Energy Storage System in Smart Homes of Smart City

S. P. Jolhe, G. A. Dhomane, M. D. Karalkar

Abstract: The Nanogrid utilizes renewable energy sources, e.g. Solar-PV, Wind, etc.; which are stochastic in nature. Due to this nature, power reliability is the main issue. To increase the reliability of the power supply and proper utilization of the available resources, Nanogrid should either connected to the utility grid directly or it must have the proper energy storage system. Energy storage system fills the gap between consumers demand and renewable power generation; which is very important issue in technical and economical consideration. The Nanogrid gives new hope of ray to the people living in off grid areas. By using energy storage system we can increase their living standard and enhance socio-economic development. This paper proposes the selection of the proper energy storage device and its calculation, control strategy also suggested for protecting storage device from over voltage and deep discharge.

Index Terms: Energy storage devices, Nanogrid/ Microgrid, renewable energy sources, stability and analysis.

I. INTRODUCTION

Nanogrids are becoming more famous now a days due to many reasons. These use, combination of the different distributed generation units such as solar PV cell, wind, biogas, biomass, fuel cells and energy storage system [1-5]. Nanogrid is more famous in rural areas, as it uses the available resources for the generation of the electricity. Due to government policies of the “solar roof top system” and power to each home [6], Nanogrid is best option for individual home or small system even in the urban areas [7-8]. Its operation is also flexible; it can operate in grid connected mode or in islanding mode [9-10]. It can operate on different frequencies, other than conventional or on DC supply [11]. The best part of the Nanogrid is that it can be operated in the combination with other Nanogrid to form a microgrid [12]. Nanogrid is small part of the microgrid or microgrid is formed with the combination of many Nanogrids. The difference in the microgrid and Nanogrid is their operating power level. The Nanogrid is up to 10kW and microgrid is from 1 MW to 100 MW. As the Nanogrid uses renewable energy sources which are stochastic in nature, power reliability is the main issue. When generation unit is generating power it should be used at that time only, but this is not possible every time. To increase the reliability of the power supply and proper utilisation of the available resources either Nanogrid should connect to the grid directly or it must have the proper storage system. The modern power electronics plays an important role in the proper utilisation and protection of these stochastic renewable energy sources [13].

India is world’s third largest electrical energy production country with generation capacity of 350.162 GW [14]. Although so huge generation of electric power, still power companies are not able to fulfill the requirements of the consumers. Fig 1 shows the electric power supply crush in India, which clearly indicates that the power is short. "Power for All", scheme is launched by Government of India for supplying electric power to all the people in the country by March 2019 [6]. With this scheme India will find the unexplored electrical power available in the country. One of the ways is solar roof top scheme for Solar Home System (SHS) and small commercial buildings or industries [15-16].
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Fig 2 shows the efficiencies of the different material solar PV panel modules. The efficiency of the panel is an important issue in number of panel required for the particular load or home and hence other factors like space required, installation material, and maintenance and hence cost.

The most important part of the Nanogrid / Microgrid is Energy Storage System. Electrical energy produced by renewable energy sources cannot be directly feed to the load. The energy storage device acts as a mediator in between renewable energy sources like solar, wind etc. and the load to be supplied. This aspect is very important in consideration of technical and economical issues. For charging, discharging and control of energy storage devices, power electronics plays an important role. With the help of power electronics devices energy storage system are capable of reducing the fluctuations due to load, peak power cut off and also in making the renewable energy sources an efficient energy system.

Following are the options
1. DC power supply
   a) High voltage DC (HVDC)
   b) Low Voltage DC (LVDC)
2. AC Power supply
   a) 16 2/3 Hz
   b) 50 Hz
   c) 400-500Hz
   d) 20 KHz

Conventional residential loads are designed to work on AC voltage. For the particular electronics load the conversion is made from AC to DC. Due to inherent losses in conversion system the conversion is not hundred percent. So one step DC and AC converter (Switching Boost Inverter) is used in this paper.

C. Energy Storage System

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Following are the storage options
- Battery
- Super capacitor
- Super Conducting magnetic energy storage (SMES)

I. Batteries

The most common and readily available choice of the electrical storage system is battery. Many factors are affecting the selecting suitable battery. The selection of the specific battery for the specific application is mainly depends on physical properties, while other decisions will be much more difficult and may involve making trade-offs between desirable and undesirable battery features.

In battery subsystem design, many considerations are included like:
- How many batteries should be connected in series/parallel?
- What should be over-current setting?
- Setting requirement in overcharging or under drained.
- What should be disconnecting requirements?
- Selection of the proper wire sizes and types.

Depending upon the requirements of the system the energy output from the renewable energy sources is stored in a battery or in a battery bank [17]. The primary functions of the battery in an integrated power system are

i. Storage: When PV array is producing electrical energy, it should be stored
ii. Supply energy on demand: Whenever needed by the consumer the electrical energy should be available to electrical loads
iii. Quality of supply: Stable voltages and currents should be supplied to electrical loads, by suppressing or

![Fig. 3. Nanogrid System](image)

B. Controller

Renewable generation is normally stochastic in nature, so as to get proper electrical supply controller is needed. Due to revolutionary changes in the power electronics, many options are open for the output of system i.e. it can operate on the different frequency or on DC grid system [11].

TABLE I. SOLAR PANEL MATERIAL AND EFFICIENCY

<table>
<thead>
<tr>
<th>Solar Cell Type</th>
<th>Advantages</th>
<th>Disadvantages</th>
<th>Efficiency -Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thin-Film: Amorphous Silicon (A-Si)</td>
<td>Production is Simple &amp; Flexible; costs is relatively low</td>
<td>Small lifespan &amp; Warranties</td>
<td>~7-10%</td>
</tr>
<tr>
<td>Poly-crystalline (p-Si)</td>
<td>Price is low</td>
<td>Small lifespan; Sensitive to high temperatures &amp; slightly less space efficiency</td>
<td>~15%</td>
</tr>
<tr>
<td>Mono-crystalline (Mono-Si)</td>
<td>Efficiency is high; life-time value is high optimised for commercial use</td>
<td>Expensive</td>
<td>~20%</td>
</tr>
<tr>
<td>Concentrated PV Cell (CVP)</td>
<td>Very high efficiency &amp; performance</td>
<td>Solar tracker &amp; Cooling system needed (to reach high efficiency rate)</td>
<td>~41%</td>
</tr>
</tbody>
</table>

The efficiency of the solar panel varies from 7% to 41%. As the efficiency increases cost also increases exponentially. So while selecting the panel one has to optimize between cost and efficiency.
‘smoothing out’ transients.

iv. Supply high peak operating currents: If needed by electrical loads or appliances, battery should provide the high peak operating currents or surge.

**Calculation of the battery**

For calculating the size of the battery or battery bank for the Nanogrid/ microgrid application, load on the grid should be calculated first. Following Table II shows different loads in particular Nanogrid.

**TABLE II. DAILY LOAD CONSUMPTION**

<table>
<thead>
<tr>
<th>S N</th>
<th>Appliance</th>
<th>Unit</th>
<th>Wattage</th>
<th>Usage (h/d)</th>
<th>Demand (Wh/d)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>CFL light</td>
<td>6</td>
<td>7</td>
<td>4</td>
<td>168</td>
</tr>
<tr>
<td>2</td>
<td>TV</td>
<td>1</td>
<td>100</td>
<td>3</td>
<td>300</td>
</tr>
<tr>
<td>3</td>
<td>Mobile charger</td>
<td>1</td>
<td>3</td>
<td>4</td>
<td>12</td>
</tr>
<tr>
<td>4</td>
<td>Mini Freezer</td>
<td>1</td>
<td>27.4</td>
<td>24</td>
<td>658</td>
</tr>
<tr>
<td>5</td>
<td>Laptop</td>
<td>1</td>
<td>65</td>
<td>2</td>
<td>130</td>
</tr>
<tr>
<td>6</td>
<td>Water pump</td>
<td>1</td>
<td>1000</td>
<td>0.5</td>
<td>500</td>
</tr>
<tr>
<td>7</td>
<td>Mixture</td>
<td>1</td>
<td>500</td>
<td>0.5</td>
<td>250</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td></td>
<td></td>
<td></td>
<td>2,018</td>
</tr>
</tbody>
</table>

The next is the choice for storage that how many days backup or storage capacity required? It depends upon consumer to consumer. Generally 2 or 3 days back up is taken. Let for our case take 3 days backup.

2018 *3 = 6, 054 watt-hour
So 6, 054 watt-hour/24 volts = 252.25 Ampere hours (Ah) (battery bank used voltage 24V; Ampere hours is to be reduced to half if 48 voltage is used).

Discharge of battery also plays an important role in calculation.

Assuming 50% discharge of battery so 252.25 *2 = 504.5 Ah capacity of battery bank is required.

2. **Super capacitor**

The super capacitor is basically developed for the military application. In recent days, it is used commercially (e.g. Power quality, laptops and cell phones etc.). The best thing of the super capacitor is; it requires very small space. Compared to metallic foil type capacitor, super capacitors have 1000 times smaller dimensions. So it has higher energy density as compared to common capacitors and batteries. Like usual capacitor, Super capacitor also uses two layer plates. Therefore, like most capacitors, this storage system also ideally suited for high power application and has very long cyclic life and, short-discharge applications. The storage capacity of any capacitor is proportional to the square of its voltage.

Like the battery cell, recently super capacitors are also operating in 2 V range. Thus cells are connected in faction of series, parallel or series-parallel combination to form module. The voltage of this module is restricted to 200 to 400 volts due to reliability issue. Super capacitors are commercially available having range of 100kW and discharge time of less than 1 to 10 seconds. The research is going on for the high voltage utility applications of super capacitor [18-19].

**Calculation of the super capacitor battery**

Let’s take an example:
6 capacitor are connected in series
Each capacitor is of 220F and 2.3V

Total capacitance and voltage = 37F and 13.8V
Energy stored at 13.8 V is 3485 Joules \( (E = 0.5CV^2) \) & 0.968Wh
Therefore each capacitor stores 162 mWh with 2.3 V

3. **Super conducting magnetic energy storage (SMES)**

Generally electrical energy is stored in other forms of energy such as chemical, mechanical, etc. The only technology which can store electrical energy in the form of electrical energy is known as super conducting magnetic energy storage (SMES). In this technology electrical energy is stored in the form of direct electrical current.

![Fig. 4. Super conducting magnetic energy storage (SMES)](image)

This system consists of basic three parts:
1) Superconducting magnetic coil
2) Power conditioning equipments
3) Refrigeration system

The principle of storing electrical energy in SMES is in the form of an electromagnetic field which is produced by DC electric current flowing through a superconducting coil. Under ordinary conditions losses result from the resistance of the wire, and energy must be supplied continuously to maintain the current. But if the wire/ coil were made up of superconducting material and kept at the required low temperature, resistance losses would be very small. Electrical energy supplied as direct current to the coil would then be stored in the electromagnetic field. By attaching this coil to the load the stored energy could be recovered as electrical energy. This system has high efficiency up to 98% when operated with 17ms.

- Coil Diameter 1000m – 1000MW for 5Hrs
- Coil Diameter 1 m – 1MW for 1 second

The major problem with this storing system is the environmental issues and high initial cost [19-20].

### III. OPERATION

Fig 5 shows all powers of the system – input solar power, AC and DC load and charging and discharging of the battery. The solar power depends on the radiation available at that time. Radiation curve is taken as trapezoidal. Same
curve will be followed by the solar PV cell for generation.

The system will operate with three different modes

1. \( P_G > P_L \)
2. \( P_G < P_L \)
3. \( P_G + P_B < P_L \)

Where

\( P_G \) – Power generated by Renewable Energy sources
\( P_L \) – Power taken by the load
\( P_B \) – Power of battery

**Mode 1: \( P_G > P_L \)**

In this mode power generation unit generate the more power than the requirement of the load. In this paper solar generation is taken; the power will increase up \( P_G > P_L + P_{B \text{(Charging)}} \). Once it reaches \( P_G = P_L + P_{B \text{(Charging)}} \), solar PV generation enters in constant power generation and variation in \( P_B \) will be there. Battery is initially get charged from the solar PV generation available in the low load duration. In the Fig. 5, battery is getting maximum power during point A to B, during B to C load increases so battery is still charging but power taken by battery is less than previous section. When battery gets fully charged over voltage protection system will be activated and battery is disconnected from the system.

**Mode 2: \( P_G < P_L \)**

As seen in the above mode 1; solar power generation now enters in the constant power generation mode so now change in the power will be observed. As the load is more than that of generated power, battery will provide only surplus power. In Fig 5, battery starts discharging from point D. As the load increases further it will be supplied by the battery.

**Mode 3: \( P_G + P_B < P_L \)**

This is very important mode. In this mode, power generated by Solar PV cell and battery is insufficient to feed the load. The system has now two options either to operate in the load shading mode (self sufficient) or take the power from the other nanogrid bus/ utility bus (if grid connected system is used). In this condition we are taking power from the other nanogrid bus, which may form Microgrid. The nanogrid system will be connected to the bus through the gateway. In Fig 5, point E to F, solar PV generation is operating in the constant power mode, battery also operates in the constant power mode, the power from the other nanogrid bus is taken for the operation of the system.
IV. CONTROL STRATEGY

As discussed above the control strategy for the protection and proper operation of the battery is designed according to the requirement of the system. The overvoltage and deep-discharge cut off values were calculated and translated from voltage cut-off values to State of Charging (SOC) values. Fig 6 shows complete operation and control strategy for the battery. Initially battery will supplying power as the solar is not yet in generation mode, from point A to B battery is in charging mode and no other load is connected to grid, so all generated power is consumed for battery charging. At point B, over voltage protection is activated and battery get disconnected from the charging. During point B and C, power supplied by the solar PV is dropped down. This power can be utilized to charge other battery in the grid. Literature [21] claims more than 30% of the energy generated was dumped. From point C to D, load is supplied by the solar PV generated power, but as the load increases, power demand increases, so battery is also supplying power. At this time solar PV generation is in constant power generation mode. At point D load is still increased, which is beyond the capacity of the battery plus solar generation, so power is taken from the other Nanogrid.

In this situation there are other options of the load shedding i.e. low priority load should be switched off. At point E battery deep discharge protection is ON and battery gets detached from the grid. All loads will be supplied by the other Nanogrid.

Fig. 7 shows the flow chart for the battery charging, discharging and protection.
V. CONCLUSION

The paper introduces the flexible control strategy for the energy storage device, e.g., battery, for the Nanogrid/microgrid. The over voltage and deep discharge control strategy was designed and developed for the Nanogrid/Microgrid. The system stability is maintained by strategic control of the energy storage device. The effectiveness of the proposed strategy for the control of energy storage device was proved by the simulation results. The power can be exchanged between adjacent Nanogrid to form the microgrid and that to without any extra communication link. Furthermore Nanogrid manages available power in very effective way; it utilizes the Solar PV generated power to its maximum capacity. The Nanogrid with energy storage devices gives new hope of ray to the people living in off grid areas or where the electric power supply by the central utility is poor. It will
increase their living standard and enhance socio-economical development.

If the Nanogrid is operated in the stand alone mode then there is considerable amount of energy available which is not been used, as shown in Fig 6 between point B and C. This energy can be generated and sold to grid, which will enhance the economics of the owner.

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