Managing Blackout in Off-grid Communities through Time Based Energy Allocation Model

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Abstract

In recent years, the smart grid has occupied the area of power and grid management research and indeed a lot of brilliant works have been done. Nevertheless, most of these works have been designed only for the improvement of traditional grids and little or nothing has been designed to address the needs of people living in off grid communities that imbibe the use of stand-alone renewable energy solutions which are not properly managed and results in blackouts more often than it solves the electricity challenges. Our proposed solution is designed to meet with the needs of users whose energy consumer patterns are often time bound. We look into the sub parameters of time and State of Charge (SoC) of batteries to allocate energy resources to devices.
Keywords: Off Grid, Smart Grid, Energy Distribution System, Consumer Patterns, Time Based Energy Allocation Model (TBEAM)

1. Introduction

There has been a dire need to improve the traditional grid about 40 years ago but the limited technology available then served as a hindrance for years until recently when there has been major improvement in the field of information and communication technology as well as home appliances, devices etc. Furthermore, the 1990's witnessed a global out cry about depleting energy sources, environmental disaster, global warming and $C0_2$ emission. All these have resulted in the adoption of cleaner production models in industries, both commercial and industrial energy efficiency and proper waste management. Governments around the world have come together to agree on policies to address the challenges in other to mitigate the drastic effect of global warming. Companies, research and development centers, universities etc. have remained resilient in their unrelenting efforts to seek viable solutions [3][4][5]. A lot of innovative solutions have emerged from their brilliant works; IBM has been doing so much in the smart metering space with its Informix Technologies, Hildebrand has been able to build on IBM's success and design an energy management solution for over 3 Million British homes in a project which was sponsored by the British Government [13].

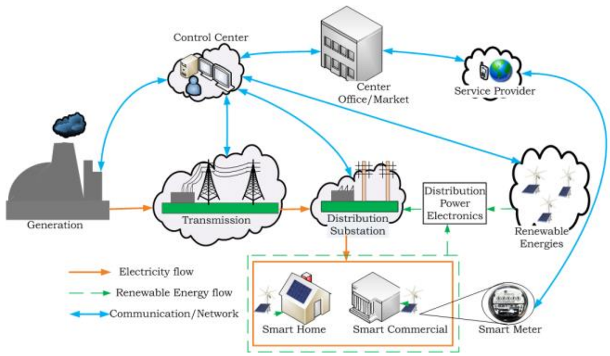

Figure 1 General Smart Grid Architecture

Projects of these kinds have been rolled out in different countries and in different sizes and there is so much that is been derived that today Smart Grid is being characterized as the next big revolution in the technology space as it will make room for interconnectivity across all sectors of society, see figure 1 [8].

2. Smart Grid Pilot Projects

Globally, a lot of pilot projects have been executed to look into the viability, scalability and deployment of various smart grid energy management solutions. Some of these projects are;

1. PG&E proposes six smart grid pilot projects to benefit customers and meet California's energy policy goals. The project involves the input of line sensors and controls to make the utility's electric distribution system more reliable and flexible; new voltage and grid control systems to lower consumer energy costs and enable the integration of customer-owned solar generation into the distribution system; and more local electricity demand forecasting to improve efficiency [22].

2. July 19 2011, New Delhi; The India Smart Grid Task Force (ISGTF) have begun a cutting-edge technological intervention to improve the management of load flows across the country's electricity grid has recommended that eight pilot projects be taken up nationwide and this to be accomplished within 18 months. It has suggested that low cost "smart meters" need to be developed to ensure that 100 percent metering is achieved with distribution companies [23].

3. BPLG and BPL Africa Deploy Smart Grid Solutions in Ghana for Volta River Authority (Ghana's National Utility); BPL has agreed to deploy smart grid technologies and broadband over power line communication technology on the 11kv power distribution network of Volta River Authority (VRA). The solution will include BPLG's Power Smart Grid Network Monitoring and Management, Rapid Fault Location, Demand Management, Non-Technical Loss Management, Substation Automation, Transformer Monitoring and CCTV Security Systems. Broadband Communications solutions include broadband internet access and VoIP telephony. With all these in place VRA is estimated to increase the productivity of their existing electrical network by delivering additional electricity and communications services [24].

The success of the smart grid will make room for well improved energy management and control of devices either within the home or remotely from other locations. It will enable us mitigate energy waste and manage consumer patterns more efficiently[21]. Nevertheless, most of these solutions cater for the need to improve the traditional grid while off grid communities face more challenges given the fact that most times they imbibe the use of renewable energy sources without proper management which results into blackouts.

3. Off Grid Energy Solution

At this point, it is important to look into the parameters that define an off-grid community in other to buttress our argument for a need to address the challenges faced in communities that solely rely on the use of renewable energy sources but often result in blackout due to poor energy management.

The term *off-grid* refers to a home or a community that is not being connected to the national electricity grid and other public utilities. The electricity architecture in off grid communities is usually stand-alone systems (SHS) or micro grids. This form of electrification is used in countries or communities with little or no access to electricity due to technological incapability, poor infrastructure or scattered population. The source of electricity could be wind, solar or hydro power systems.

Off grid communities are self-sufficient; they do not depend on municipal water supply, sewer, natural gas for home heating or similar utility services.

Today, people living in well developed countries and who face little or no challenges with infrastructures also imbibe this practice with a keen desire to mitigate their ecological foot prints. In the United States over 200,000 families are living in off-grid and many communities in developing and under developed countries are still yet to go on the grid, the current global estimate are at 1.7 billion people live off-grid. In Sub-Saharan Africa, the problem is acute as about 90 percent of the rural population and 74 percent of the total population lack access to electricity [20].

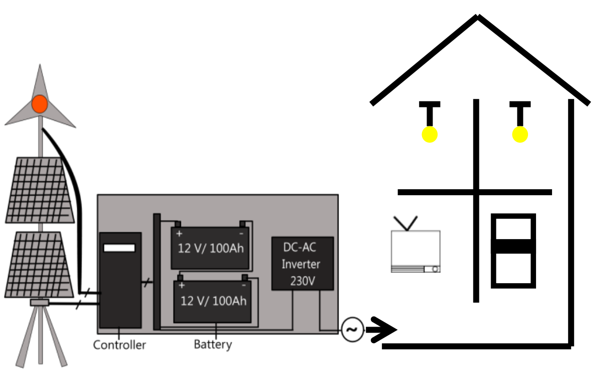

Figure 2 Off Grid Renewable Energy System

As we can depict from the figure 2, it's a simple energy resource which powers up the basic devices for everyday needs of the consumer but is highly prone to result in black out due to improper management.

As we have been able to put together an image of what an off-grid is, it is much easier to define an on-grid as the total opposite of that. The on-grid electrification source relies on the national power grid and depends on the use of all other public utilities. They are well serviced and supported by large corporations in contrast to off-grid where individuals or home owners are the ones responsible for the management of their home electrification.

Below are some distinct parameters that clearly distinguishes the difference between On-Grid and Off-Grid-

Table 1 On Grid / Off Grid Parameters

On Grid Parameters	Off Grid Parameters
Energy- Generation is Large Managed by Institution	**Energy**- Generation is limited Managed by Individuals
Devices- Viable Infrastructure Brilliant Networks	**Devices**- Basic Infrastructure Simple systems
Consumers Patterns- Lavish Consumption	**Consumer Patterns**- Basic needs

The 3 key parameters that we are interested in are- Energy, Devices and Consumer patterns, we will address each parameter in detail;

1. **Energy Generation**; this refers to the energy generation source. As earlier indicated in the national electrification grid energy generation is usually a mix of various types of energy source to meet the demands of the nation e.g. Japan's total energy consumption

for the year 2008 was 22.3 Quadrillion Btu and it comprises of Oil (46%), Coal (21%), Natural Gas (17%), Nuclear (11%), Hydro (3%), other renewables; solar, wind, geothermal, etc. (1%) [25]. In contrast, off-grid energy generation is always limited to renewable energy systems such as solar, wind and hydro all of which are environmentally influenced. If a wind turbine is set up in a community with limited wind speed it will utterly fail in producing energy and same goes for other sources of renewable energy. The limited energy generated will be stored in batteries for later use in homes, so the proper management of these systems is of intrinsic value to addressing the blackout crisis that is prone to occur due to limited energy generation.

2. **Devices**; communities situated in cities and are connected to the national electric grid enjoy the use of various devices that support their everyday activities e.g. flat screen TV's, kitchen accessories etc. and due to valuable improvement of the traditional power grid to smart grid systems most of these devices are connected to a network which makes room for automotive control regardless of location and since energy is guaranteed consumers are not bother about how much energy they are using. The situation is not the same in off grid communities as people rely on the use of simple low powered devices in other to mitigate electricity demand as supply is limited.

3. **Consumer Patterns**; due to the high level of energy management that on grid communities enjoy from large utility companies and the added values of smart grid consumer are lavish in their electricity consumption and are not bothered about how much energy they consume even though most devices today are designed to be low powered. In off grid communities, the home owners usually know how much energy they are generating but the ability to balance the supply with the growing demands is in question and consequently results in blackout.

For the rest of this paper we will be addressing this energy management faced in off grid locations through a user defined smart grid approach which is designed based on our proposed Time Based Energy Allocation Model (TBEAM).

4. Time Based Energy Allocation Model (TBEAM)

Time is a valuable parameter when it comes to energy consumption and in off grid locations where consumers need to meet basic needs e.g 7hrs of PC usage per day, our ability to design an energy management solution based on time of device usage is of intrinsic value as energy is limited. In other to address this challenge we look into the feasibility of allocating energy resources to devices based on user proposed time usage and amount of energy stored in the batteries. So what we have done is look into the consumer patterns of people residing in off grid locations and extracts the sub parameters of time-

- **Time of use** (h): Daily usage of device as defined by consumer.
- **Time of the day**: Period of the day (Morning, Midday, Afternoon, Evening and Night) in parallel to how much energy can be re-generated through the energy source at that given time of the day.
- **Battery State of Charge** (Ah): This key parameter, alerts of us how much energy we do have stored in the battery and how much of energy can be allocated to each device.

- **Time extension**: This parameter enables the consumer make adjustment on predefined time of usage to meet with energy needs in unforeseen circumstances which are inevitable.
  So based on the above outlined sub parameters we propose our Time Based Energy Allocation Model which takes note of every device within the location and based on the predefined time of usage allocates power to each device.

4.1. Energy Allocation

K_i = Device Rated Power [W]

L_i = Load Ampere [A]

Q = Inveter Voltage[V]

T_i = Device Usage Time[h]

SoC = State of Charge(Battery) [Ah]

i = 1,2,3…….N (Device Number)

$R\%$ = Back Up Stored Energy

In other for us to calculate the load on each device we divide the rated power for each device by the inverter voltage.

Equation 1 Load

$$L_i = \frac{K_i}{Q}$$

Then we further make a summation of all the amount of power required by all the devices

Equation 2 Daily Energy Consumption

$$L_N T_N = \sum_{i=1}^{N} L_i T_i$$

At this point we look back into the SoC of the battery to allocate the required amount of energy to the devices.

Equation 3 Back Up Energy Storage

$$R\% = \frac{SoC - L_N T_N}{SoC} \times 100\%$$

This will result in the amount of energy that's been left stored in the battery after the needs of the day are met.

4.2. Test Scenario

We decided to test the model to enable us realize its feasibility in addressing the afore mentioned challenges and then we put up a scenario with the following:

- Solar Module- 500W
- Micro Wind Turbine- 500W
- Hybrid Controller
- 2 Batteries- 12V / 100Ah each
- DC – AC Inverter – 230V

With this in place, given that we are in a sunny environment with high wind speed and given the gain and loss of energy storage within the batteries, we have 120 Ah instead of 200 Ah from the 2 batteries and a 230V Inverter given locations across Europe and Africa.

Table 2 Devices-Watt in Ampere

Storage (Ah)	Device	Watt	Load Current (A)
120	TV	54	0.234782609
	Pump	75	0.326086957
	Fan	15	0.065217391
	Light	49	0.217391304
	Fridge	260	1.130434783
	Radio	20	0.086956522
	Charger	20	0.086956522
	PC	20	0.086956522
	etc	30	0.130434783
		544	2.365217391

So we then calculate the devices load based on the user defined daily consumption to enable us figure out how much energy is being required and meet with the need based on the State of Charge of the battery which is presently rated at 120 Ah.

Table 3 Daily Energy Consumption

Device	Time (h)	Usage (Ah)	Back Up (Ah)
TV	7	1.643478261	87.10652174
Pump	0.5	0.163043478	
Fan	8	0.52173913	
Light	8	1.739130435	
Fridge	24	27.13043478	
Radio	4	0.347826087	
Charge	2	0.173913043	
PC	6	0.52173913	
etc	5	0.652173913	
		32.89347826	

5. Test Results & Discussion

So, with this in place our daily consumption is about 33Ah and since we have 120Ah as the State of Charge, after daily allocation we have a backup of about 87Ah.

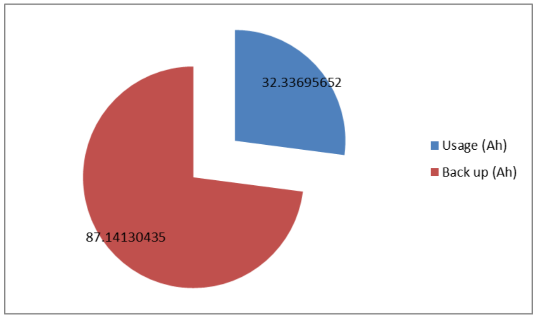

Figure 3 Scenario Result

With the result in figure 3, we have been able to prove that if renewable energy projects in off grid locations are designed around the user's need based on the sub parameters of time and through the adoption of our proposed Time Based Energy Allocation Model it is feasible to properly manage energy consumption and mitigate black out.

6. Conclusion and Future Works

Based on our findings we intend to go into the next phase of the Model which is to develop a software which we do intend to develop into a device to serve as the controller to host devices on the network and a multimedia representation of the SoC of the batteries through the fuel gauge and then enable users control how much energy is being consumed. As figure 4 below illustrates,

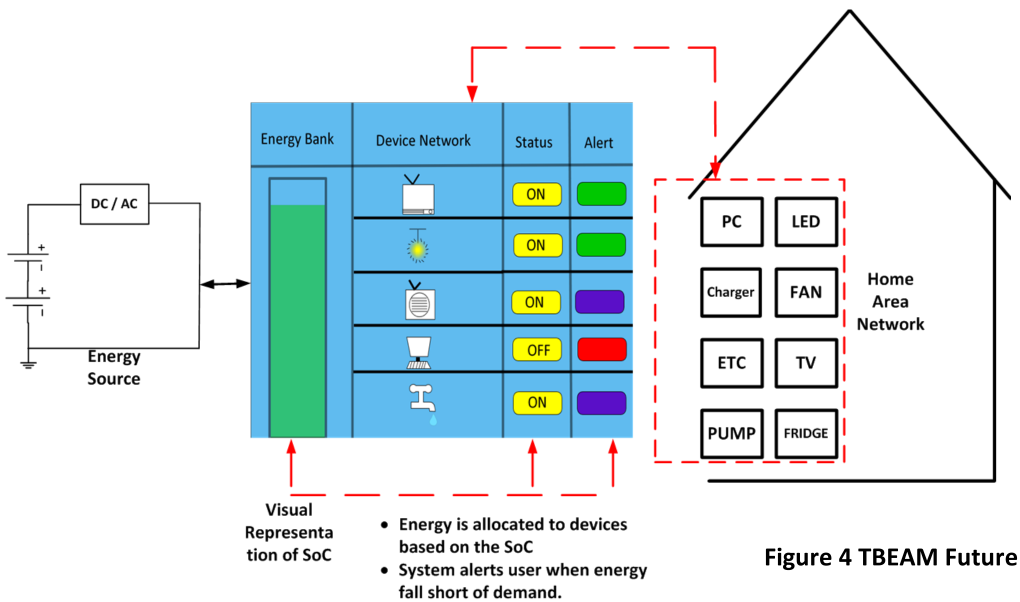

Figure 4 TBEAM Future Work

our proposed solution is at the center, managing the energy source and the device network of the appliances within the home. Even though the idea might appear to be simple for those who reside in on grid communities, we are sure it will make room for proper energy management and also mitigate blackout in off gird communities.

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