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A Demand-Response Scheme Using Multi-Agent System for Smart DC Microgrid

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ABSTRACT

This article describes a framework for load shedding techniques using dynamic pricing and multi-agent system. The islanded microgrid uses solar panels and battery energy management system as a source of energy to serve remote communities who have no access to the grid with a randomized type of power in terms of individual load. The generated framework includes modeling of solar panels, battery storage and loads to optimize the energy usage and reduce the electricity bills. In this work, the loads are classified as critical and non-critical. The agents are designed in a decentralized manner, which includes solar agent, storage agent and load agent. The load shedding experiment of the framework is mapped with the manual operation done at Kisiju village, Pwani, Tanzania. Experiment results show that the use of pricing factor as a demand response makes the microgrid sustainable as it manages to control and monitor its supply and demand, hence, the load being capable of shedding its own appliances when the power supplied is not enough.

KEYWORDS

Demand-Response Scheme, Dynamic Pricing, Load Shedding, Multi Agent System, PV, Smart Microgrid

1. INTRODUCTION

The aging grid technologies coupled with the need for a greener energy system have urged the development of the smart grid. Information and Communication Technologies (ICT) are the heart of the smart grid. The smart grid is considered as a system of systems that engenders a plethora of advanced and smart applications such as distributed intelligence, smart metering infrastructure, demand response schemes, and self-healing (Bayindir, Colak, Fulli, & Demirtas, 2016). According to (Zaballos,

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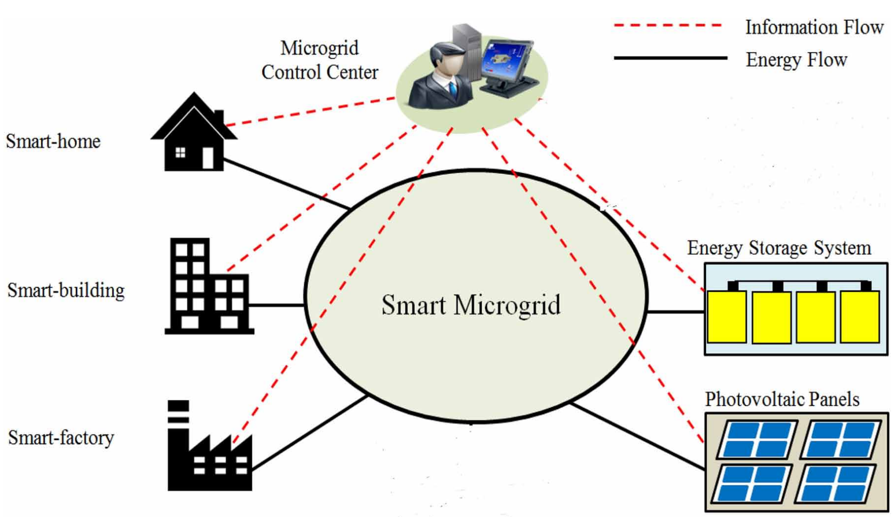
Vallejo, & Selga, 2011), the smart grid is an electricity network that can intelligently and smartly integrate the actions and users connected to it (generators, consumers, transmitters, distributors and those that do both) so as to efficiently deliver sustainable, economic and secure electricity supplies.

Developing countries are facing arduous challenges to modernize the aging grid due to, among others, poor ICT infrastructure unregulated energy market. For instance, the Tanzania Electric Supply Company (TANESCO), which is the sole supplier company of the electricity in Tanzania, the transmission side, is the part, which has been implemented in the process of monitoring and controlling with smart grid and lesser extent to the primary distribution side of the grid system. There is still a need to automate the control of electric power to increase efficiency in all aspects of the electric power system, optimize cost to consumers and reduce the number of staff and human errors. In addition, the use of renewable energies such as solar and the wind is more valuable in the utilization and provision of electricity in places without access to the national grid. When the smart network system has been integrated with renewable energies as a source of power, this is referred to the as smart microgrid. According to Kihwele & Kyaruzi, (2004), microgrid system is capable of rapidly detecting, controlling, managing, analyzing and responding to various perturbations in the network by integrating advanced control methods such as agent-based systems.

The control and management of distributed energy systems using multi-agent systems in the smart grid have been seen to work effectively in the provision of autonomous actions. The study by Jiang, (2006) discussed that agent-based system can be applied in the management of distributed energy systems including demand-side management, storage, and generation. Another use of multi-agent systems has been implemented in the simulation of discrete event emergency medical services in London hospitals, (Anagnostou, Nouman, & Taylor, 2013). Other sectors by which multi-agent systems can be applied are e-health, transportations, and infrastructure.

In microgrid systems, the role of control is important for reliable communication, efficiency operations, and autonomous actions. The level of control and monitoring in microgrid depends on different aspects incorporated such as latency, memory consumption, security issues and power management. Normally, the microgrid can be either operates in synchronous mode (connected to the grid) or asynchronous mode (islanded). Figure 1 described the Direct Current (DC) microgrid concept based on an islanded mode with solar as a renewable source of energy. Some advantages of microgrid systems are increasing reliability, money saving, revenue generation and aiding economic growth.

Figure 1. DC Microgrid control system



This work is an extension of our previous paper (Rwegasira et al., 2017). Specifically, a demand response scheme is proposed to reduce the energy bill for individual houses. A dynamic pricing algorithm is proposed to shed non-critical loads and to reduce the peak to average energy consumption. The dynamic pricing algorithm permits a user with surplus energy to earn money by selling unused energy when the prices climb up. The rest of the paper is organized as follows: Section 2 describes related work. Problem Statement is formulated in Section 3. The mathematical models for the various blocks in a DC microgrid are elaborated in Section 4. Section 5 details the multi-agent system for control and management of the DC microgrid. Simulation results using Repast are discussed in Section 6. Finally, Section 7 concludes the paper.

2. RELATED WORK

It is well accepted that peaks of energy consumption or the decrease of power generation may cause a power outage, grid instability, frequency variations, etc. Load-shedding and energy storage system are two well-known techniques to shave power peaks and increase grid stability (Seethalekshmi, Singh, & Srivastava, 2011). Load shedding temporally eliminates some loads out of the system during peak demands. Load-shedding techniques are applied on the customer side with the objective of reducing the electricity bills. In the DC microgrid, prioritization strategies are used to prevent power outage for critical loads. In Xu, Liu, Chen, & Gao, (2016), the authors proposed an optimal load shedding using Markov decision process for an islanded microgrid. A connected microgrid is at the risk of sever islanding in the event of a fault in the main-grid. Load shedding techniques for severely islanded microgrid are viable to prevent instability and to match supplies with demands (Das, Nitsas, Altin, Hansen, & Sorensen, 2017; D'Agostino et al., 2017).

In the DC microgrid, the intermittency problem of solar energy is warded off using batteries energy storage system (BESS) (Fu et al., 2013). In industrial settings, peak demands and cost savings can be shaved using BESS coupled with optimal sizing (Oudalov, Cherkaoui, & Beguin, 2007). Data centers are as energy-hungry facilities in the ICT industry in which batteries are considered as the suitable candidate to lower the electricity bill and reduce peak power demands. A cost-efficient centralized BESS with partial discharge that accounts for the nonlinearity of the battery capacity and its reliability is developed by (Aksanli, Pettis, & Rosing, 2013).

Demand side management is a factor, which goes in parallel with the provision of constant and efficient power to the end users. The importance of demand response on consumer side has been addressed in Ciara, The, Engineering, Supervisor, & Duignan, (2011) to describe how it can be in cooperated with the grid for maximum production of the electricity. It involves reducing electricity use through activities or programs that promote electric energy efficiency or conservation, or more efficient management of electric energy loads. (Saini, 2007) Described on how demand response can have a greater impact on the society with respect to energy usage and utilization.

Multi-agent system, MAS, has become popular in control and optimization (Leitão, 2009) (Lee & Kim, 2008). In the energy sector, MAS has been applied to, for instance, control, optimize, simulate, and manage the smart grid (Merabet et al., 2014) and microgrid (Kantamneni, Brown, Parker, & Weaver, 2015). The control of islanded and grid-connected microgrid with distributed energy resources, DERs, is a complex task. To create an autonomous microgrid, proposed a two-layer control algorithm combined with MAS. Three types of agents were used: a local agent, a regional agent and a service agent. The DER unit is controlled and monitored by the local agent. A regional agent controls all local agents within a given region. Finally, the service agent provides services, e.g. weather forecast, to both local and regional agents. In residential areas with renewable energy, decentralized coordination and load-shedding among houses are treated by (Celik, Roche, Bouquain, & Miraoui, 2017). The architecture is articulated around an aggregator to dynamically change the price. The authors considered controllable and non-controllable loads for operation scheduling. They further defined two agents: home agent and aggregator agent. Home agents use a genetic algorithm to control the operation of the controllable appliance with the aim to reduce the electricity bill. Logenthiran, Srinivasan, Khambadkone, & Aung, (2012) Presented the multi-agent for real operation in a microgrid whereby the focus was on central scheduling and demand-side management. The model formulated based on the power generated and those consumed by the battery as well as the loads. In the modeling of DC microgrid, three main areas of concentration are generation part (source of power), storage part (battery) and the consumption part (loads). In modeling of the source of power, the main characteristics are the (current vs voltage) I-V and (power vs voltage) P-V behaviors. For storage modeling, the focus is on charging and discharging behaviors while on the consumer side, the most case scenario depends on the random generation of power and demand-side management. In this research, the modeling focus on solar and Photovoltaic (PV) panels' characteristics with respect to sun irradiations, battery storage with respect to State of Charge (SoC) while on load the focus is on uniform distribution with respect to time *t*.

3. PROBLEM STATEMENT

Access to reliable and affordable electricity is still a problem in Tanzania, especially in rural communities. According to Mwinyiwiwa, Kivaisi, & Msoka, (2013), only 14% of the Tanzanian population has access to electricity in rural areas. At the same time, the increase of productive investments has also increased the demand for electricity. More people need access to quality healthcare, communication, and education which all depend on a reliable supply of electricity. TANESCO, the main publicly-owned supplier of electricity in Tanzania, fails to satisfy this demand (Peng & Poudineh, 2017). As a result of this, the Renewable Energy Agency (REA) and other solar power companies such as Helvetic Solar, TAREA, and Ensol have invested in solar technologies and projects in Tanzania. These efforts have helped many communities where they have been implemented (Couderc, 2017; Aly, Jensen, & Pedersen, 2017; Jadhav, Chembe, Strauss, & Van Niekerk, 2017).

However, despite these efforts, many of these solar projects suffer from control and optimization challenges. There is still an imbalance between the supply and demand for electricity. Sometimes the demand exceeds the capacity of the solar implementations. This can cause instabilities in the system and reduce the quality of power that is generated. In order to deal with this situation, skilled people are used to controlling and operating these solar implementations. They monitor and make sure that every part of the system is working. They also manually respond to any events that may overload the system. This process tends to be inefficient and slow. As a result, people cannot reliably depend on the availability of electricity at all times.

In order to solve these challenges, there is a need for more autonomous and reliable control mechanisms to balance supply and demand of electricity. Solar-based microgrid in these communities needs new approaches for automatic load scheduling as well as peer-to-peer power-sharing mechanisms in cases of excess power. Existing approaches depend on centralized architectures where one component controls the process (Hatziargyriou, Asano, Iravani, & Marnay, 2007). These approaches do not scale well once the scope of the microgrid increases with demand factors. In addition, they introduce single points of failure that reduce the reliability and resilience of the whole system. There is a need for more decentralized mechanisms which can also offer other desirable features such as fault detection and tolerance, self-healing and dynamic pricing (Olivares et al., 2014).

4. MATHEMATICAL MODELS FOR A DC-MICROGRID

4.1. DC Microgrid-Kisiju Pwani Model

The need of modeling of any system is very important for the success and predictions of the results. The work by (Mwinyiwiwa et al., 2013), focus on the production of power through photovoltaic panels. This section explains how the modeling of solar, battery and loads have been done in order to achieve load shedding and demand response based on power and price. Table 1 shows the algorithm and the states which have been used to model the work.

4.1.1. Solar Modelling With Power Consumption

The means of converting the solar energy into a usable amount of direct current (DC) electricity can be done through the absorption of sunlight into the solar panels. Modelling of the solar panels is a common solution when describing different characteristics and behavior of solar. This characteristic of the solar panels are normally based on the voltage, illuminations and temperate of the surroundings (Chen, 2011).

To compute the altitude and azimuth angles, (1) and (2) were used:

$$\alpha = a\ \sin^{-1}\left\{\sin\left(L * \frac{\pi}{180}\right) \times \sin\left(\delta * \frac{\pi}{180}\right) + \cos\left(\delta * \frac{\pi}{180}\right)\cos\left(L * \frac{\pi}{180}\right)\cos\left(\omega * \frac{\pi}{180}\right)\right\} \quad (1)$$

Table 1. Algorithm for the DC microgrid

Algorithm	PV Solar panel	Storage Battery	Cri.Load	Non-Cri.Load
Function	Perform load shedding based on demand, Display the price on hourly basis	State of charge (SoC) of the battery	Maintain the power level, no shedding	Control the power usage on the allocated devices for shedding
Action	Provide power to the microgrid	Act as a backup of main solar to provide power to the loads	=load profiling at certain time.	= load profiling at certain time. Range of the power consumption of the devices **Important devices**: Lights, fridge,TV **Non important devices**: AC, washing machine
Rules1	$P_{s=}$power supply, $P_{threshold=}$ Threshold power	**Power supply and consumption**		
	$P_s > P_{threshold}$	SoC battery>= 50%	Switch ON	Switch ON
	$P_s < P_{threshold}$	SoC battery>= 50%	Switch ON	Isolate from solar, get from storage
	$P_s < P_{threshold}$	SoC battery<= 50%	Switch ON	Isolate from storage, get from its own battery.
Rules 2		**Algorithm of the price**		
	Price is high: If the demand is high than the supply			Control the devices and either (i) switch off the Non important devices (ii) use your own battery (iii) if you have surplus, sell to the grid
	Price is low: Demand is low than the supply			Switch all the devices Reserve the battery power for future use
Results	Power consumption, price against time	Power consumption against time		Power consumption, price against time

$$\theta = \sin^{-1}\left\{\frac{\cos\left(\delta * \frac{\pi}{180}\right)\sin\left(\omega * \frac{\pi}{180}\right)}{\cos\left(\alpha \frac{*\pi}{180}\right)}\right\} \quad (2)$$

where a is the apparent solar time, L the latitude in degree, δ the declination angle, and ω the hour angle.

4.1.1.1. Solar Modeling With Power Production

To compute the total solar irradiation of the sun, (3) was also used:

$$S_{irr} = \left(1 + C\right) A e^{\left\{-k/\sin\alpha \frac{*\pi}{180}\right\}} \quad (3)$$

where A, C, and k are factors, which depends on the number of solar cells, calculated as:

$$A = 1160 + \left\{75\ \sin^{-1}\left\{(360\ /\ 365) \times \left(N - 275\right)\right\}\right\} \quad (4)$$

$$k = 0.174 + \left\{0.035 \sin^{-1}\left\{(360\ /\ 365) \times \left(N - 100\right)\right\}\right\} \quad (5)$$

$$C = 0.095 + \left\{0.04\ \sin^{-1}\left\{(360\ /\ 365) \times \left(N - 275\right)\right\}\right\} \quad (6)$$

The calculation of the PV model was based on several constant values as tabulated in Table 2, which lead to having (7):

Table 2. Solar cell parameters

Parameter	Constant Value
Number of Suns, G	1000W/m^2
Temp, *T*	273
Boltzmann's const, K	1.38e-23
Charge on an electron,q	1.60e-19
Diode quality, A	1.2
Band gap voltage, Vg	1.12
Open cct voltage per cell a temperature *T1*(25), Voc_*T1*	32.9V
Short cct current per cell at temp *T1*, Isc_*T1*	8.21
Open cct voltage per cell at temperature *T2*(75), Voc_*T1*	29.9
Short cct current per cell at temp *T2*(75), Isc_*T2*	6.62
array working temp, *TaK*	*TaK* = 273 + *TaC*
reference temp, *TrK*	*TrK* = 273 + 25

$$Ian = Isc_{T1} * Suns * \left(1 + a * \left(TaK - T1\right)\right) - Ir * \left(\exp\left(\frac{\left(Vc + IaRs\right)}{Vt_{Ta}}\right) - 1\right) \tag{7}$$

where by:

$$\mathrm{Vt}_{\mathrm{Ta}} - \mathrm{A*kt} / \mathrm{q} \tag{8}$$

$$Ir = Ir_{T1} * \left(\frac{TaK}{T1}\right) .\hat{} \left(3 / A\right) * e^{\left(-b*\left(\frac{1}{Tak} - \frac{1}{T1}\right)\right)} \tag{9}$$

$$b = Vg * q / \left(A * k\right) \tag{10}$$

$$Ir_{T1} = \frac{Isc_{T1}}{\left(\exp\left(\frac{Voc_{T1}}{A * Vt_{T1}}\right) - 1\right)} \tag{11}$$

4.1.2. Solar Modeling with Pricing Control

The calculation of price-ahead was controlled by different parameters include: number of houses in the microgrid (N), predictable available energy for the next hour (E), predictable power at the next hour (a vector of length N), the maximum and minimum price of in the microgrid, (q_{max}, q_{min}) a safe margin energy (ζ), the step of the price increase, (L) and the current price (q_i).

The algorithm works as follows: At the i[th] time and at the kth day, the algorithm computes the consumed power by all N houses. This value is checked against the produced energy. In case the total energy demands are very close to the generated energy, then the price for the next interval of time is increased by a constant step T . In case the demands in energy is less than the produced energy, then the prices are lowered by a constant step T . The algorithms guarantees that the price will not leave the margin, that is $q_i\left(k\right) \in \left[q_{min} \quad q_{max}\right]$. The algorithm should maintain high values for q_{max} so that only critical loads are powered on.

Function *price-control* **(*i, N,*** k , ζ **)**

{

$P_i^d\left(k\right) \leftarrow \sum_{j=1}^{N} p_j^i\left(k\right)$; //Compute the current energy consumption

$E_i^p\left(k\right) \leftarrow \sum_{j=1}^{N} e_j^i\left(k\right)$ // Compute the actual available power

{

if ($P_i^d\left(k\right) + \zeta \geq E_i^p\left(k\right)$)

$q_{i+1}\left(k\right) \leftarrow \min(q_i\left(k\right) + T , q_{\max})$ // increase the price else if ($P_i^d(k) + \zeta < E_i^p(k)$)

$q_{i+1}(k) \leftarrow \max(q_i(k) - T, q_{min})$ *// reduce the price*

else

$q_{i+1}(k) \leftarrow q_i(k) + T$

endif

}

return q_{i+1}

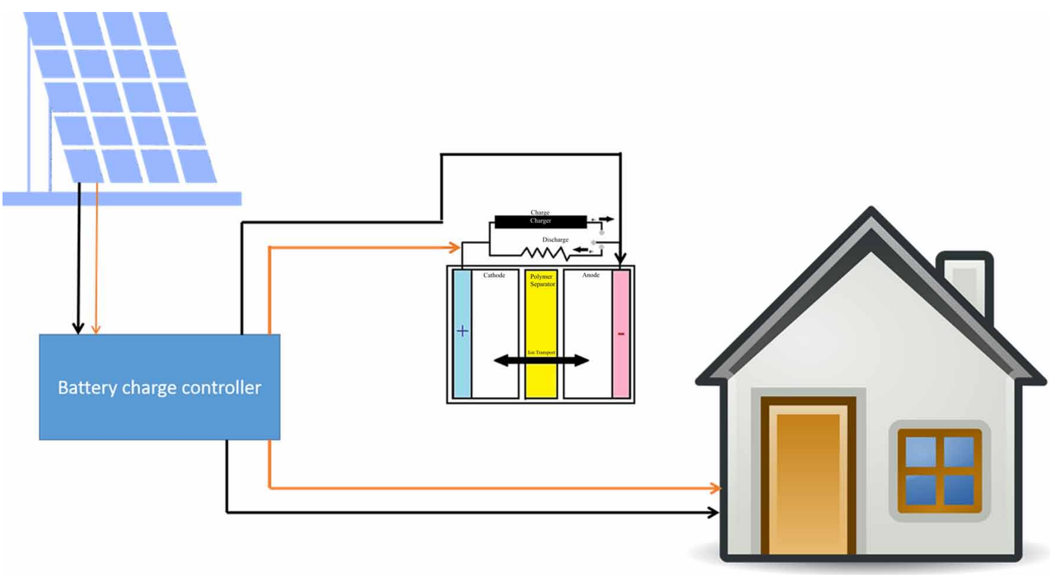
}

4.1.3. Storage Modeling

In a PV- microgrid, the electricity generated by PV panels depends on the weather condition, orientation of the panels, etc. This and other factors create electricity generation intermittency. To circumvent this problem, batteries should be used to store the surplus energy and used when the PV panels do not produce enough electricity for the house. Chemical batteries are the widely used technology in the renewable energy sector. Electrolyte, anode and cathode are the most important elements that determine the electrical behavior of the battery. During charging, chemical battery converts electricity into chemical energy using the principle of oxidation-reduction. Batteries are charged and discharged using a solar charge controller (SCC). Figure 2 shows the connection of a solar charge controller to the PV panel, a battery and DC appliances inside a residence.

The solar charge controller is an embedded system that implements a charging/ discharging algorithm along with other protection features such as protection against overcharge and undercharges (c. Batteries have several parameters that depend on the battery-type, applications, etc. In DC-microgrid and for lead-acid battery, the most important parameters are SoC (State of charge), DoD (depth of discharge), rated capacity, voltage rating, capacity, Coulombic efficiency, and cycle lifetime. The DoD

Figure 2. Connection of a solar charge controller



for a lead acid battery should not drop below 50% of its rated capacity. The capacity of the lead-acid battery can be determined using Peukert's law as given in equation (12):

$$C_{bat} = I_d t \quad (12)$$

where C_{bat} is the battery capacity in Amp-hour, I_d is the discharge current (which is supposed to be constant), and α is the Peukert's coefficient. The original Peukert's law has been found inaccurate by (Doerffel & Sharkh, 2006) and they proposed several empirical equations for lead-acid battery.

In this work, SoC is the most appropriate parameter that needs to be continuously tracked for home energy management system. For a lead-acid battery, SoC can be determined using the dynamic model developed by (Ceraolo, 2000) which is shown in *Figure 3: Lead-acid equivalent circuit model*. The charging and discharging of the battery has been calculated using equation (13):

$$C(t) = C(t-1) + \left\{ \frac{\Delta t \times \Psi_b(t)}{V_b(t)} \times P_{rew}(t) - P_u(t) \right\} \quad (13)$$

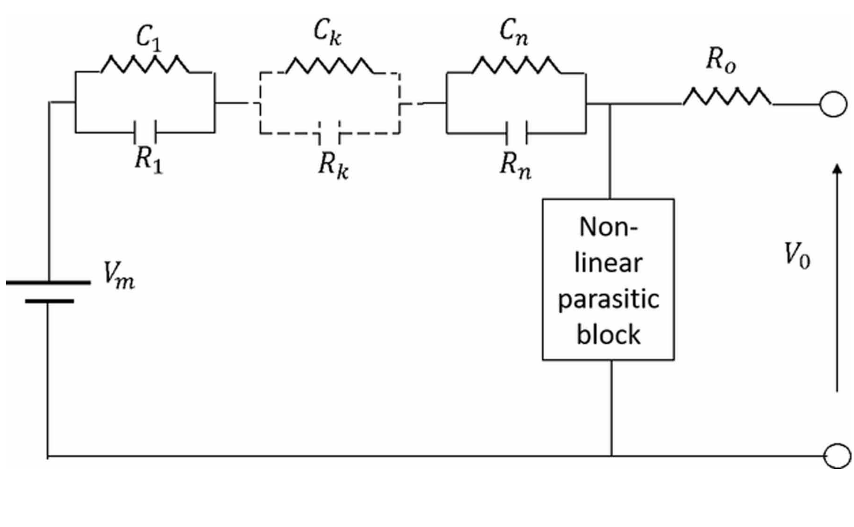
where $P_u(t)$ is the renewable battery power, $P_{rew}(t)$ is the total renewable power, $V_b(t)$ is the voltage of the battery terminals at time t, $\Psi_b(t)$ is the battery efficiency, and $C(t)$ and $C(t-1)$ are the battery charges at time t and t-1 respectively.

4.1.4. Load Modeling

With modeling of the load, the main attribute is to generate the random values at given number of intervals. Equation (13) was used which based on the uniform distribution with a specified number of values needed:

$$r = Ai + (Ai + Bi) * rand(N,1) \quad (14)$$

Figure 3. Lead-acid equivalent circuit model



where A, B represent intervals of the random numbers to be generated, N random generated numbers, and i the ith number generated.

Moreover, the two scenario functions for buying and selling power to grid are described as follows.

4.1.4.1. First Scenario: Buying From the Grid

The load (house) is responsible for energy control and monitoring. The keeps on monitoring the status of the battery (SOC) to predict, in an hour-ahead, the available power. In case the energy stored in the local batteries does not cover the predicted need, then the agent checks for the energy prices in the next hour. If the prices are affordable, then the agent will buy the extra power from the micro-grid. In case the prices are high, the agent will power-off non-critical loads.

4.1.4.2. Second Scenario: Selling to the Grid

In case the energy stored in the available energy in one hour-ahead is significantly higher than the predicted demands, then the agent will check the current prices at the micro-grid. If the prices are high, then the agent can sell the surplus. The house can also decide to attach more battery and save the extra-power in case the prices are low.

The aspect of load categorization is based on important and less important appliances where by the user can decide to switch the device to reduce the cost when the price is high. Table 3 shows the types of the appliances selected for this work where by the light bulbs, TV and Fridge are important while the air conditioner is less important.

5. IMPLEMENTATION OF MULTI-AGENT SYSTEM

5.1. Repast Simphony Platform

In our simulation work, we used Repast simphony to develop and simulate multi-agent systems. Repast Symphony is a Java-based toolkit that offers different simulation platforms such as Java, Logo, Groovy and Statecharts, for developing agent-based models (Bragen, Collier, Murphy, Ozik, & Tatara, 2012). It is an open source tool that allows to easily design and simulate dynamic systems that involve multiple interacting agents and provide the step by step simulation. Repast has already been used to model and simulate different applications and use cases in the electric power domain. It has been used to model and simulate the interaction of smart homes with distributed power generation in order to minimize individual power costs and peak power consumption (Kahrobaee, Rajabzadeh, Soh, & Asgarpoor, 2012). It has also been used to simulate very complex and dynamic distributed electricity markets in smart grid scenarios where customers with competing goals and constraints buy and sell electricity to each other with dynamic prices (Kahrobaee, Rajabzadeh, Soh, & Asgarpoor, 2014). Moreover, Repast in agent execution provides a tick driven synchronous and scheduler single thread approach while in terms of interaction it allows method calls and resource sharing.

Table 3. Appliances with their power consumption

Device	Capacity	Amount
Light bulbs	13W	6
TV	40W	1
Fridge	150W	1
Air Conditioner	1000W	1

5.2. Agent Collaborations

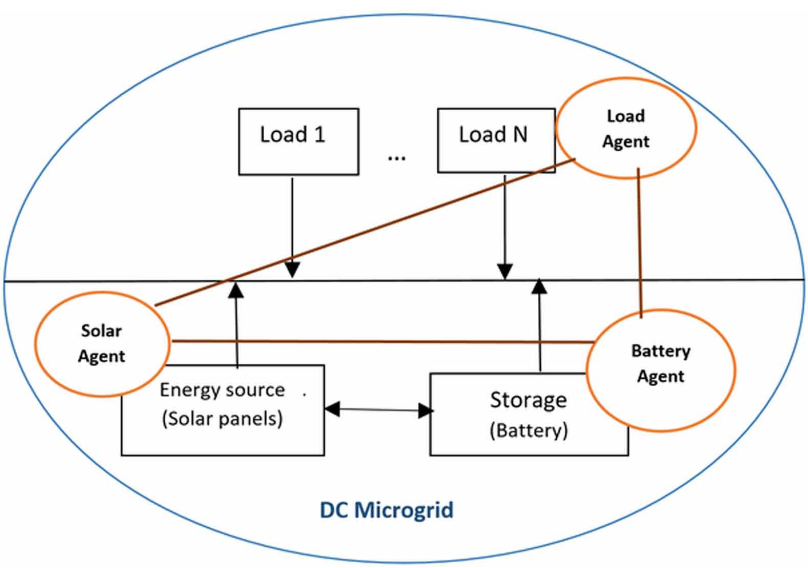
There are three agents in this microgrid, which are solar, storage and load. The load agents have their own solar and storage, which has similar characteristics like the main solar except that it, can perform load shedding. Figure 4 shows the set-up of the agents and their interconnection between each other. Table 2 also summarizes the functions of each agent implemented in the Repast.

5.2.1. Solar Agent

This is the main power supply to the battery and loads. The behavior of this agent is to obtain the solar radiation from the sunshine and generate the power from it. The higher the sunshine results in the maximum power production. The expected maximum power will be generated at noon where the sunshine is the highest peak. The solar agent learns the behavior of the environments through sun radiations and illuminations then produce an output of power. That action is autonomous and it changes according to the sunshine of the day. This agent is also responsible for charging the main battery up to the maximum level (80% of the SoC) and then supplies the loads. Moreover, the distribution of power depends on the number of loads and their consumption of power per daily basis. The main solar is accountable for categorizing the critical and non-critical loads and to perform load shedding when the power is not sufficient. In addition, the demand response of the solar agent is focusing on how the loads are able to provide extra power to the main storage for continuous distribution of power. This is also responsible for the pricing control as described in the previous section.

The "*ChargeController*" function is the one with attributes to perform the control logic. It is responsible to control and monitor the status of the power consumptions supplied to the grid and notify the pricing function on whether to increase the price or decrease it. At every iteration, the systems keep on updating and checking the production. If the solar panels have enough power to distribute into the system, then the price will remain unchanged. Moreover, the control of the battery level for charging and discharging is done with this agent and in case there is an inefficient power supply, the following can be done: (1) increase the price and announce to the system, (2) disconnect the non-critical loads.

Figure 4. Agent collaborations in DC Microgrid



5.2.2. Storage Agent

The main task of this agent is the storage concept and act as a backup of the solar agent. It monitors the charging and discharging activities and ensures the constant provision of power to the critical loads. This agent provides power when the solar do not have sufficient power to support the loads. Extra power is also shared to this agent to make demand response scheme based on pricing effective and efficient. Moreover, each individual load agent has its own battery storage which has the following functions: (1) control the charging process, (2) determine the health of the battery, (3) forecast the power demand of the load, (4) prioritize the appliances, i.e. important and less important devices based on the available power either from local battery or the grid and (5) guarantee safe operation and optimal performance of the battery system.

The "*SupplierBattery*" function which extends to the "*SolarBattery*" function maintains the SoC of the Lead-acid characteristics and act as a backup into the main system. The main storage battery focus on controlling the overall system while the individual battery monitors the consumption of the individual house. The capacity of the individual load (house) is specified by the owner based on the consumption and need. The individual storage agent keeps on monitoring the consumptions and the level of the supplied power. If the load (house) has been disconnected, then the battery has to automatically switch on.

5.2.3. Load Agent

This agent has its own solar and storage for power usage where it can use it as per demand. The power consumption of each load is generated randomly per hours using (14). The load agent provides automatically extra power to the main source and responds to its own power when load shedding takes place. In addition, the load agent has a capability of either deciding to use its own power generated or the power from the grid.

The "*RandomGeneratePower*" function provides the owner of the grid to specify the maximum and minimum power each user. This was done in order to generate the load profiling based on the context of an electric company in Tanzania, but also to have the flexibility of the system. Apart from this, another function is the "*consumer*" function which focuses on demand and supply attributes. For every iteration, the agent has to monitor on the pricing behavior in the solar agent and decide on: (1) Switch off the battery and use the grid if the price is low, (2) Continue to use the power from its battery.

Also, depending on the availability of the charging capacity, the agent has to make shedding on the less important appliances. This is done through the "*LoadPower*" function which for every iteration it is able to anticipate the power consumption of the load to be used. Therefore, this will provide the time for important appliances to continue to be used. Table 4 summarizes the functions of each agent.

Table 4. Functions of each agent

	Agent		
	Solar	**Battery**	**Load**
Method at time t	Solar irradiation and illumination of the sun	Charging and discharge	Random values generated in Kwh
	Current production for 24V to 48V dc.	Status of the health of charge	Get excess power method, Run: for running simulation and Distribute power method
	Run: for running simulation	Reserve the power for future use	Distribute power method
	Distribute power method		Perform load shedding to its appliances based on the demand
	Charger Control, Supplier function, power grid control		Selling/buying the power to the grid with respect to the price

6. RESULTS AND DISCUSSION

The results are demonstrated with 3 houses which have critical and non-critical loads. The simulation has been run with 100 tick counts, which is equivalent to 100 hours. The working voltage is 24V and 48V dc for individual and main storage battery respectively. When running the Repast, there are several parameters a developer has to insert based on the model. In our case Figure 5 shows some part of the parameters which for every running option, the user can change with respect to his/her targets, i.e. increased number of houses, storage level, price values, power from the source and be able to see how the load shedding will take place. In this case, when running different scenarios, it will then be possible to analyze the power consumptions in the microgrid and make plans as required especially on how long the grid will provide power to the loads. Sidewise, Figure 6 shows the 2-dimensional figure of the microgrid with a solar panel as a source, battery as storage and loads indicating critical and non-critical loads. For every step of the simulation, the changes of the power consumption and usage will also be changed in all agents until the indicated 100 ticks diminished. This is also one of the advantages of using the Repast simulation tool where the visualization of the output can be seen at each step of the simulation.

The price profile of the grid is an important feature for the forecasting demand in the country. The individual customer needs to know the plan of its usage upon knowing the ahead price in the grid. In Figure 7 and Figure 8 show the time-based price of the power and the next price ahead when there is shedding and without shedding. If at the peak hours and the power generation is not enough, the source agent can decide to disconnect the non-critical load and leave the critical load on the operation mode. In this case, it is easy for the customer to decide on its power consumption by automatically switching off its heavy-duty appliances or decided to connect with its own battery if it has enough storage capacity. From the Figure 7 it shows the price is high almost all times due to the shortage of power from the supplier. The parameter of the price increment will be set by the control center in

Figure 5. Part of the parameters

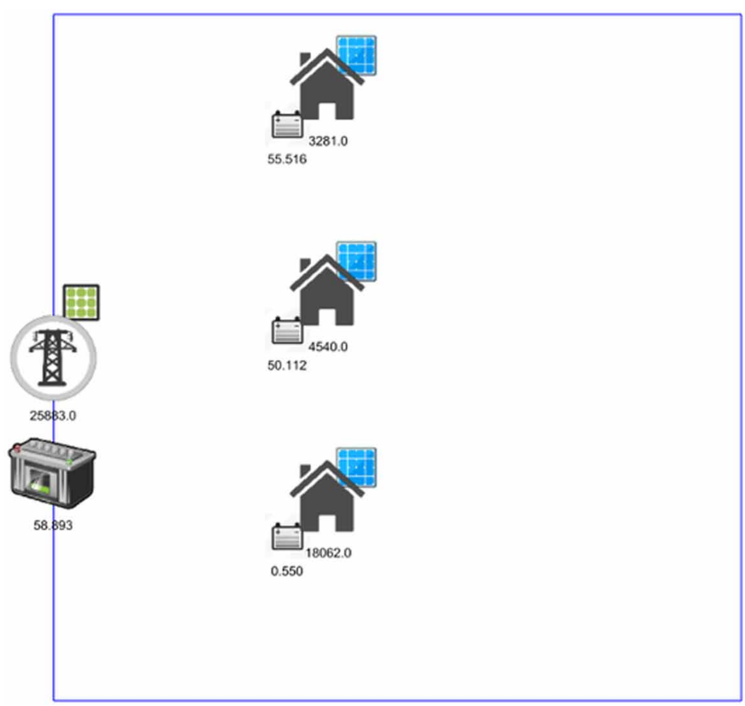
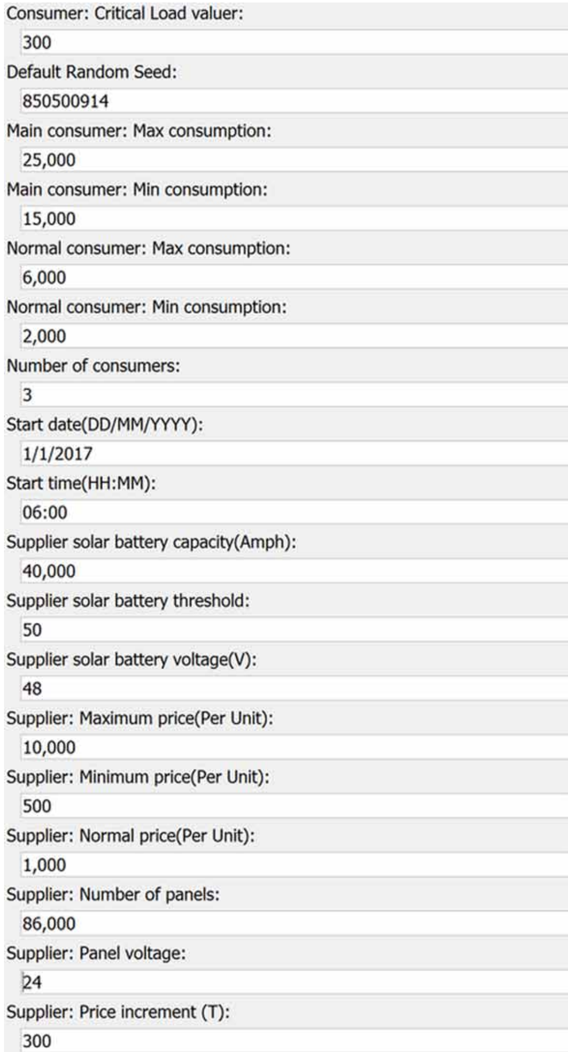


Figure 6. 2D visualization of the microgrid



which the price depends on several factors such as the consumption rates, the weather conditions as well as different offers in the grid system. Also in Figure 8 the price has been low most of the time with some few spikes going to high when the power was running down and this has happened due to the increase of supplier solar panels and battery storage capacity.

With respect to the community, the utilization of the demand response schema and price management provides the stability of the system and makes a better profit. The reason for this is due to the fact that majority of the users will keep on tracking the pricing profile and make use of electricity efficiently. Moreover, many users may decide to use their battery storages during peak hours and leave the grid only for critical loads such as hospitals and schools. In the long run, if every community can manage to control and monitor its own microgrid based on price control, then the effect of deficiency power will be decreased.

The load profile graphs can be seen in Figure 9 showing the shedding and non-shedding of the appliances to an individual house. In this manner, in the time of the highest price peak, the house

Figure 7. Price vs time when shedding

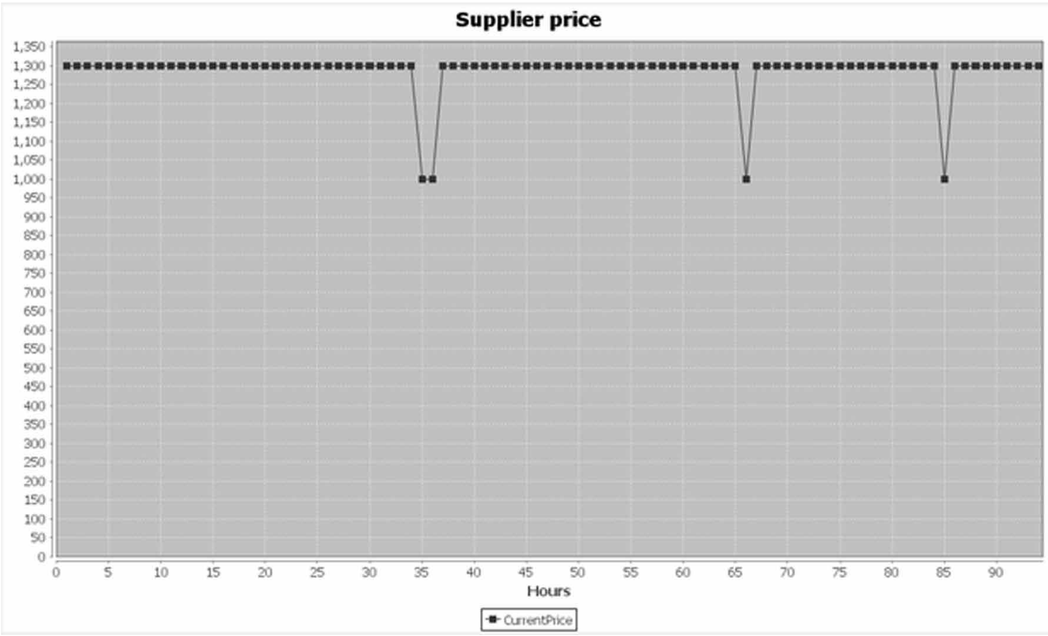
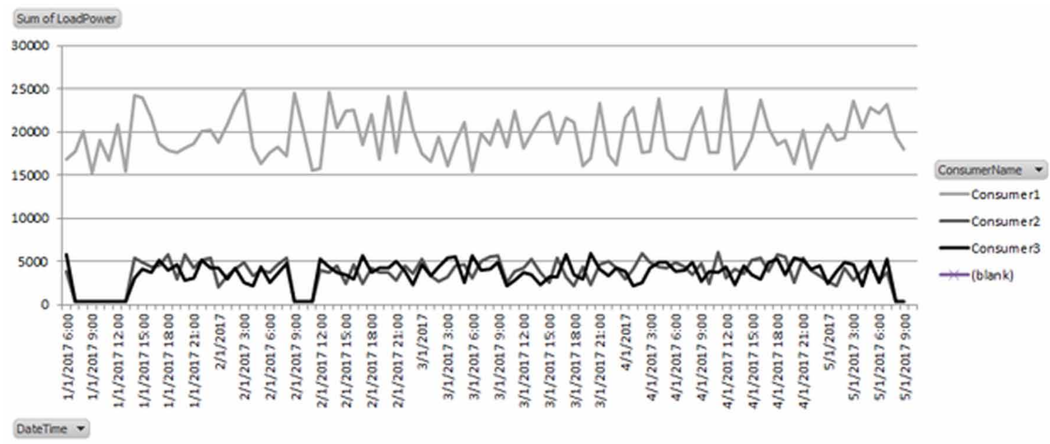


Figure 8. Price vs time without shedding

decides to switch off some of the less important appliances in order to reduce the cost. Therefore, the only option is either off operation or decide to use its own battery. With respect to the price to become low, it can be seen that the supplier has enough electricity to the supplier to consumer load and hence, no load shedding process.

Figure 9. Consumer power consumption vs time without load shedding

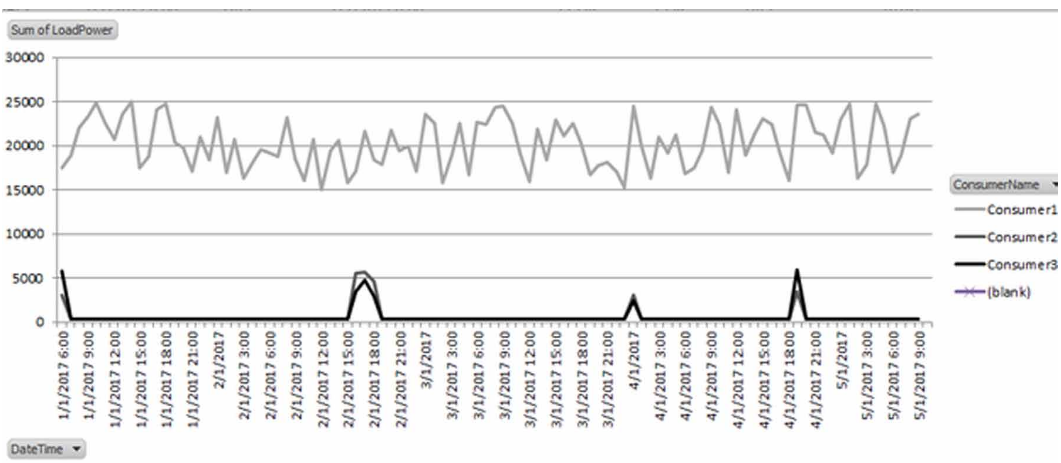


From Figure 10 when the load shedding takes place, the supplier continues to provide electricity to the critical load and cut off the non-critical loads. At the same time, the price of electricity was high due to that fact that it has less power to supply. This may be due to weather conditions, high demand and so on. Therefore, in this case, the non-critical loads decide to utilize its own battery and reduce the consumption through switch off air conditioner and just remained with the important appliances, i.e. TV, light and fridge. The spikes seen on the graphs are when the price was lowered by the supplier and hence, the non-critical loads return into the microgrid.

7. CONCLUSION

The design and implementation of microgrid systems depend much on the perfect modeling of its components. This work shows the effect of both load shedding and no load shedding on modeling of the solar driven DC microgrid with the effect of demand response based on pricing. The ideas of an individual load to disconnect the non-critical appliances have been seen to work successfully when

Figure 10. Consumer power consumption vs time with load shedding



the DC-microsystem suffers from power scarcity. In addition, the use of battery management system for checking the DoD is important for the microgrid system to improve the battery health. With different numbers of houses and different parameters, using the multi-agent system, the solar agent can provide power to the microgrid and leave the critical load in a safe mode as well as make use of demand response to solve the issue of supplying and demanding. In addition, the effect of demand response can be achieved with load agents to provide extra power to critical appliances automatically.

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