THE ROLE OF RENEWABLE ENERGY SOURCES ON THE SMART GRID AND MICROGRID

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Abstract

As technology continues to evolve and society grows, the need for greater access to energy as well as the demand has increased. Energy demand and the need to maintain and protect the environment have fostered innovations such as the Smart Grid and Renewable Energy Systems. The advent of the internet, smart meters and remote communications devices has allowed for the advancement of Smart-Grid & Micro-Grid Systems. Renewable energy sources are presented in this paper. Photovoltaic power generators and Wind turbine generators and hydroelectric pump storage systems are presented and their deployment to provide fast and efficient and reliable energy is discussed. The necessity of employing computer energy management architecture is also presented. These components working in tandem are necessary for the success and future of smart grid and microgrid systems. Although the cost and labor necessary to transition traditional grid systems may be high initially, the role renewable sources play in sustainable, efficient and reliable energy management will be of greater benefit following deployment.

Introduction

With the evolution of technology and the growing demand for energy; it is a necessity to have access to fast, efficient, and reliable power. Taking into consideration the current state of our world; additional considerations for grid systems such as cost effectiveness and environmental impact are a must. Smart grid and microgrid systems are the culmination of these modern considerations for power management. These grid systems utilize Internet based functionality to effectively monitor, maintain, and control the grid infrastructure both locally and remotely. Renewable energy plays an important role in the growth of these grids by offering clean and accessible energy.

Renewable Energy Systems

Renewable energy sources include energy that can be collected from renewable resources that are replenished naturally over a period of time. These resources typically include; wind, sunlight, rain, waves, geothermal and biomass. These resources are utilized in the form of wind power, solar energy, hydroelectric power, thermal energy from beneath the Earth’s surface and organic materials that are converted to energies such as ethanol or wood.

Smart Grid Infrastructure

Renewable resources are key components in the success of Smart Grid energy systems. A smart grid energy system is a power grid that utilizes the Internet, real time communication, sensors and renewable sources [1]. Many smart grids are looking to replace or integrate into existing grid systems to...
provide a cleaner, more efficient and reliable energy distribution. The integration of renewable resources as energy generation for a power grid, is a major part of the initiative for environmentally friendly energy production. By utilizing renewable resources, it will reduce the amount of nonrenewable resources that must be used which will directly reduce the amount of pollution produced through the use of those materials. Smart grids also provide a more reliable system with its Internet based architecture. With the grid utilizing the Internet along with sensors and SCADA; smart grids allow for instantaneous fault detection, self-healing, remote maintenance, and real time communications.

**Photovoltaic**

This paper will look into three renewable energy sources. One of the prominent methods of generation for smart grids and distributed generation systems are solar panels or photovoltaic cells [2]. These cells collect solar energy from sunlight and then convert it to useful electrical energy. Photovoltaic cells utilize the photovoltaic effect, which describes the interaction of photons produced by the sun and the semiconductor material that the cells are constructed from. Solar panel architecture includes conducting material along the outer edge and back of the semiconductor material that collects the generated electricity. Recent advances in solar panel technology have led to lower cost and the application of systems directly to consumer loads.

**Wind Turbines**

Another of the renewable energy systems that have grown recently are wind turbines. Wind turbines utilize Earth’s natural production of wind to generate electricity. As the wind blows, it rotates the propellers of the turbine, which spins the turbine rotor, driving the generator and then producing electricity. The speed of the wind and the pitch angle of the turbine propellers contribute to the amount of electrical power generated. Wind turbines produce clean energy, though they have a large footprint. Besides having large components, wind turbines are typically found in a large collections occupying a significant area that has a steady flow of wind.

**Hydroelectric Pump Storage**

The next renewable energy system is hydroelectric pump storage. Hydroelectric energy systems generate electricity by the act of flowing water and can also provide energy storage. They are connected to a natural body of water or are integrated within a body of water system. A dam is constructed between two reservoirs of water at differing elevations, as water passes through the dam energy is produced. The more water that passes through the dam turbines, the more energy that can be produced. Despite the clean aspects of hydroelectric power; dams can disrupt the ecosystems that exist within established bodies of water.

**Energy Management**

Within smart grid systems; there must be architecture installed to help manage and control the integration of these renewable resources and grid technology, and that is known as Energy Management. The energy management architecture consist of computer aided tools that can be used by operators to maintain an efficient balance between energy supply and demand [3]. This system monitors, controls and optimizes energy generation and transmission through the collection of data which aids in reliability and efficiency. The energy management architecture utilizes systems such as
programmable logic controllers and supervisory control and data acquisition to promote ease of use, remote communication and overall maintenance.

**Supervisory Control and Data Acquisition**

Smart Grid architecture utilizes Supervisory Control and Data Acquisition (SCADA) to perform grid monitoring and control through the collaboration of both software and hardware elements. Fundamentally, SCADA architecture is comprised of Remote Terminal Units (RTUs) and Programmable Logic Controllers (PLCs) that connect to devices within the grid, end terminals, and ultimately the SCADA software [4]. This allows smart grid operators to control system processes on site or remotely, monitor and process data in real time, interact with system devices such as motors, sensors and human-machine interface devices, make informed and operation critical decisions, and to keep detailed records of system operations. Overall, SCADA systems can be critical to grid communications, data processing, and fault reporting which help to maintain efficiency and minimize downtime.

**Smart Grid**

This paper will explore the reliability of renewable energy systems. The interconnection of photovoltaic cells, hydroelectric pump storage and wind turbines that make up a smart grid system which is managed by an energy management architecture. Reliability is the expectation of continuous performance and equality [5]. In this case, the ability for an energy system to produce, maintain, and distribute uninterrupted energy speaks to its reliability. Reliability can be evaluated individually at three levels independently or collectively; generation, transmission and distribution. It can be reinforced through redundancy, which then translates to minimal system downtime or disconnection from the desired load [6].

**Photovoltaic Investigation**

First, solar power generation is evaluated. The experiment is performed with a lamp used to emulate solar energy, a solar panel to collect the light and generate electricity, and the inverter used to invert energy that is to be applied to grid. The efficiency of the inverter was simulated using the solar cell and varying values of irradiance. The irradiance can be varied be either adjusting the brightness of the lamp or by using a slider function digitally. COS127-1S is the three-phase power quality meter used to measure the power at the inverter output ($P_{AC}$) and the Solar Panel Emulator measures the active power generated from the panels at the inverter input ($P_{DC}$). It can be seen from the data in table 1; that as the irradiance increases in intensity, the efficiency of the inverter becomes greater. So one can infer that a greater percentage of irradiance minus shading leads to more efficient operation of the inverter. This also means that the lower the irradiance, the lower the power that can be fed to the grid.
Table 1: Solar Station Table Power Generated per % of Solar Irradiance

<table>
<thead>
<tr>
<th>IRRADIANCE in %</th>
<th>COS127-1S</th>
<th>Solar Panel Emulator</th>
<th>Efficiency ( \eta = \frac{P_{AC}}{P_{DC}} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>37</td>
<td>71</td>
<td>0.52</td>
</tr>
<tr>
<td>10</td>
<td>110</td>
<td>143</td>
<td>0.77</td>
</tr>
<tr>
<td>20</td>
<td>256</td>
<td>288</td>
<td>0.89</td>
</tr>
<tr>
<td>50</td>
<td>686</td>
<td>719</td>
<td>0.95</td>
</tr>
<tr>
<td>100</td>
<td>1395</td>
<td>1440</td>
<td>0.97</td>
</tr>
</tbody>
</table>

The chart below is a line graph illustration of the relationship between the AC power and the efficiency. It can be seen that the efficiency percentage increases as the AC power increases, although it seems to trend towards a plateau of 97% efficiency once the AC power is greater than 1300 W. The losses experienced at the inverter remain approximately constant as the irradiance increases. Table 1 indicates that as the percentage of irradiance increases, the power being generated increases, which also causes the power being inverted to increase; and based on the graph in figure 1, as our \( P_{AC} \) increases, the conversion efficiency increases.

Figure 1: PV Station Inverter Chart AC Power v. Efficiency
The shading of a solar panel array is simulated here and it is observed how shading affects the energy produced at different irradiance levels. Figure 2 shows a solar array that is experiencing maximum irradiance at 100% with 80% shadowing. A slight difference between the power measurement on the inverter and that on the software can be observed and assumed it is created due to the losses in the system. As shown in Figure 2, the blue line on the graph represents the power for the solar system per the variances in the irradiance and shading; and the purple line is the Maximum Power Point tracking (MPP), which tracks the maximum power while considering loses to auxiliary components. It can be seen from the graph that as solar modules are cast in shadows, it affects the current and power. As modules are shaded; the maximum power point is altered which leads to a drop in the inverters power and direct voltage.

**Wind Turbine Investigation**

The next experiment is the Wind Power Plant. The wind power plant station utilizes a motor, motor control system, power measurement unit, power switch, transformers, a wind turbine synchronization unit and computer aided software.

The wind power plant station simulates the generation of power produced by a wind turbine that experiences various wind speeds [7]. It is observed that as the wind intensity reaches a certain level, the generators idle speed rises linearly with the wind speed. When the system is operating at full load, the pitch controller regulates the speed to maintain the generator power at the rated level. As the speed changes, the generator frequency, phase angle and voltage are regulated to achieve...
synchronization. The below graph shows the generator voltage when it is not synched. Then the next image is when the system becomes fully synched with the generator.

Figure 3: Wind Power Plant Unsynchronized to Grid
Hydroelectric Investigation

The next experiment is the Pump Storage Power Plant. The pump storage power plant is used to simulate power generation by the flow of water through a hydroelectric turbine. The more water that flows through the turbine the more power that can be produced. The hydroelectric dam is stationed between two water reservoirs that are at two different elevations; this promotes the positive flow of water. The pump storage experiment station controls a motor, a motor control, a synchronization unit, power switch, transmission lines, variable impedance, power meter and computer aided software.

A major drawback to the use of hydroelectric energy in a smart grid system is availability. Hydroelectric dams aren’t rapidly deployable and typically must be within a reasonable proximity to the grid system.

Energy Management Investigation

Another experiment station is the Energy Management System. The energy management experiment station contains an external voltage source, a motor, motor control, variable resistive load, capacitive load, inductive load, power meter, power switch, delta/wye switch unit, and computer aided software. This station is utilized to mimic a controlled load and management system for the grid.

The energy management experiment station can be configured to simulate a balanced load; resistive/capacitive, resistive/inductive, and resistive/capacitive/inductive. The connection for the resistive/capacitive load can be seen below and the measurements through that RC load are simulated. Each of the configurations for the balanced load can be seen in the images below along with their simulated measurements. The resistive/capacitive load, the resistive/inductive load and the
resistive/inductive/capacitive load. These different configurations are key due to the fact that there are a number of configurations that can be utilized in actual grid infrastructure.

**Smart Grid/ Microgrid**

The final experiment is one that interconnects the other stations to the Smart Grid. The smart grid experiment is where the transmission lines form the other experiment stations interconnect. This station connects all of the systems, monitors the grid and measures the energy values through the SCADA computer software.

![Smart Grid Diagram](image)

**Figure 5: Smart Grid Diagram**

**Cost**

As part of the investigation into the efficiency, reliability and overall effect renewable energy has on smart grid systems; the cost analysis is evaluated. Cost is an important factor in determining viability of a grid system in a specific locale. The cost of a microgrid varies depending on the size of the grid system and the application. Some microgrids require higher initial cost, while others require greater engineering cost throughout the process of the grid installation. The below date is an illustration of cost from a 2018 study for microgrid development for specific applications.

<table>
<thead>
<tr>
<th>Segment</th>
<th>IQR</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Campus/Institutional</td>
<td>$4,936,109–$2,472,849</td>
<td>$3,338,666</td>
</tr>
<tr>
<td>Commercial/Industrial</td>
<td>$5,353,825–$3,399,162</td>
<td>$4,079,428</td>
</tr>
<tr>
<td>Community</td>
<td>$3,334,788–$1,430,805</td>
<td>$2,119,908</td>
</tr>
<tr>
<td>Utility</td>
<td>$3,219,804–$2,323,800</td>
<td>$2,548,080</td>
</tr>
</tbody>
</table>

Table 2: Data Table for Cost Associated with Grids [8]

It can be concluded that the community microgrid application has the lowest mean cost, while the commercial/industrial grid has the highest mean cost. A campus or community grid configuration

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would be the ideal application to investigate with the experiment setup at hand. Conventional generation accounts for roughly 76% of campus grids and 54% of community grids. Then energy storage contributes to 15% of the community grid total cost.

![Figure 6: Chart of Total Microgrid Cost v. Microgrid Generation Capacity](8)

Another important factor into the total cost of a microgrid system is the cost associated with the controller. The cost per megawatt for a microgrid controller ranges from $6,200/MW to $470,000/MW and the mean cost is estimated to be $155,000/MW. Research shows that the controller cost as a percentage of the total cost generally decreases as the microgrid grows in size. Cost also come in the form of adding additional infrastructure, which has been shown to be highest in the community and utility markets.

**Conclusion**

Smart grid and microgrid systems present an architecture for the rapid deployment of energy that utilizes renewable energy sources. The operation of these grid systems with renewable energy sources offer clean energy production that is replenished naturally. The smart grid infrastructure can allow for reliable energy to be produced and distributed within strained regions. This is made possible through energy management software, SCADA and Internet of Things grid components, which decrease the need for physical/in person maintenance. Although Smart grids and microgrids have many benefits to their deployment including remote operation, there are considerations that must be made. This includes the conversion of exiting grid systems or the introduction of new grid infrastructure, which can be an expensive and extensive project to undertake. From the investigations, it is suggested that the most effective approach to the implementation of smart grids and microgrids is at a localized/community level. The localized grid approach is best to serve an intended community and to manage cost over time; it will also minimize the strain on renewable resources and reduce the carbon footprint.
References


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