Intelligent Central Energy Management System for Remote Community Microgrid

A. Vosloo and K. A.Raji

Abstract— South Africa's rural communities experience limited electrical power availability; networks are sparse. Electricity suppliers do not cover all national rural regions often major areas of the African continent also suffer. Rural communities need an electrical supply where they reside. The high cost of transporting power remains a limiting factor. Electricity suppliers face difficulty in funding required constant expansion onto a national utility power grid. Communities are often widespread and usually in the most isolated corners of any country. Manpower skills shortages and a lack of infrastructure management and control lead to unresolved power issues. Within microgrids, a limited amount of energy can be stored by designated source holders, such as batteries. Microgrid technologies, constantly under study, are implemented globally via different concept designs. Because of the ever-growing size of such grids and a limited energy absorbing capability of the systems from natural resources, energy management within microgrids is under scrutiny. This study focuses on energy management within a microgrid. Software simulations were made using Simulink/Matlab/SimPowerSystems. Parameters were adjusted on the grid to observe control reaction. A Stokvel charge share concept was proposed, wherein state of batteries' charges and user consumption determined how grid loads should be controlled.

Key words — Agent based energy management system, charge reserve share, DC microgrid, distributed generation

1 INTRODUCTION

Communities in rural Africa are widespread and often isolated. Because of this energy suppliers find it difficult to supply electricity as both capital and running costs for long distance power transportation is exorbitant. Suppliers must also import human resources as villages do not possess infrastructure or skill to install the constant expansions onto the national utility power grid. In this way, much of rural sub-Saharan Africa enjoys little or is without a supply of electrical energy [1].

Basic needs such as cooking supper that is taken for granted in urban areas are difficult to deal with without electrical energy in these rural areas as this requires light and constant availability of low voltage power. Research has up to now focused on methods to bring electrical energy to these remote dwellings and methods to control and manage sources being generated and consumption [2].

Microgrids might be a better solution for these rural communities, providing villages with their own electrical power supply, thus making them independent of the national grid [3].

Microgrids are isolated islanded systems which generate, manage and provide electrical energy within itself. Using microgrids limited energy can be saved by the designed source holders such as batteries. Microgrid technologies must be expertly managed to control different aspects within this limited charge window [4].

State of charge (SOC) is seen as the full range of available energy that can be delivered by a battery. This range is measureable between when a battery is fully charged and when it carries no charge. Because of the limiting SOC of batteries, the problem is limited energy is available for a given time. Energy management deals with controlling power flow in a system by having a limited amount of energy, or to work with it in a "saving manner." To extend the time of use from a limited source, load monitoring and control are required [5].

Section 2 gives the background to the study area and a typical microgrid layout is provided in Section 3 where a DC microgrid system is described. The scenarios surrounding AC and DC generation is provided in Section 4; system modelling and analysis are provided in Section 5. Obtained results are discussed and analysed in Section 6 and Section 7 concludes the paper.

2 BACKGROUND TO THE RESEARCH PROBLEM

More than 1.2 billion people worldwide are without access to electricity - which included in excess of 550 million people in Africa and 300 million in India. Often, the traditional approach to serve such communities has been to extend the central utility power grid. This approach is however, technically inefficient and financially unviable because of a combination of capital scarcity, insufficient energy service, reduced grid reliability, extended building times and construction challenges to connect in remote areas [6].

As most utility power grids are inaccessible to rural communities, power sources must be taken to the location of need in the form of microgrid configurations. Rural communities are, therefore, today dependent on natural resources for light and heat for basic household requirements.

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Schnitzer et al. [6] record technologically and operationally microgrid distributed systems are ready to provide communities with electricity services today - particularly in rural and "peri-urban" (close to urban) areas of less developed countries.

Because of isolation from the utility grid, 230Vac single phase supplies are unavailable.

By the installation of direct current (DC) microgrids, energy can be generatedfrom natural sources such as wind and from the sun.

DC voltage can be generated and used as base voltage supply to the grid.

Most of today's electrical grids in countries worldwide operate using alternating current (AC) grids where 220 V and 110 V are used on appliances in low voltage applications.

AC grids have expanded and preferred because of long distance transmission advantages in using transformers.

To obtain AC voltage, it must either be generated directly in that form or inversion techniques applied to change a DC supply into the AC form.

AC voltage can also be inverted by using different switching devices such as inverters.

Electronic components in inverters and converters are expensive when considered in manipulating voltages on large power electronic systems.

When a DC grid is considered, its generation is directly connected to a grid. Grid DC loads can be fed from this DC source without the need for AC inversion techniques to change the DC bus system to an AC bus system.

This study deals with generation of DC voltage, maintaining and managing a DC microgrid for different agents and to eliminate need for an AC voltage inversion because of the cost involved.

Microgrid energy management is a key factor to observe to manage loads and storage units within the system.

A control algorithm is tasked to provide shared energy between grid users.

A charge share concept has been derived and tested on a software model platform via Matlab.

The drive behind the algorithm is to allow energy distribution to users according to daily use and SOC level within a battery system.

3 MICROGRID LAYOUT

Figure 1 indicates a rural microgrid of the 13.5 kW Photo Voltaic (PV) system at Makueni County, Eastern Kenya [7].

This community received such a generation unit to provide water and electricity.

Note the DC generation in **Error! Reference source not found.** is located in the central part of the rural area. Solar panels convert sunlight energy into electrical energy.

It is vital important to illustrate this microgrid's generation is located as close as possible to loads.

Microgrids of this scale do not have long transmission lines to supply power to other towns and areas far from the generation site.

Figure 1: Bird's eye view of the 13.5 kW PV system in Makueni County, Kenya

Various distributed networks are present and heavily dependent on the grid's layout. Physical layout is determined by location of generation, storage units and where loads are situated. Energy management is applied to control the use of the limited sources in these areas.

AC v DC Generation

In the "War of Currents" era in the late 1880s, George Westinghouse (known for his AC generation system invention) and Thomas Edison (inventor of DC generation system) became opponents because of Edison's promotion DC for electric power distribution over AC [8]. AC and DC generator technologies evolved from that era to the latest methods of power generation and motor technologies today. AC technology was favored for its ability to step voltages up and down through the use of transformers.

In 1839, Endmond Bequerel created the world's first photovoltaic cell [9]. From that time, photo voltaic technology evolved and became one of the biggest renewable generation sources in the world. This is an independent technology that generates DC, considered useable in microgrid environments. Renewable energy systems appeared in different types of energy absorbing / generating platforms. Such systems are seen as renewable with a low to no carbon footprint because energy is directly obtainable from nature in a readily available state, without having to convert one energy form to another to use it.

4 SYSTEM SIMULATION

Figure 2 illustrates the overview design of an agent-based energy management concept in the Matlab software model. The solar system is situated on the left which is driven by a reference irradiance signal. Irradiance can be manipulated by adjusting the trend to match the W/m² against time of the day taking into account the clearness index or the site.The battery on the right receives charge energy from the solar system and used as a storage medium.

The battery acts as the energy supplier to the grid when low irradiance is present, or at night when no sunlight energy is available. Battery charge control is used to trigger the charge cycle on pre-set parameters and to protect the battery against over-charge and over drainage conditions.

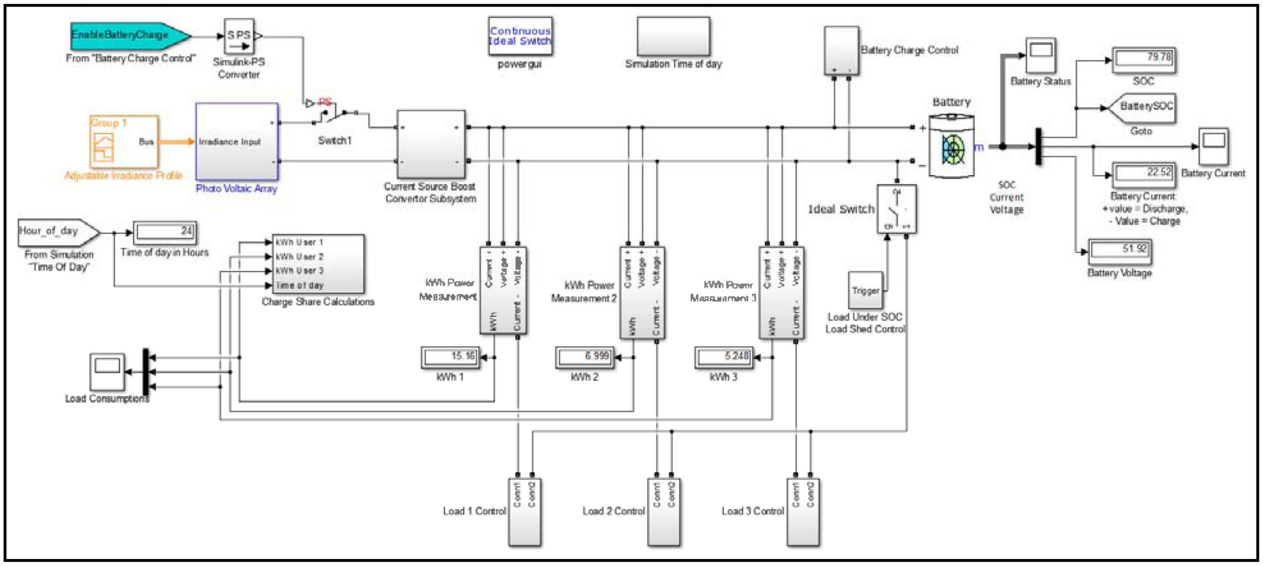

Figure 2: System Model in Matlab

A load control block, situated at the bottom of the Figure 2 is used to simulate load status conditions. Time during the simulation will determine time of day and that is where load patterns are developed.Power measurement determines energy kilowatt hours consumed by each load.The sum of the consumed loads are compared by the state of charge of the battery and thereby a percentage calculation of SOC is made. The remaining charge will be distributed between the loads according to their respective consumptions. SOC can be set at initial start-up on the simulation. Equation 1 gives the formula structure to produce charge share values to each user. The formula forms part of the control structure within the model to derive the quantities of remaining energy to be left aside for grid users according to their level of energy use and their battery's charge condition.

This mode of control ensures local communities work sparingly with such a limited energy resource. Communities would also manage their charge share load patterns.

$$kWh_{peruser} = \frac{1-\left(\frac{kWh_{User}}{kWh_{TotalUsers}}\right)\times kWh_{UsableBatterySOC}}{[N_{Users}-1]} \quad (1)$$

5 RESULTS

Figure 3 indicates the battery SOC starts to perform from a pre-set value of 65%. Battery current is positive for the initial constant load. Battery voltage is 51 V on start-up. At 15000sec the battery current begins to go negative as charging begins until 43000 seconds when charging stops. SOC is 100 % at 43000sec with a bus voltage at 55 V. For the rest of the battery current it must be noted that positive current is present when loads draw current from the battery, but negative current shows charging.

Point A shows 90 % SOC at 6pm. Marker B, D and C in Figure 4 indicates respective user consumer values for the day. User 1 has two variable loads which are varied accordingly and show more step formation through the day as consumption continues. User 2 is not at home during the day and starts to consume energy only at 6pm. Marker D shows user 2 started to consume energy only from 6pm. Point C crosses the 6pm mark and User 3 indicates daily consumption.

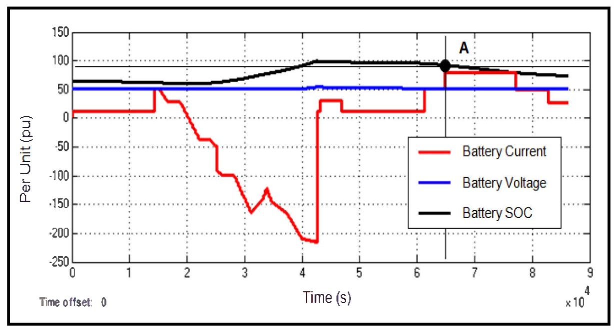

Figure 3: Battery status describes bus voltage, battery current and battery SOC fluctuations

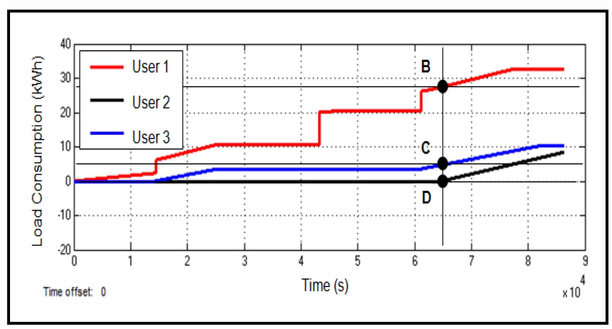

Figure 4: User load consumption shows daily use of energy consumed by each grid user

Figure 5 indicates the charge share reserve values being calculated continuously throughout the day. Point B in Figure 4 shows that User 1 was the biggest energy power user that day. If one looks at the red line in Figure 4 then it is evident that the charge share algorithm was allowing the least amount of battery share to that user. The same applied for Users 2 and 3 where it may be observed they were allowed a similar charge until the 15000sec point.

User 2 used no power the entire day until 6pm - at Point D in Figure 4. Then in Figure 5 it becomes apparent the maximum energy was constantly allowed during the continuous calculation process.

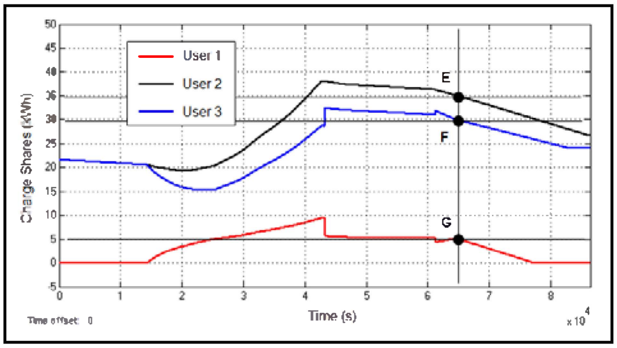

Figure 5: Energy charge share quantities are calculated on a continuous basis and shared between each user by the algorithm

Points G, E, F show the crossing points for Users 1, 2 and 3 respectively when they cross the 6pm timeline. When 6pm is reached the charge share algorithm will stop to calculate the sharing values and allows energy only then to be deducted from the charge share values. From 6pm onwards all trend lines can be seen with a negative declined slope.

Table I: Charge share algorithm indicates division of remaining SOC between load users.

User	Energy consumption during day kWh)	Charge energy left for each load to use after 18:00 (kWh)	% Energy reserved for each load to be used at night from remaining SOC
1	28	5.15	7.58%
2	0	34	50.00%
3	5	28.85	42.42%
Total	33	68	100.00%

Energy charge sharing is functional - through introduction of the charge share algorithm into the simulator microgrid environment. This energy management strategy allows each user a power share portion form the remaining battery SOC.

6 CONCLUSIONS

A charge share algorithm was designed and tested on Matlab simulation software. The goal was to share energy between users depending on each user's daily energy consumption.

From this test it was observed the charge share values had been calculated continuously throughout the day. This confirmed operation when the most significant user had been allowed the smallest charge portion of the remaining SOC - to be used at night after 6pm; the smallest energy user allowed a bigger share of energy.

This system allowed each user a reasonable energy share during daytime and night, depending on requirements from users and duration of use.

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