracking (MPPT) controller to stabilize the solar array's optimal voltage and boost the converter's output to maintain the 48V battery voltage, while integrated protection functions prevent overcharging. The second control task is handled by a DC-DC buck converter, which steps down the 48V battery voltage to a 13V DC set-point, ensuring the safe and optimal operation of the radio under test. A Proportional-Integral (PI) controller is embedded to regulate the voltage set-point for the radio's input, maintaining stability regardless of variations in solar irradiation. In this system, the battery functions as a DC link buffer, storing excess power and promoting overall system stability. The Kit's control board operates at a frequency of 6.66 kHz, with all control components discretized to function at this set frequency. To allow users to observe the control goals and system performance in real time, a custom HMI was developed.

D. HMI

An HMI has been implemented for real-time monitoring and data acquisition, with LabVIEW serving as the front-end software, as illustrated in Figure 5. The Kit, which features RS485 serial communication capabilities, establishes data communication with a portable PC via an RS485-to-USB module and LabVIEW's VISA serial communication functions. The HMI displays real-time graphical information on system signals, such as the power and voltage levels of the PV array, battery, and load. This allows users to monitor system performance under various conditions, including power consumption during radio transmission, output voltage setpoints, battery charge and discharge status, solar array power output, and hardware-level error codes. Since both the Kit and HMI are open-source, users have the flexibility to configure additional data for display. The system also supports bidirectional communication between the PC and hardware, enabling users to modify key parameters, such as adjusting output voltage setpoints to accommodate different communication devices or connecting additional DC loads.

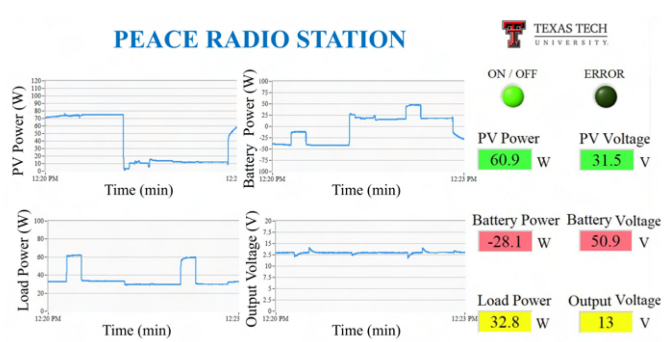
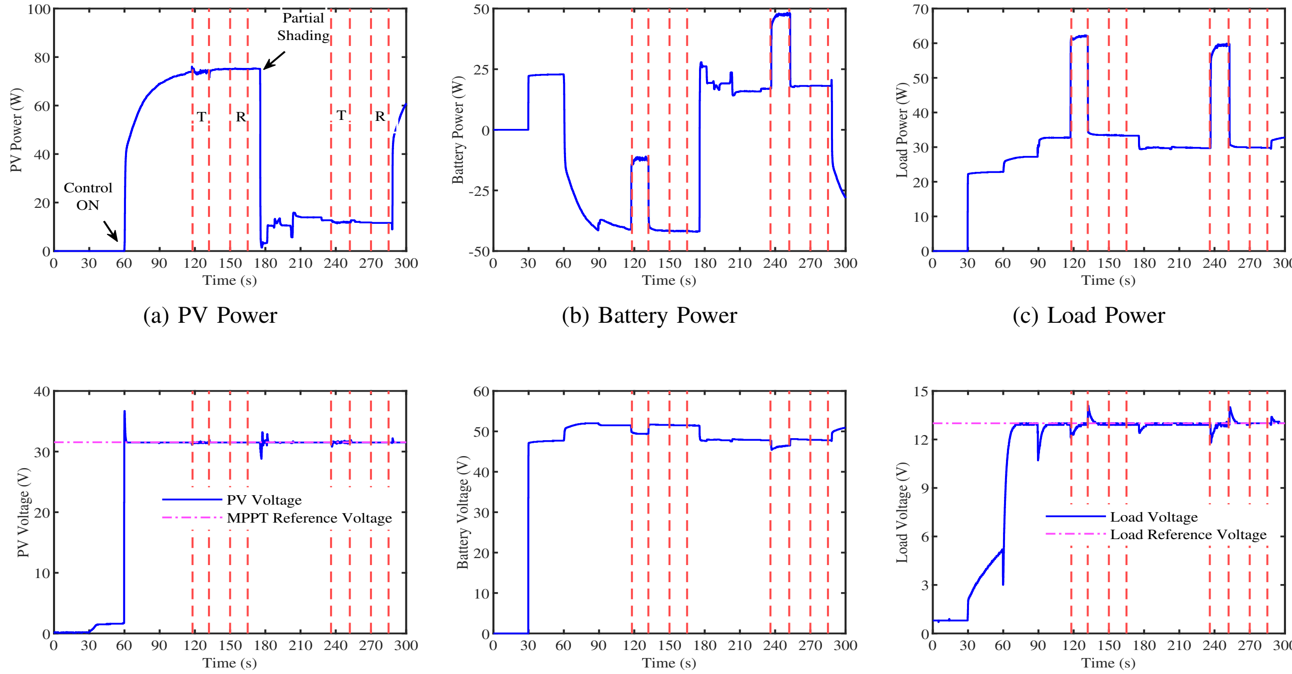


Fig. 5: LabVIEW HMI



(a) PV Power (b) Battery Power (c) Load Power

(d) PV Voltage (e) Battery Voltage (f) Load Voltage

Fig. 6: Field Test Results: Transmission Period “T”, Receiving Period “R”

III. Results and Discussion

A. Field Test Results

A field test was conducted to experimentally validate the reliability and deployment of the PEACE station. The 5-minute test was designed to evaluate the system’s performance under various outdoor and operational conditions. The experimental results are presented in Figure 6, with the operational sequence outlined as follows:

At $t = 30$ seconds, the battery pack was connected by activating a switch conveniently located on the front of the cart for easy connection and disconnection. At $t = 60$ seconds, the controller on the power converter was enabled, initiating the control sequence. The first step was to maximize power delivery from the PV array, as shown in Figures 6 (a) and (d), which depict the solar power and voltage, respectively. At this point, the voltage was regulated to around 31.5V, reaching the optimal MPPT voltage setpoint. This allowed the solar panels to deliver approximately 80W of power to the system, with some power being directed to the 100Ω resistive load and the excess power used to charge the battery (indicated by negative power). Simultaneously, the second control objective was met: stepping down the battery voltage to a fixed setpoint of 13V DC, ensuring stable operation of the radio, as shown in Figure 6 (f).

At $t = 90$ seconds, the radio’s input power switch was activated, turning the radio ON. At $t = 120$ seconds, audio transmission (denoted as “T”) via the microphone was enabled, operating at a frequency of 447.18 MHz in UHF mode, which is near the system’s highest power consumption. From a distance of approximately 20 meters, the handheld transceiver clearly received the transmitted audio. Continuous transmission was maintained for 15 seconds. The results show a significant increase in power consumption during transmission, with the load power spiking to around 60W, as illustrated in Figure 6 (c). This total load power accounts for both the resistive load connected to the platform and the power requirements for radio operation. Correspondingly, battery power also increased, as shown in Figure 6 (b). Following the transmission test, the platform was evaluated for receiving audio. Using the handheld transceiver, audio was received (denoted as “R”) by the radio for 15 seconds, with clear audio being heard. During this receiving period, the power demand was minimal, resulting in low changes in power consumption.

To further evaluate the system under realistic conditions, significant partial shading was introduced by physically covering the solar panels. The shade was applied from $t = 180$ seconds to $t = 290$ seconds. As shown in Figure 6 (a), a decrease in power from the solar array was observed during the shaded period, and simultaneously, the battery pack began supplying power to the system, as indicated in Figure 6 (b). The system was then tested for transmission and reception following the same procedure as before. During the transmission period, battery power delivery reached a maximum of nearly 50W, further validating the performance of the PEACE station under both normal and abnormal conditions. Despite the shading, the system successfully maintained stable radio operation, consistently providing sufficient power for communication. This field test demonstrates the potential of the PEACE station, even at its current prototype stage. While improvements, such as enhancing mechanical robustness with waterproof and dustproof features, are possible, the system has proven its reliability in sustaining operation under challenging conditions.

IV. Application and Conclusion

This prototype's capabilities would most effectively support a city in the initial moments after a disaster opening up communication for citizens whose normal devices have become temporarily obsolete due to local damage. Some specific solutions and implementations of the PEACE station would be utilizing the PEACE station in conjunction with something like the General Mobile Radio Service (GMRS). GMRS maintains a few radio frequencies that can be used when a family or group buys a GMRS license and receives a call sign. Not everyone has to be an expert HAM radio operator to use a radio system; rather, individuals could be trained and familiar with operating the stations in similar disasters using their family's or organization's GMRS license. The PEACE stations are self-powered and would be functional whether the power infrastructure was functioning or destroyed. Furthermore, the stations could be placed in community-designated relief sites that community members would be able to locate in a time of emergency. Drills and practices could be held amongst Emergency Medical Services, Police, radio operators, and other community members on how to use radio communication to progress the continuity of governance and avoid dehydration, starvation, and death in a crisis.

Additionally, assigning PEACE stations for SKYWARN reports to the NWS could prove to be a lifesaving strategy in cities whose locations are prone to inclement weather, allowing weather updates to be sent out independent of easily damaged WIFI and cellular networks. Keeping these stations in medical facilities, retirement homes, children's homes, and prisons could also aid operations at these vital institutions during emergencies and natural disasters. Capabilities such as Winlink 2000, allow HAM operators to send emails with their radios, and the Automatic Packet Reporting System (APRS) can even enable HAM operators to send texts and share locations. As a city gets relief and begins recovery from an incident, sending emails via radio becomes a primary means of official correspondence for updates and reports to the state and federal government. Setting up the PEACE station with these functions could change the world of disaster relief, adding efficiency in communication never before seen in the midst of chaos and crisis.

As natural disasters continue to ensue, the role of radio operators will stay a necessary part of relief plans. The PEACE station can be implemented in cities across the nation, to greatly aid first responders and citizens. There is no excuse for long-term lapses in communication when the potential radio capabilities made possible by the PEACE station and other similar systems exist. It will be the responsibility of community members, local government officials, and even larger organizations like FEMA to take the next step towards progress in emergency management to utilize radio systems, set up repeaters, and create avenues that further off-grid living and communication for communities all over the United States so that PEACE can be delivered in disaster.

Acknowledgment

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