Mobile On/Off Grid Battery Energy Storage System (MOGBESS)

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***Abstract*—As the use of the power grid has become more integral to everyday society, a growing momentum towards a more dynamic power system resides on the horizon. With the invention of renewable and distributed energy resources, this push is beginning to become a reality. However, these resources are mainly implemented stationary designs. In this paper, the authors explore the possibility of implementing these resources into a Mobile On/Off Grid Battery Energy Storage System (MOGBESS). This system implements a hybrid inverter and a battery energy storage system (BESS), which is then integrated through an external primary controller. The system is then configured into a portable chassis that implements plug-and-play connectivity. Such a design takes into account both the consideration of the original stationary design and the mobile system, which includes system control and communication, operational power, and mobile protection.**

***Keywords*—Battery energy storage system, hybrid inverter, mobile, primary controller, interconnection, communication protocol**

Introduction

With some of the recent power outages across the US, specifically those in the last few months, recognizing both the fragility of the grid and the lack of backup power for many individuals presents a significant need. Over the last few years, renewable energy resources have become more popular as the correlation of burning fossil fuel resources and global warming has become better understood. However, considering the intermittent nature of these renewable resources, distributed energy resources (DER) are required to successfully implement these resources into the prevailing power systems. Some of these resources include items like an inverter or a battery energy storage system (BESS). Although grid-connected energy generation systems exist on the market, the currently available options do not implement much flexibility. Instead, they are intended to be installed permanently in one location. Furthermore, portable units are becoming available, but are usually a compromise of power output or trading fossil fuel systems for renewable generated energy. If this DER were made portable, applications could be to extend into other areas of interest. Therefore, this work aims to focus on the design challenges and requirements needed to configure readily available DER system components into a mobile, more versatile system.

Legal Considerations

As interest into grid interconnection has grown over the years, the legal requirements for interconnection have increased as well. To work properly, the power grid must adhere to a set of specific guidelines, and by extension, systems that interconnect into the power grid must also adhere to these standards.

Interconnection Considerations

It should be noted `before one begins such an endeavor that interconnection to the power grid will come at the discretion of the local utility provider. Most providers have published an interconnection handbook which outlines polices, processes, and required components for systems intending to operate as a DER. Required components are described in terms of UL certification and NEC codes. Regardless of the system, these will be the major constraints to which the design must conform. Furthermore, individuals seeking to own DER's must be permitted by the utility provider once their system has met the provider's policy. Consequently, it is imperative that each policy be understood and followed. While standards and codes are many that could apply [1], the limitations of space will only allow the most pertinent of this design to be mentioned.

UL Certified Components for Interconnection

In nearly every utility interconnection handbook the following standards are mentioned: UL 1741 SA standard for inverters, UL 1008 standard for automatic transfer switches, and more increasingly UL 9540 for battery energy storage systems. UL 9540 is one of the newer standards combining both UL 1741 SA Std for inverters, converters, controllers, and interconnection system equipment for use with distributed energy resources, UL 1973 Std for batteries in stationary applications, UL 1642 Std for lithium-ion batteries, and many other applicable NEC and IEEE codes [2]. For many utility providers, streamlined approval is promised for systems that fall under certain power export parameters (often 10kW or less) and are comprised of components that have achieved UL certification. While a few utility providers may not directly specify particular certifications, like UL 1741 SA for example, such components will be required to demonstrate conformity to the IEEE standards.

UN Certified Components

In special regard to the design of the MOGBESS a unique requirement that is not directly referenced in the interconnection handbooks will need to be considered, namely UN 38.3. This is due to the prevailing stationary design of the vast majority of DER systems. With the desire to have mobile system, any implemented lithium-ion batteries, which are classified as hazardous materials, will need to conform to UN DOT 38.3 standards [3].

Off the Shelf Considerations

One of the main components of distributed energy resources (DER) will be centered around an inverter, which will convert the power created by renewable resources into usable power, in terms of voltage, current and frequency, for both external loads and the grid. Another piece of this structure is a battery and the corresponding battery management system (BMS), which will store unused energy created by the renewable resources and export that stored energy when needed. Since the mobility of the system will be a primary goal of this design, consideration of the type of inverter, the battery, and custom BMS will be critical early decisions to find the most appropriate "fit."

Hybrid Inverter

The vision of this system will be one that can harvest renewable energy (PV, wind or tidal) and convert it in for both immediate use and storage for future use. Such a design choice will need to utilize a hybrid or bidirectional inverter that can provide both grid services as well as store excess energy in a battery backup. Additionally, the bidirectional nature of the inverter will allow it to provide power factor correction and improve efficiency of power consumption by absorbing or injecting reactive power as needed. A key challenge facing this design, as mentioned before, will be finding an "off the shelf" inverter with UL certification already in place. Communication protocols the inverter utilizes will also come into play as will be discussed in later detail.

Lithium Ion Batteries

An equally important consideration to the inverter will be the battery chemistry/type and its accompanying required technologies such as a battery management system [4]. Due to the energy density and high-performance, lithium-ion batteries will be the choice for this system. This particular chemistry choice does not come without its own set of challenges and is why UL has developed Std 1642 for their construction and operation. These types of batteries necessitate a rather sophisticated BMS to protect the battery from overcharging and over-discharging that could result in permanent damage to the batteries themselves (over-discharge) or even explosion (overcharge). As was noted above, different inverter manufactures have different voltage ranges for their batteries. Higher voltage requirements will impact available "off the shelf" choices that may or may not be placed in series to achieve certain higher voltages. This challenge will provide a further constrain on the design. While it is true major online retailers offer a host of lithium-ion options, the vast majority contain internally sealed BMS's that cannot be placed in series nor communicated with. Integrable lithium-ion batteries then must have an external BMS that will have the flexibility of design to meet power requirements. Similar to the communication protocol of the inverter, the BMS will also need to be able to send and receive communication with the system and, by extension, the inverter for the inverter to operate. Without real time data from the BMS, the inverter will not work by both manufacture's design and UL standards.

Inverter, BMS, Battery Compatibility

While currently there are many fully integrated stationary systems that meet these requirements, it is difficult to pick and choose components to achieve optimal design without specialized engineering solutions. This is true, especially if designers desire to utilize other batteries beyond those contained on the inverter manufacturer's compatibility list. For instance, when looking at voltage and current requirements of the inverter and battery energy storage system, the two will need to be compatible with each other to meet the requirements of charging and discharging the battery. Therefore, affinity, in terms of communication and power requirements of the BMS, the system controller and, by extension, the inverter will occupy a primary place for MOGBESS unit design.

Distribution Power Considerations

Such a system is intended to be operable in at least three different modes of operation: grid connected, islanding (backup), and mobile power. The challenges and requirements facing each mode of operation are different.

Grid Connection

UL 1741 SA governs grid connection in which the system must mesh well with the power grid in terms of frequency, voltage, and monitoring the status of the grid. To do this properly, the inverter will need to know the status of the grid it is connected to, namely its voltage, phase angle, exact frequency. This measurement must be done with a reliable meter that has been vetted by UL so that the system does not unintentionally island by injecting power to a faulted grid. When receiving power, the inverter will be consuming power by charging the battery system. This will be beneficial even when there is not a renewable energy available because it will provide power factor correction and peak shaving capabilities when the load demand is high or highly inductive.

Backup Connection

When the system is desired to operate in islanding mode, there will be two different options. In the first mode, the system operating under grid-connected mode but ceases operation due to a grid fault. Inverter manufactures have very clearly defined grid connections from backup connections so that unintentional islanding does not happen. While the inverter will cease power export from the grid connections, the DER will need a way to physically change the connection on the load to remove it from the grid. Once this physical disconnect and connection is made, the system will then activate the backup connections and invert the stored DC energy of the batteries to AC power for the load. The physical disconnect/reconnect will be the job of an automatic transfer switch that can direct power flow from the different generation sources, namely the MOGBESS and the grid. As it turns out, UL 1008 Std for automatic transfer switches governs how these devices must operate in a timely and safe manner. Consideration should also be given to this device and how it will integrate into the system, especially in terms of communication protocols when the system is expected to provide automatic backup power.

When the system is mobile, it will also technically be on backup mode. However, the accessibility to the power stored in the batteries will be more difficult to utilize unless considering design solutions to this challenge. Mobile use will be discussed in depth later in this work.

System Control and Communication Considerations

The MOGBESS unit will be comprised of several different components that will need to be able to communicate with each other. Since some components operate using different communication protocols, certain protocol converters will need to be considered to allow for smooth communication. Control over the individual components will be important for the transfer and storage of all data flowing from each component. All the data within the system will need to flow through a primary controller which will run the source code and maintain hierarchy over all other components. Any incoming data will be stored and then displayed through the on-board user interface. However, such a setup will present challenges regarding connectivity, initializing the source code properly, and possible cybersecurity concerns.

Primary Controller

Using a primary controller as the main control center of the MOGBESS unit will allow for the system to communicate with any authorized connected devices, providing storage for incoming data. The primary controller will communicate with other components within the system through necessary communication protocols and compatible physical connections. The data coming in from each connected component will be displayed via the user interface. The user interface will allow for specific users to access real-time data from the system and alter any of the necessary source code. The specific design and layout of the user interface will be dependent upon the circumstances of the specific MOGBESS unit. Some limitations within the built-in functions of the primary controller can be improved through additional storage and wireless communication boosting devices. Additionally, depending on the specific type of controller, the main source code may require minimal adjustments to run certain communication protocols. The primary controller will also require a connection to a steady power supply, ensuring that the controller functions properly and will be able to maintain necessary operating speeds.

Source Code

The source code, programmed onto the primary controller, will be necessary to ensure proper communication and data transfer between the controller and any connected devices [5]. The source code must also be capable of defending against potential cybersecurity threats outlined by the IEEE for battery storage projects. Some of the main challenges and concerns involve unauthorized third-party agents accessing the source code or other lines of communication and making unwanted alterations. Certain security measures such as TLS/SSL encryption or key-based SSH authentication will be important measures within the source code that help add layers of protection to the overall system. Additionally, numerous operating systems and programming languages exist that include built-in security features and can be selected from to add additional layers of protection to the source code. The source code will be initialized to communicate with each connected component through each device’s unique IP address. After compiling all the incoming data, the source code will be referenced by the user interface to display the information in real-time settings. Any access to the incoming information or the source code will need to be limited to authorized personnel. Limiting certain access will help to add layers of cyber-physical security to the on-board system.

Communication Protocol

One of the key differences between the MOGBESS unit and systems that already exist is that this design implements control of the system via the primary controller, which is external to the inverter. This primary controller will need to receive information from not only the inverter, but also the BMS, implemented meters, and any other determined source of information critical to the operation of the system. Therefore, a common communication protocol will be required throughout these various devices [6]. Considering that the communication devices could each implement different protocols, the main protocol chosen on the primary controller side will be obliged to be flexible enough to allow for intercommunication. This will be done with different protocol converters syncing the varying protocols.

It is important to also consider how the primary controller will interact specifically with the inverter. Although many inverters showcase communication ports for external access, inverter retailers have created roadblocks for modification of their systems. Often, these ports are intended for read-only communication, and inverter retailers will often remove external write access for the security and integrity of their product and its operation. Since the primary controller would not be able to write to the inverter registers—one of the most important features of the design—this restriction will not work with the MOGBESS unit. Therefore, it will be important to have a thorough conversation with the inverter retailer about what level of read/write access will be available and select workable components accordingly.

Mobile Considerations

When looking at the previous considerations, it becomes clear that an externally controlled battery energy storage system has a complex design, even when stationary. However, a new level of complexity is added when designing a mobile system. The MOGBESS unit will necessitate the ability to have plug-and-play connectivity, allowing the system to be easily transported. It will also require the ability to provide power to all its components for the system to function properly. With its portable design, the system will need to have a well-coordinated startup and shutdown procedure to allow for routine setup. Mobility also poses a challenge in safety, particularly in the grounding of the chassis that holds the system together.

Mobile Distribution Power

When moving to a mobile design for this system, the first consideration is determining how the system should be operating when mobile. Since hybrid inverters will only run grid mode when sensing a grid connection, the inverter will have to be run on backup mode when mobile. Since grid access will most likely be limited when mobile, this requirement should be easy to attain. However, determining how to turn off the backup power quickly becomes an issue. Typically, the inverter will leave backup mode when grid connection becomes available. Since the system will not have a grid connection when mobile, the inverter will continue to provide power indefinitely. Therefore, the most practical solution to deactivating the mobile backup power is to disconnect the backup power from its source, which is the battery energy storage system. To do this, a high power MOSFET will need to be implemented between the negative terminal of the battery and the negative terminal connection on the inverter acting as a switch to sever the connection. This will provide the primary controller direct access to this connection, allowing for backup power to be utilized safely and efficiently in a mobile setting.

Since this system is intended to be easily mobile, easy connectivity will be critical to the design. While setup of the system at the load will undoubtably require a licensed electrician to install required subpanels and NEC standardized connectors, it is intended that this be a one-time application. Consequently, easy connectors, such as twist-lock cables and camlock cables, will need to be enforced for connecting and disconnecting external components to the system, such as grid connection, backup connection, and photovoltaic (PV) panel connections. In addition to these connectors, this system will require connection options, such as ground-fault circuit interrupter (GFCI) outlets, that will allow for external loads to be connected to the mobile system. All these connectors will need to be in a central location for ease of access for the user.

Operational Power

When the pre-modified version of this system is installed, all the components needing operational power are found in the inverter and the BMS for the batteries. However, this design will require several communication components external to the inverter and the BMS that will require operational power. Therefore, a system needs to be implemented to power these components. The source of this operational power will be from either the grid-side or the backup-side power, depending on which mode the inverter is in. To switch the operational power between these modes, the primary controller activated TRIACs will need to be put in place between both connections to the operational power. The primary controller will apply a gate voltage to “turn on” the TRIAC corresponding to the inverter’s mode of operation.

One of the most integral communication components that will require operational power will be the primary controller. If this primary controller loses power, the source code for the system will be reset and the communication lines between the devices will be abruptly lost, causing system failure as well as safety concerns. In addition, if the inverter is not active, the operational power components will not have a power source to access. To avoid this dilemma, an uninterruptable power supply (UPS) will need to be implemented between the source of operational power and the components. This will provide a readily accessible standby power for the system when the inverter is not capable of powering external components.

Startup and Shutdown Procedures

Most of these primary controllers do not have a dedicated power button. Instead, these devices turn on when power is received. When considering the startup and shutdown procedures the MOGBESS unit will need to implement, this lack of control poses as a challenge and safety concern. However, many of these controllers are capable of implementing a low power mode. This feature will be incorporated within the MOGBESS unit with a physical button connected to the controller, allowing a user to turn on and off the system when need be. When the MOGBESS unit is “off”, the primary controller will operate in low power mode. The UPS will provide a minimal amount of energy to keep the primary controller active, but the controller will not be functional for the system to be used. In this state the sytem must have the capbabilty to leave low power idle mode and turn fully on. Once the MOGBESS unit is requested to turn “on”, the primary controller can easily access its required operating power because it will already have access to it through the operational power connections. Furthermore, the battery backup of the UPS will be replensished as these connections become energized.

Considering the process of turning the system “on” and “off”, it is important to acknowledge the startup and shutdown protocol procedures that will need to be followed to safely reach a steady state. These procedures will have source code specific actions that will need to happen in a sequential manner. During startup, it is pertinent that all required communication paths are initialized and checked through the primary controller before the inverter and battery energy storage systems are deployed. Finally, the shutdown procedure will require that all systems, especially those that are running through the inverter, shut down before the primary controller enters low power mode.

Chassis Grounding and Protection

Mobile goals for the MOGBESS provide a unique challenge for grounding and protection. Electric vehicles and their design provide a clue in which the system could monitor ground faults while mobile [7]. During stationary operation, the system will utilize the grounding of the building (load) to keep any user from faults that can accidentally energize the chassis by sending current to ground. However, during mobile operation, the ground will have to “float” using the chassis as ground. For DC systems this is a safe and well-known design and operation. However, given the high voltage of AC operation, the system will need to utilize some additional safety features to protect individuals who could be injured by ground faults by touching the chassis. To do this, the system will utilize a simple voltage divider with chassis mount resistors and a system controller activated TRIAC that will tie the ground and neutral busbars together. During grid and backup modes, these bus bars will remain independent but in mobile mode, they will need to interconnect. In the event a ground fault occurs, the current will need to travel through the voltage divider to the chassis and drop to 1/100 of the voltage from the fault source. It should be noted here that chassis resistors should be selected in such a way that it limits the current to safe amounts which by industry standard is less than 5mA [8]. Between the chassis and the final resistor on the voltage divider, a current transformer will be attached to monitor the line to detect if any current goes to ground. If it does, the current transformer will send the signal to the system controller. In response, the high power MOSFET between the inverter and the negative terminal of the battery will be turned off and thereby sever the power source from the system. In this way, in the event of a fault, an individual would only receive, at most, 2.4V and a 2mA current for a very brief time before the system would detect the fault and shut power inversion down.

Conclusion

Design and integration of a mobile, grid-connected battery energy storage system is no trivial matter. The MOGBESS unit is complex, and there are many challenges to be met regarding the existing standards, policies, and procedures. Since there are no industry manufacturing standards for readily available components, integration solutions will require unifying communication protocols as well as novel engineering. This design has sought to present a series of considerations and potential solutions to challenges facing such a system. It is the hope that the work here can provide a road map toward the actualization of such a design. This system is intended to clarify how such a design will work properly with all components and how all those components can communicate with one another in a mobile, multi-mode, efficient, and safe manner.

ACKNOWLEDGMENT

The authors would like to thank Dr. Hamid Nazaripouya, who has spent many hours guiding, directing, and challenging every step of the design. In addition, the authors would like to thank Dr. Michael Gard for his leadership throughout this project.

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