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Smart Grid Improvement UsingMicrogrids: Problems and Possibilities

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Abstract—Smart grid development has been accelerated by technological advances in the energy sector, calling for interdisciplinary research into power systems and management. Transmission and distribution losses, energy theft, and environmental concerns are all problems in India, the world's third-largest producer and user of electricity. Because of these problems, the energy sector is looking into cutting-edge technology to improve the reliability, longevity, and safety of the grid. The goal of this research is to identify potential factors that might aid in the growth of India's smart grid. Prominent academics, researchers, and industry specialists working in the electricity sector participated in questionnaire surveys, interviews, and workshops to analyze the smart grid's many parts.The underlying infrastructure, including smart grids, is rapidly maturing as smart cities and countries become a reality. The necessity for privacy-preserving multisubset data aggregation is a significant obstacle to implementing a smart grid. Customers may participate in demand-side management and integrate renewable energy sources with the advent of the smart grid. The intermittent and variable nature of renewable energy sources makes their integration into the smart grid challenging.

KEYWORDS- Micro-grid, Demand Response, Adaptive Stochastic Control, Distributed Energy Resources (DER), and Smart Grid

INTRODUCTION:

Increasing energy consumption, decreasing primary energy supply, and conventional and outdated electrical transmission and distribution networks have all contributed to an unsustainable energy situation in modern civilization. With rising temperatures throughout the world, less resources to generate electricity, and more people depending on that electricity, it is clear that old grid layouts will need to be updated and new solutions and technologies developed.

Distributed Generation (DG) of electricity has gained traction as a cutting-edge solution in recent years due to its many benefits, including increased efficiency and environmental protection, lower transmission and distribution losses, stronger local power grid support, and enhanced system stability. Photovoltaic systems, wind power, small hydro turbines, tidal power, biogas, and other forms of renewable energy are common complements to DG plants.

Individual distributed generator applications may create more issues than they resolve. Taking a systemic approach that treats generation and loads as a single entity (a "microgrid") is the best way to fully exploit the promising new field of distributed generation [1-3].

Microgrids are tiny, local distribution systems that include variable and constant loads, as well as a variety of microsources including microturbines, fuel cells, PV arrays, and wind turbines, and storage devices like flywheels, energy capacitors, and batteries. Power quality is improved for consumers since the system is both grid-connected and capable of operating in isolation from the grid (known as "island mode") in the event of faults or other external disruptions. Microgrids' capacity to do so is a major selling point. Microgrids also have the potential to reduce power losses in the distribution network, improve power quality, decrease emissions, and increase local dependability [4].

While there are several benefits to using a microgrid, connecting the system to the distribution grid may be difficult. Problems may be broken down into many categories, including those relating to regulations and client involvement. Technical challenges include the integration of renewable sources and the associated problems, protection issues with the integration of renewables, and operation constraints, while regulatory challenges may relate to regulation policies, the legality of microgrids, and the engagement between microgrid firms and customers.

The future of the world's electric systems is being shaped by three major factors: government regulations, customer demands for more efficiency, and the development of more sophisticated computational and hardware technologies. Government policies at all levels, from international to local, are being driven by environmental concerns to increase energy efficiency, reduce energy waste, and increase the use of renewable energy sources.

All types of new renewable energy and storage technologies, on the one hand, and new energy efficiency and conservation approaches, on the other, are seeing increased adoption as a result of these considerations. Consumers are taking more initiative and being given greater control over their energy use, which is having a positive effect on their day-to-day life. They are simultaneously increasing their energy consumption. One example is the widespread adoption of electric vehicles (cars and trucks), the management of electricity storage to locally match supply and demand, the ownership of distributed generation from ever-increasing renewable energy sources, and the remote control of in-home appliances to promote energy conservation. Opportunities that did not exist even a decade ago are now available thanks to the availability of new technology including more pervasive and cognizant SCADA sensors, secure 2-way communications, integrated data management, and intelligent, autonomous controllers.

All of these factors will have to be taken into account in order for the electric energy system of the future to be successful. Despite the many papers and conferences dedicated to the Smart Grid in recent years, the phrase is still widely misunderstood. While several definitions of the Smart Grid have been presented, users have often settled on narrower ones that are more applicable to their immediate context.

A comprehensive, all-encompassing definition of the Smart Grid is provided below. The current conventional electric energy system is described, followed by the areas that need updating to offer the information and control required to transition to the future-looking safe, secure, and efficient Smart Grid. While not an exhaustive treatment of the topic, the papers included in this Special Issue provide a representative sampling of the Smart Grid's upcoming transformations.

FROM SMART GRID TO MICROGRID

The evolution of power networks is referred to as "smart grid" [5, 6]. Smart grid is an electricity network that can cost-efficiently integrate the behavior and actions of all users connected to it (generators, consumers, and those that do both) to ensure economically efficient, sustainable power system with low losses and high levels of quality and security of supp The European Regulators Group for Electricity and Gas (ERGEG) developed based on the definition from the European Technology Platform Smart Grids (ETPS). A simplified explanation of the smart grid model may be seen in Fig. 1.

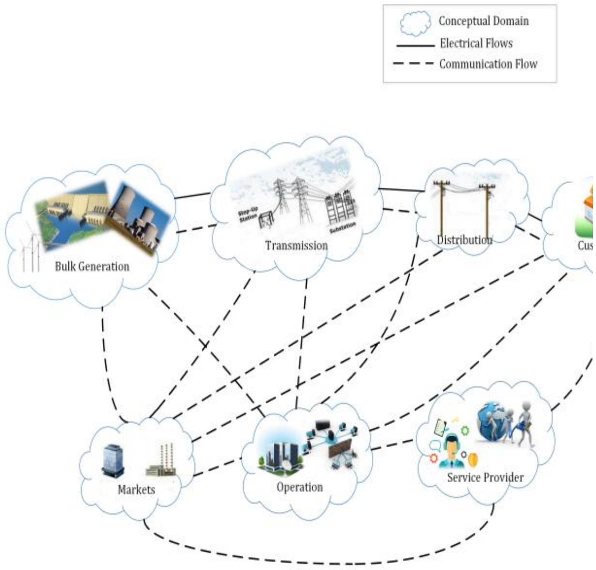


Fig. 1. Smart grid conceptual model

While smart grid has numerous benefits, it also faces many challenges. These include, but are not limited to, the following: bidirectional communication systems; integration to grid with renewable energy resources; inefficient use of the DG; insufficient current grid infrastructure and storage; and so on. Effective DG usage may be achieved by regional management of electricity production, energy storage, and load [5, 9].

The function of the microgrid in the smart grid is crucial. It is a minor part of the broader grid that includes practically all of the parts of the utility grid. Microgrids are smaller in size and may function autonomously from the main utility grid, whereas smart grids occur at the larger utility level, such as major transmission and distribution lines.

Third, a Future Smart Grid Architectural Model Depending on the configuration of the AC and DC buses, three broad categories of microgrids may be identified. The three types of microgrids that are being suggested are AC microgrids, DC microgrids, and hybrid AC/DC microgrids.

AC Microgrid

DC and AC loads, as well as distributed generators and batteries, are all linked to an AC bus in an AC microgrid. Since most loads and the grid itself operate on AC, AC microgrids may be simply incorporated into the existing AC infrastructure. Therefore, it is more powerful, flexible, and easy to regulate. However, the efficiency drops dramatically [10, 12] when DC loads, DC sources, and energy storage devices are all coupled to the AC bus through DC/AC converter.

Direct Current Microgrids Using an AC/DC converter, DC microgrids link their shared DC bus to the larger grid. DC microgrids function in the same way as AC microgrids. Since just one power conversion is required to link DC buses in a DC microgrid, power conversion losses are minimized compared to those in an AC microgrid.

As a result, DC microgrids are superior in terms of system efficiency, cost, and size.

In addition, DC microgrids are more stable since they don't use reactive power [10, 13-15]. This makes them an excellent choice for the integration of DERs. The literature [11, 16] presents many DC microgrids, including the monopolar, bipolar, and homopolar varieties. Inverter-Based Microgrid Direct integration of both ac- and dc-based DG, Energy Storage System (ESS), and loads is made possible by the hybrid AC/DC microgrid, which is shown in Fig. 2.

This design incorporates the best features of both AC and DC microgrids into a single system, including lower overall costs, lower energy losses during conversion, more efficiency, and greater dependability. In addition, synchronization of generating and storage units is not required when DG, loads, and ESS are all linked directly to either the ac or dc networks [17-19].

SMART GRID ELEMENTS AND THEIR DUTIES

Interface Components for Intelligent Devices 4.1 The following are the components of a microgrid:

Microgrids rely on distributed generators (DGs), which are power plants placed at or near the end user's premises. Microgridsmay use either renewable resources, like solar photovoltaics (PV), wind, small hydro power, ocean, etc., or non-renewable resources, such reciprocating engines, gas turbines, contemporary Combined Heat and Power (CHP) units, etc., as their primary source of electricity production.

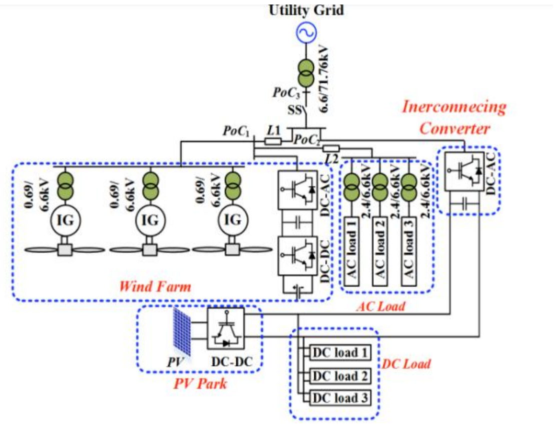


Fig. 2.A general structure for hybrid microgrid.

In order to transform the energy from DG sources into an ac form that can be used by the grid, a power electronics interface is often used. The circuitry required to change the form of electricity is included in the power electronics interface [21]. These converters might be either single-stage (DC-AC) or two-stage (DC-DC and DC-AC) designs. Harmonic performance is enhanced at lower switching frequencies [22] due to the converter's built-in output filters (L, LC, LCL, and LCL with damping resistor). Distributed generation for a microgrid has to be carefully chosen, taking into account the characteristics and costs of the various technologies involved [12, 23].

Devices for storing energy

Electrochemical systems (batteries and flow batteries), kinetic energy storage (flywheel), and potential energy storage (pumped hydro and compressed air storage) are the three main types of energy storage technologies. Detailed 4 comparisons of various energy storage technologies may be found in [24-27]. Since large-scale energy storage systems like pumped hydro storage and compressed air energy storage systems are often only employed in the high power range for conventional power systems, they are not a good fit for residential or commercial renewable energy systems [28].

Microgrids might benefit from the use of energy storage devices in terms of addressing power quality, dependability, and stability between loads and distributed generating resource output. The characteristics of loads and dispersed energy resources allow for the identification of the most appropriate energy storage systems. The following is a brief overview of some of the most important forms of energy storage now in use for MG applications:

Batteries are widely employed as a form of energy storage. Batteries may be broken down into many different types, including lead acid, nickel cadmium (Ni-Cd), nickel metal hydride (NiMh), and lithium-ion (Li-on). Long-term energy storage is a good use for lead acid batteries despite their low performance and short cycle life (1200-1800 cycles). Ni-Cd batteries provide better energy densities, need less maintenance, and have a longer cycle life compared to lead acid batteries. However, the high cost of investment is its primary drawback. NiMh batteries have the same cycle life as lead acid batteries and have a higher energy density than Ni-Cd batteries by around 25-30%. Li-on batteries have a higher energy density than lead acid, Ni-Cd, and NiMh batteries, but they also have a higher initial cost and a shorter lifespan [28-30]. To lessen the blow of PV integration's unintended consequences, a battery storage system that is itself integrated into solar PV systems has been suggested [31]. Simulink and Homer were used to do techno-economic analyses of several battery storage devices, and the results were published in [28].

Flywheel energy storage devices feature a high energy and power density, as well as a lengthy life cycle. However, one of the drawbacks of flywheel energy storage is that it often results in significant friction losses. They may be used to smooth out the power output from intermittent sources like wind and solar [26]. In [32, 33], a UPS service for mission-critical loads is provided via a flywheel storage device linked with a diesel generator. - Supercapacitors, also known as ultracapacitors or electric double layer capacitors, are non-chemical energy storage devices that combine the best features of capacitors and electrochemical batteries. A super capacitor's employment of a porous membrane to facilitate ion movement between two electrodes allows for the direct storage of electrical energy with a negligibly slow reaction time [29].

In addition, its capacitance and energy density values may be many orders of magnitude higher than those of capacitors. The supercapacitor has a lower energy density than lead acid batteries but a greater power density, longer cycle life, and an energy efficiency of roughly 75-80%. One major drawback, however, is the exorbitant price, which is almost five times more than lead acid batteries [30].

Supercapacitors have been offered as a viable option to smooth out the variations caused by wind and wave power's intermittent nature [34, 35]. - Extremely quick reaction times, great efficiency (up to 95 percent), high implementation cost, and a long lifespan (tens to thousands of cycles) characterize SMES systems. Power factor correction, frequency management, transient stability, and power quality enhancement are all possible uses [36, 37].

Microgrid frequency and voltage are managed in island mode by SMES powered by wind energy (Ref. To counteract power oscillations caused by wind generation, the SMES system is used while the microgrid runs in grid-connected mode to provide the constant power flow at PCC. - Vanadium redox battery (VRB) is a commercially available flow battery that offers numerous benefits over various conventional BESS, including a long life cycle, minimal maintenance, independent power and energy capacity, rapid charge and discharge response, and high efficiency. When compared to BESS [29], however, operational and maintenance expenses are still very expensive up front. Recent commercialization of this technology has resulted in a dearth of published work on VRB-based microgrids [39–41]. The significance of ESS on smart grid is shown by a case study based on the concept in Fig. 3. Hokkaido Island in Japan's 6.0 GW power grid is reduced to 100MW, with electricity coming from hydro, thermal, and nuclear plants.

When a maximum renewable power penetration of 10% of original power system capacity is considered, a renewable energy park consisting of wind and/or solar system is linked to the power system. This research extends the basic model presented in [42] to illustrate how current smart grids react to a large penetration of renewable energy, as well as how grid code limitations may be overcome with the use of storage technologies. Whenever the amount of power created by the wind turbines is more than the reference power provided by a low pass filter, i.e., when the wind speed is less than the rated speed, the advanced pitch controllers [43] may smooth the power traveling to the line. Traditional pitch controllers are ineffective until wind speeds above their quoted threshold. Two wind farms' generational differences in wind speed are seen in Fig. 4. Frequency variations are shown in Fig. 5 and Fig. 6 for various penetration levels of wind power under high and low load situations, respectively, when only the traditional pitch controller is in operation. Peak penetration of wind power is associated with increased frequency fluctuations.

Frequency fluctuations, however, are kept within a tolerable range for high load conditions when the advanced pitch controller is used (see Fig. 3). As can be seen in Fig. 4, the frequency is not successfully controlled by the advance pitch controller when the load is low. However, as illustrated in Fig. 9, the frequency may be kept at its rated value when an ESS is integrated into the smart grid (Fig. 3). The Energy 5 Capacitor System was employed as the ESS in this investigation. As a result, ESS will play an important part in the future operation of smart grids, despite the fact that the primary issues still include ESSs' costs and lifespans.

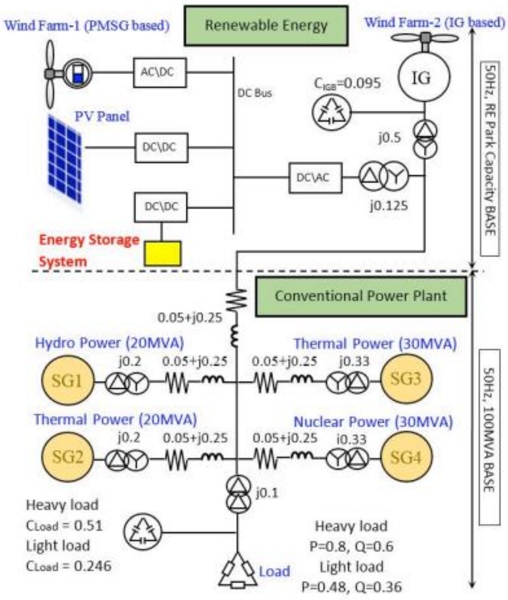


Fig. 3. Smart grid with energy storage system

Electric utilities and their consumers have previously benefited greatly from these traditional characteristics. However, the new requirements of energy-savvy, computer-savvy, and environmentally-concerned consumers, combined with regulatory changes that promote sustainability and energy independence from foreign sources, availability of more intelligent technologies, and ever-increasing demands for sufficient energy to drive the global economy, necessitate a fundamentally different electric energy system of the future in all 5 of the aforementioned areas.

It's important to remember that the electric system described above is not being replaced by the Smart Grid; rather, the Smart Grid is expanding upon existing infrastructure to better use current resources and enable the introduction of novel capabilities. For instance, large-scale wind and solar energy will become substantial portions of the generating mix wherever cost justifies it, although centralized sources of generation will still play a significant role in the Smart Grid. In order for users to be able to locally and/or remotely manage their smart appliances and temperature settings, a cyber-secure, two-way communications system must be made available.

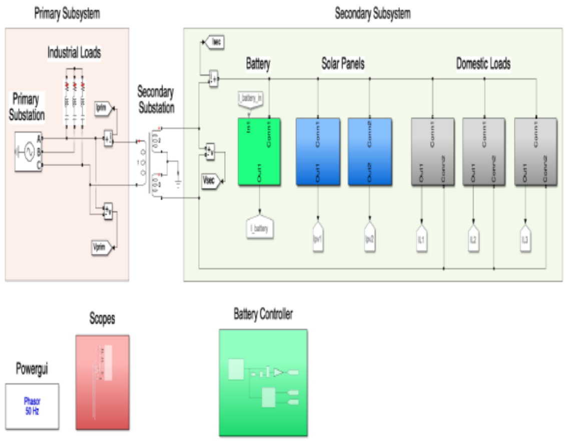
The utility will be able to know the current state of the electric system thanks to monitoring and control of the system's components. Together, real-time data, integrated system modeling, and cutting-edge diagnostic tools and procedures will allow for the early discovery of faults, fueling PM and WM initiatives. In the event of an equipment failure, the system will automatically reconfigure itself with the help of adaptive and autonomous optimization controllers. The management of the Smart Grid energy system will rely heavily on distributed generating and storage resources, as well as remotely operated equipment, in order to optimize power flow, remove load pockets, and reduce system losses in the event of an emergency. It's worth noting that the proposed Smart Grid construction would be very expensive and will need a long-term, iterative deployment procedure.

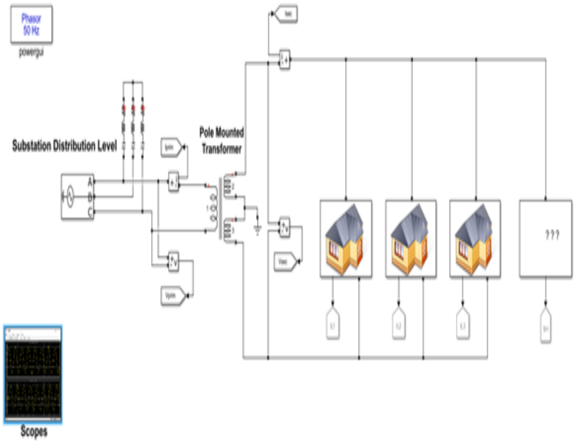
What Is a Smart Grid?

In this Special Issue, we discuss the Smart Grid, which is not some far-fetched idea but a real global transformation that will see real technologies developed and deployed to provide intelligent management of the electric grid over the coming decades. Some parts of the Smart Grid system described above may turn out to be too expensive, in which case they will have to wait until more affordable alternatives become available or the benefits to society outweigh the costs. To put it another way, the ultimate Smart Grid is a vision, one that must be cost-justified at each stage before execution, then tested and verified before widespread adoption. By integrating information, two-way, cyber-secure communication technologies, and computational intelligence across electricity generation, transmission, substations, distribution, and consumption, the Smart Grid can be made clean, safe, secure, reliable, resilient, efficient, and sustainable. This concept encompasses the whole breadth of the energy system, from the first stages of energy production to the last stages of energy consumption. It should be clear to the reader that many proposed definitions are subsets of this system-of-systems definition; for instance, if defined as smart metering, it addresses the consumption and to some extent the distribution part of this definition, but not the full spectrum of integration required to implement the Smart Grid.

Achieving a fully functional smart grid will be a long-term endeavor that will take years or perhaps decades. To be considered a Smart Grid, it is not required that all features be implemented simultaneously, nor is it even practical to do so. Justifying the costs and ensuring a decent return on investments is essential for both. Each new component, however, will be able to "Plugand-Play" into the Smart Grid thanks to the interoperability of open systems after the technologies have been tested.

Simulation & Results





Voltage generators, interphase voltage, phase angle in the first phase, and a 50 Hz voltage frequency to simulate the standard grid. The Series RLC Loads in this case are 11kV light industrial loads that consume electricity from the grid. They may be described in terms of the load characteristics, the nominal voltage and frequency (50Hz), the amount of active power consumed, the amount of inductive reactive power, and the amount of capacitive reactive power.

The Linear Transformer transforms the 11kV of incoming electricity into the safer 230V of secondary substations. The voltage, resistance, and inductance of each winding, as well as the magnetization resistance and inductance of the whole block, are all parameters of a transformer.

When referring to households that use power from the grid, the word "loads" is often used. These Loads include numerous parameters, such as a starting current amplitude, phase, and frequency (all set to 50Hz), a voltage phase, an internal resistance, and a load profile built from historical data [6]. This section will also cover the hierarchical structure of component objects that make up each Load agent.

Figure below depicts a similar circuit created for simulating domestic loads like those seen in typical houses. Connectors 1 and 2 link this Norton's theorem-based circuit to the rest of the microgrid (see Figure). The theorem shown by Thevenin's theorem is the inverse of the theorem that states "any linear electrical system consisting only of voltage sources, current sources, and resistances can be represented by an equivalent current source connected in parallel with an equivalent resistance at its terminals."

That which is acquired at the network's terminals when these are shorted out is this "equivalent current." As a corollary, "equivalent resistance is [given by] the resistance obtained at the system's terminals with all its voltage sources short circuited and all its current sources open circuited." Norton's equivalent circuit may be used to model any system with linear sources and impedances, since this theory is valid for all frequencies. The micro-grid simulation model's ac source was modeled using a Simulink Controlled Current Source block. The default settings for this CCS are a 50Hz operating frequency, 0 amplitude, and 0 phase angle. Additionally, the parallel resistance of 106 was selected. At this level, the impact of a further increase in resistance on the current in the related circuit is negligible.

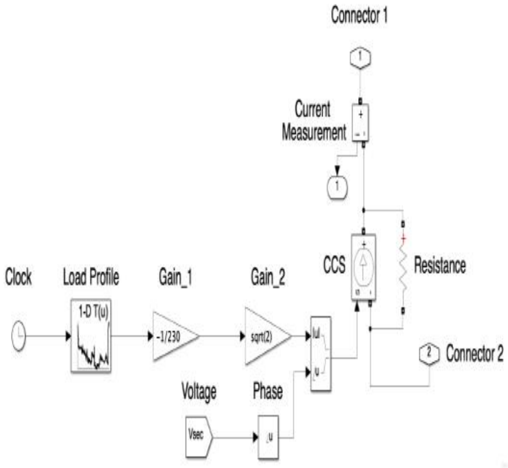


Figure: Simulink block diagram of the domestic load subsystem.

Solar Panel

A replica of the solar panels was made using a circuit that was similar to that used for typical home appliances.

Block schematic of the solar array subsystem in Simulink

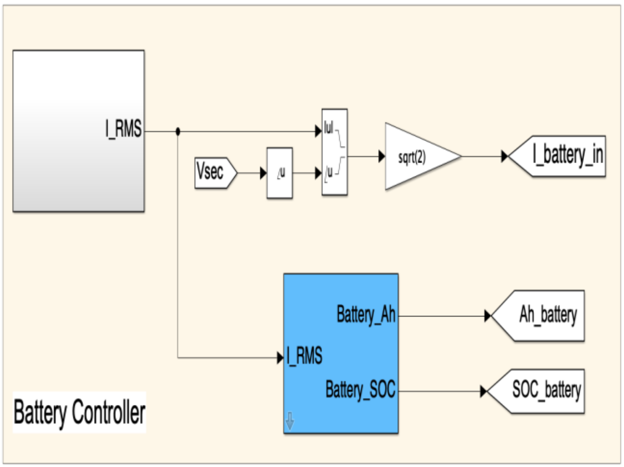
In comparison to the load subsystem, there are three major differences. To begin, a Simulink theoretical PV power profile is used as input data instead of the load profile from the household's demand. Second, converting the power data into an RMS current value yields a positive gain since power is being provided to the micro-grid rather than withdrawn from it.

Since this model represents a generator producing power in a single direction (to the micro-grid), the CCS is grounded rather than in parallel with the other micro-grid agents.

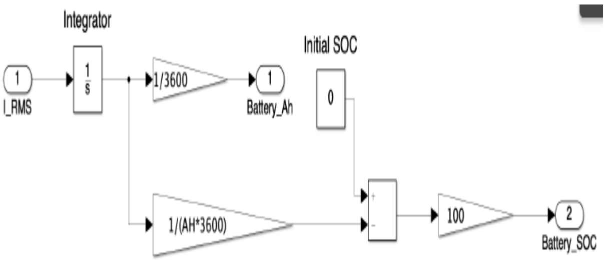
Energy Supply and Control System

The battery subsystem was modelled using a similar circuit topology, again based on Norton's theory. The circuit's block diagram is shown in Figure B.1 of Appendix B. Frequency was set to 50 hertz, and amplitude was set to zero, for the AC type CCS used in the PV model and the loads. The value of the parallel resistance to the CCS was also set at 106.

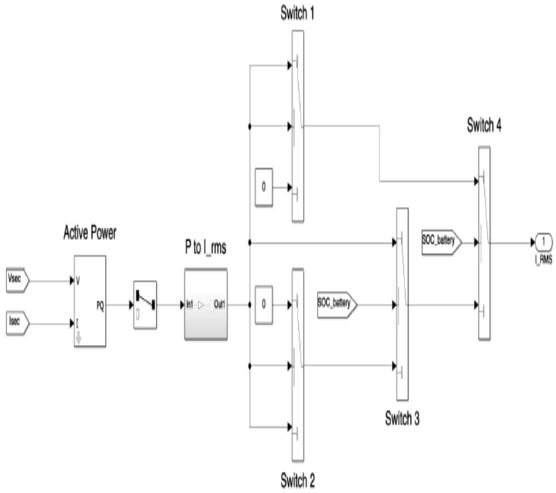
The input current phasor provided to the CCS was determined using the output of the generic battery controller shown in Figure. To get here, we had to first convert the peak voltage and current of the secondary system into an active power figure. The Active & Reactive Power construction component in Simulink was utilized for this purpose. In the same way as previously, Equation was used to convert the active power to the RMS current value. It is now possible to replicate the maximum and minimum charge and discharge currents that may be applied to a battery by adjusting the maximum and minimum values of this RMS current. Using a series of switches, the RMS current was redirected to change the battery's operational State Of Charge interval. This RMS current value was then integrated using a Simulink integrator block (Figure) to get the instantaneous SOC of the battery.



(a) First layer of the battery controller subsystem.



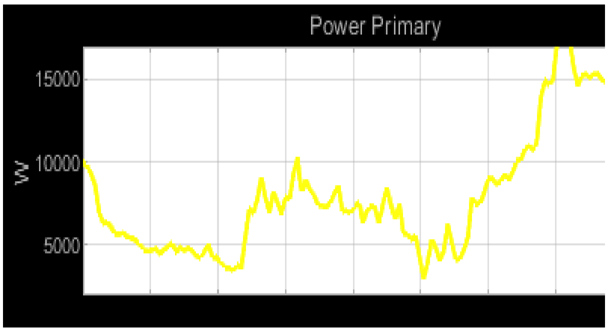
(b) Capacity and SOC battery controller subsystem

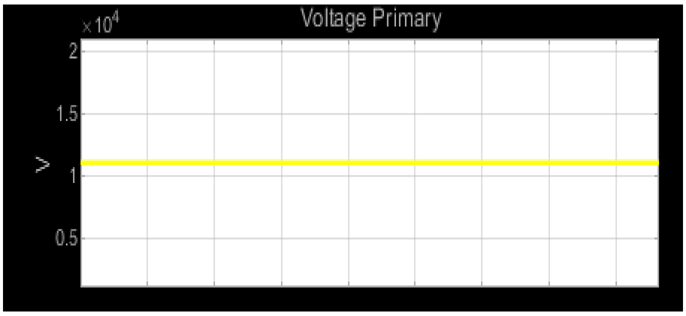


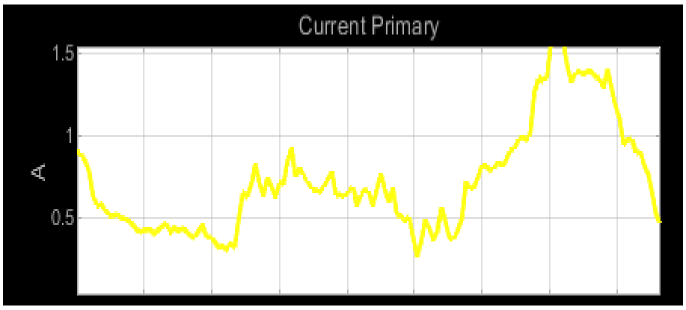
(c) Charge and discharge current battery controller subsystem

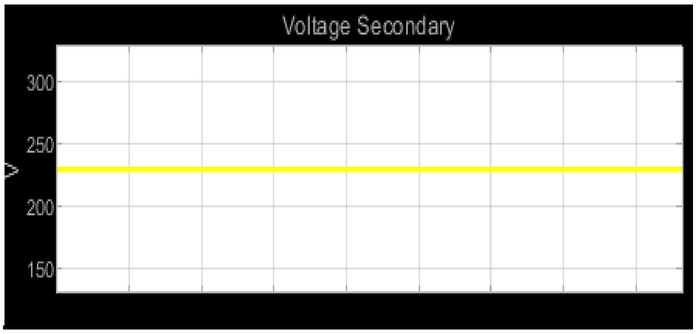
Figure 4.4: Simulink block diagrams of the subsystems constituting the battery controller

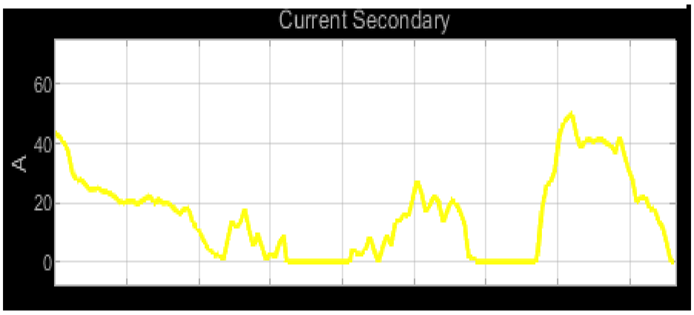
Results & Measurements

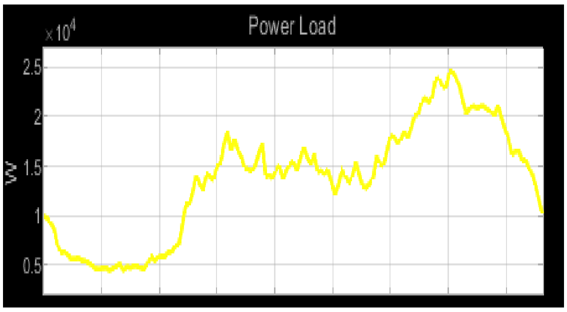


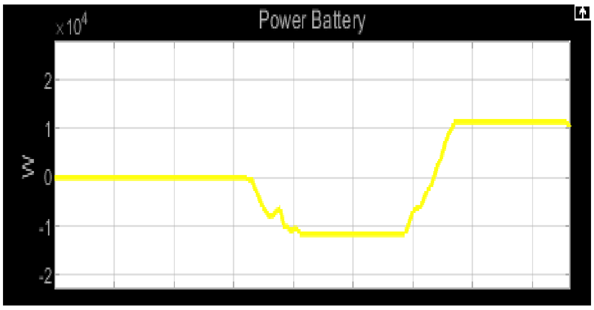


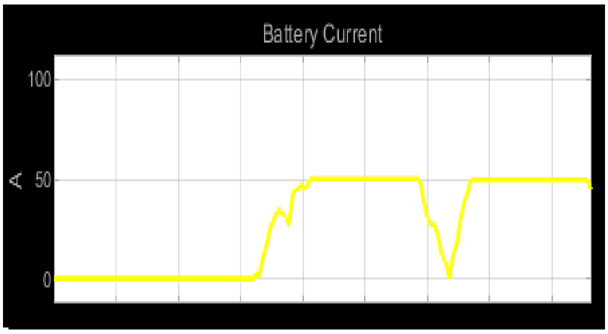


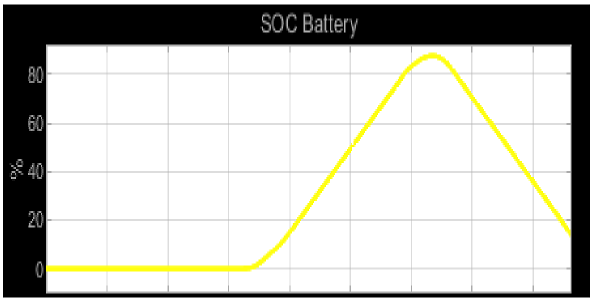


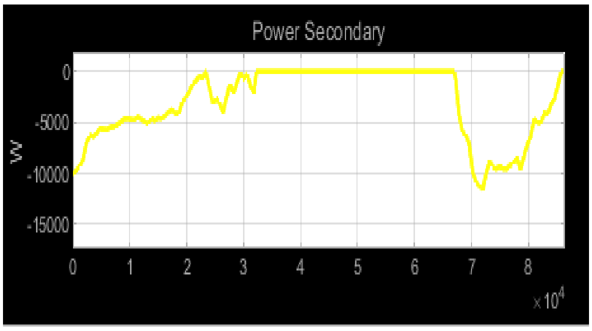


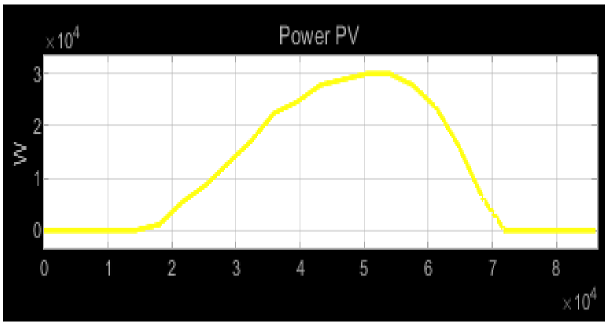


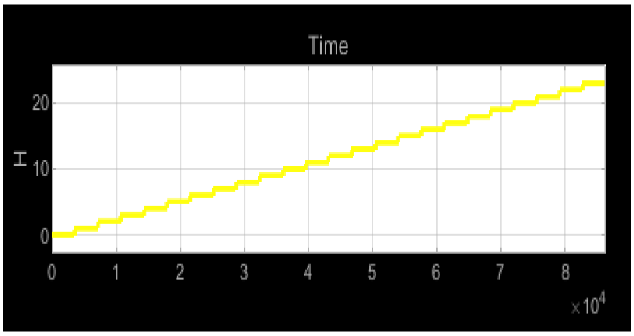












This data and energy management system for the Smart Grid must be adaptive and stochastic by definition, so that it can optimize supply to meet demand within economic constraints to reduce costs for consumers, regulators, and industry stockholders regardless of weather, crew status, or equipment performance. Decision support and portfolio management instruments, activity based accounting, and preventative maintenance programs are just a few examples of the kinds of advanced, computational command and control systems employed by certain utilities today.

But often the computational systems used in these controller computations are decision systems based on policy and regulations. Linear programming methods are used to take risk and volatility into account. While these systems excel at anticipating the "next worst" scenario that might affect the electric grid, they are less effective at figuring out what needs to be done to avert the "next most likely" scenario. The novel complications of the Smart Grid provide the Operational

Research engineer and operator with a multi-stage, time-variable, stochastic optimization issue. Importing Approximate Dynamic Programming (ADP) and Mixed-Integer, Nonlinear Programming solvers from the petrochemical and transportation sectors is necessary for the Adaptive Stochastic Controller (ASC) for the Smart Grid.

We have assessed savings after adopting such autonomous, adaptive controllers in these other sectors, and these might be replicated in the electrical sector if the import of these intelligent controllers is effective. Optimizing the electric system model used by engineers to plan upgrades to the grid today, ADP Adaptive Stochastic Control uses ADP to solve the Hamilton-Jacobi-Bellman problem. Just as models are employed in Model Predictive Control (MPC) in other fields, feedback loops and a critic function are essential in this context to demonstrate causation. Over time, the number of critical Smart Grid outages should decrease thanks to the ADP Adaptive Stochastic Controller's real-time feedback loops for Machine Learning Systems that provide simultaneous Load & Source Control and Dynamic Treatment Optimization.

Conclusion

This study proposes a comprehensive literature assessment of the present electrical environment in the UK, highlighting the primary constraints of the existing network.

A unidirectional and vertically integrated grid was shown. Due to the need for a substantial high voltage transmission network, energy transportation losses of up to 9.1% [48] of total produced power are incurred by this structure based on huge power plants with no optimal geographical placing.

This research has also shed light on the many smart grid projects that have sprung up in response to the introduction of Smart Meters. Electrification, decentralization, and digitalization were identified as the three trends in this changing energy environment that, when combined, would allow for a speedy transition to a Smart Grid. From Demand Side Response to decentralized energy resources, several different solutions now available or on the horizon were investigated. They were cited as examples of how innovative business models may be created thanks to the emergence of new income streams from the exponentially growing number of market players. Locational DUoS from Piclo is seen as the most promising of these new incentive plans. This report also uncovered the unifying goal shared by all these initiatives: improving grid efficiency to cut down on losses and expenses for consumers. However, this in-depth study also found that metering data privacy and, more critically, a lack of information about energy storage in a smart micro-grid setting were the major difficulties opposing the widespread adoption of SG projects.

This work aimed to demonstrate the design and implementation of a resilient, adaptable, and scalable smart micro-grid model as the foundation for the creation of a future program evaluating the Return On Investment of SG projects. To accomplish this, similar circuit models were used to simulate the micro-generators, energy storage devices, and loads found in a typical electrical distribution system. After being shown analytically sound, this model helped shed light on the previously unknown non-linear behavior of batteries inside a smart micro-grid.

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