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Developing Cost Effective Demand Response Management Algorithm For Ac/Dc Hybrid System

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ABSTRACT:*The focus of micro-grid developers is to meet the required power demand of final consumers in small localities at every point in time. Fortunately, there exist hybrid power sources (ac/dc) in most parts of Nigeria, though in most cases are not optimally utilized due to its very high initial investment cost.as consumers electricity requirement /consumption pattern varies per time, it is important to have a system that considers their demand response pattern for most effective economic power management.*

INDEX TERMS:*About four key words or phrases in alphabetical order, separated by commas.*

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I. INTRODUCTION

Meeting consumers' satisfaction has been a major challenge to micro-grid project developers because of the huge capital required to match demand with generation at various time of the day. Moreover, there exists a mismatch between peak PV power generation time and peak load power consumption time. This timing skew result in conditions where the generated PV power cannot be optimally utilized to perform peak load power unless huge capital is invested on energy storage units thereby making the system not to be economically viable.

As a way out, Demand Response Management (DRM) system has been proposed by many authors as a means of improving overall system performance by influencing either the quantity or time pattern of energy consumption in order to meet consumers' need. Palensky and Dietrich (2011) defined Demand side management (DSM) as a portfolio of measures that is aimed at improving energy utilization at the consumer end which includes adoption of smart energy tariff with incentives for certain consumption patterns or the use of more efficient appliances and sophisticated real-time control of Distributed Energy Resources (DER). Tsado Imoru and Segun (2012) added that Demand Response System (DRS) is the ability of the smart grid to respond to consumers varying demand in an automated real time fashion. This enables the system to vary supply to consumers in an attempt to meet their instantaneous demand. This might involve load-forecasting techniques to predict when peak load will occur and optimize algorithm that can then be applied to reduce peak load. The system consists of two distinct parts: Distribution software and hardware module. Pedrasa, Spooner and MacGill (2010) presented method of optimizing energy consumption through the use of algorithmic enhancement decision support tool which enables consumers to assign values based on priority to various loads. Through this method, an optimization problem was developed and solved using Particle Swarm Optimization (PSO) while Anil, Chatterji and Mahesh (2012) adopted the same approach in residential load management and recorded a cost saving of about 36%. Furthermore, Mohsenian-Rad et al, (2010) considered reducing the peak to average load ratio through deployment of energy consumption scheduling (ECS) devices. These devices were assumed to be embedded into smart meters, connected to the grid and local area network. It involves development of an algorithm to determine optimal energy consumption schedule for each subscriber and incentives used to optimize the load consumption.

II. DEMAND RESPONSE MANAGEMENT ALGORITHM (DRMA)

This algorithm enables the system to vary supply to consumers to meet their instantaneous demand. It involves a load clipping technique whereby a load limit (LL) is set for individual household and an optimization algorithm is applied to reduce the load whenever it exceeds this set limit. To do this, the different loads are given

different priority level based on the status of illumination sensors (IS), motion detectors (MD) and the priority (P1, P2 and P3) levels of the load. Figure 2.0 is Layout of Sensors and DC Loads for a Three (3) Room Building
This section shows the step by step process involved in achieving DRMA.
Step 1: Get the value of DC load limit (LL)
Step 2: Get the status of illumination sensor (IS)
Step 3: Get the status of motion detector A, B and C (MD1, MD2 and MD3)
Step 4: Get the value of Current Load (CL)
Step 5: Is CL greater than LL? If yes, go to step 6. If no, go to step 13
Step 6: If IS=0 and Manual switch=0, turn off outside light, set IS=1 and return to step 4. Otherwise, go to step 7.
Step 7: If MD1=0 and Manual switch1=0, turn off room 1 light and fan, set MD1=1 and return to step 4. Otherwise, go to step 8.
Step 8: If MD2=0 and Manual switch2=0, turn off room 1 light and fan, set MD2=1 and return to step 4. Otherwise, go to step 9.
Step 9: If MD3=0 and Manual switch3=0, turn off room 1 light and fan, set MD3=1 and return to step 4. Otherwise, go to step 10.
Step 10: If room with priority level 1 has P1 set to 1 and Manual switch1=0, turn off fan in this room, set P1=0 and return to step 4. Otherwise, go to step 11.
Step 11: If room with priority level 2 has P2 set to 1 and Manual switch2=0, turn off fan in this room, set P2=0 and return to step 4. Otherwise, go to step 12.
Step 12: If room with priority level 3 has P3 set to 1 and Manual switch3=0, turn off fan in this room, set P3=0 and return to step 4. Otherwise, go to step 13.
Step 13: If RESET=1, go to step 1. Otherwise, go to step 2
Step 14: End.
The flow chart for this algorithm is presented in figure 1.0.

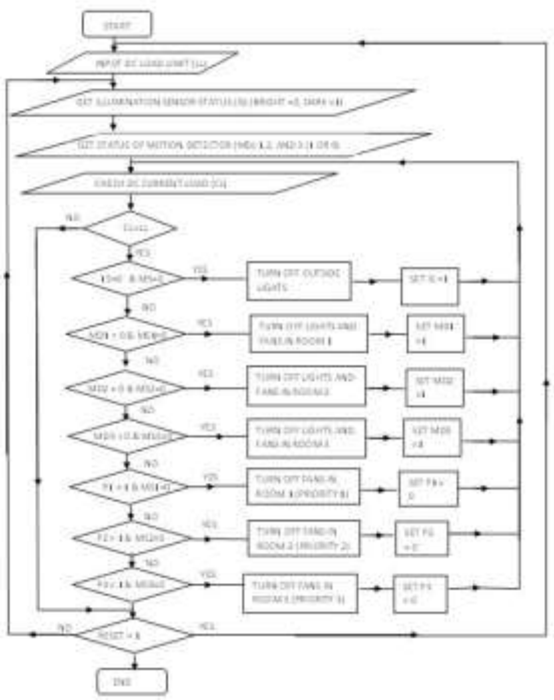

Figure 1.0: Demand Response Management Flowchart

III. IMPLEMENTATION OF DRMA

The system for the implementation of DRMA consists of different parts: master controller, sub controller, illumination sensor and motion detector.

A. Master Controller

This is placed very close to the metering system at the point of termination of the grid in the consumer premise. Most smart metering systems have the ability of implementing the algorithm of the master controller.

B. Sub-Controllers

These are located very close to the load and are room level sub-controllers that are placed in each room and connected to the master controller. The room-level sub-controllers control the operation of a multi-port converter. The master controller assigns different priority levels to each room-level sub-controller while the room-level sub-controller determines different priority levels for the different output port of the multiport converter. The input voltage to the converter is 380volts DC while the output voltage from each of the output ports is 24volts. Each of these output ports can be turned on or off based on instruction received from the controllers.

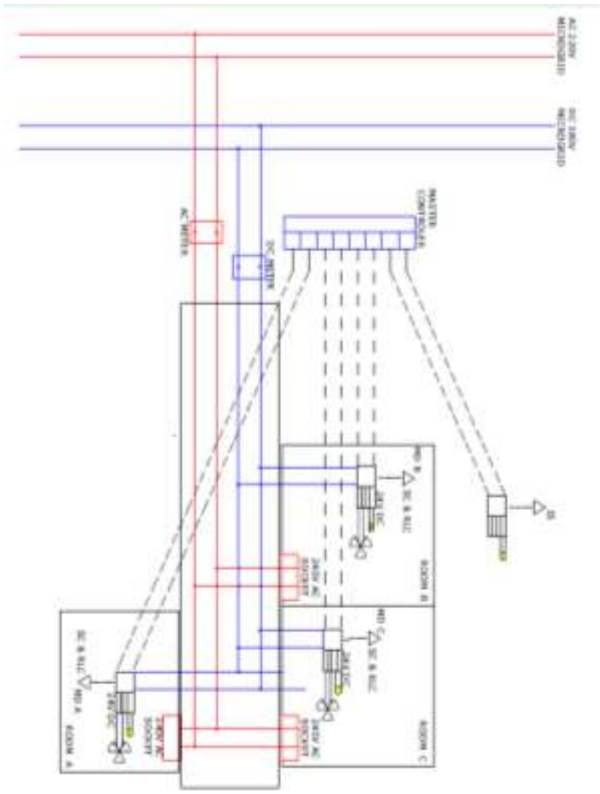

Figure 2.0: Layout of Sensors and DC Loads for a Three (3) Room Building

C. Illumination Sensor

This controls the surrounding lights. When the load limit is exceeded, the controller assigns priority level value to these loads based on the status of illumination sensor. If the surrounding is bright, the illumination sensor sends a Boolean value of "0" to the controller. The controller subsequently assigns a low priority level to the load which causes the load to go off. On the other hand, if the surrounding is dark, the illumination sensor sends a Boolean value of "1" to the controller which then assigns a high priority value to the load. On this condition, the master controller allows this load to remain on and considers other option for load shedding.

D. Motion Detector

This device is placed within each room to detect the presence of occupants based on the monitoring of motion within the room using RADAR (Radio detection and ranging) signal. It sends the Boolean value of "1" to the controller when motion is detected and a Boolean value of "0" when no movement is detected within a specified time interval. For the purpose of this work, the Lights in each room were assigned higher priority than the fans for easy understanding of the process. This can be altered by interchanging the connection port of the light and fan.

IV. SIMULINK IMPLEMENTATION OF DRMA

The algorithm for the master controller is implemented in SIMULINK environment using the enable subsystem, trigger subsystem, if else conditional subsystem and "AND gate" logical operator. Figures 3.0 and 4.0 shows the various DRM subsystems.

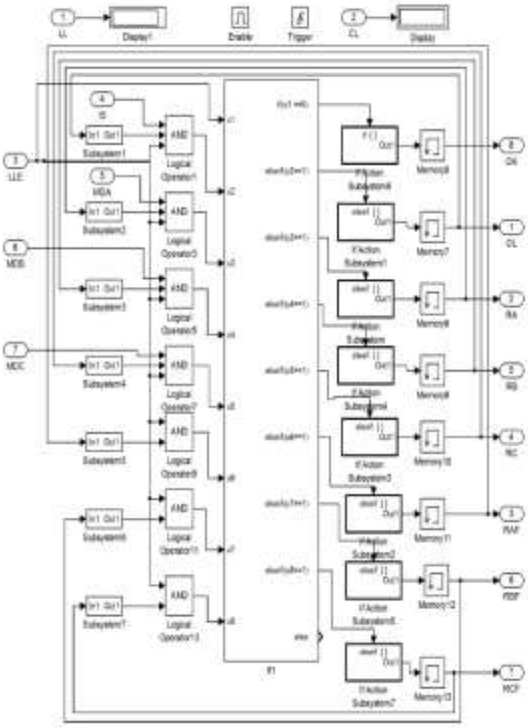

Figure 3.0: Simulink Implementation of DRMA of IF ELSE Subsystem and some other Components

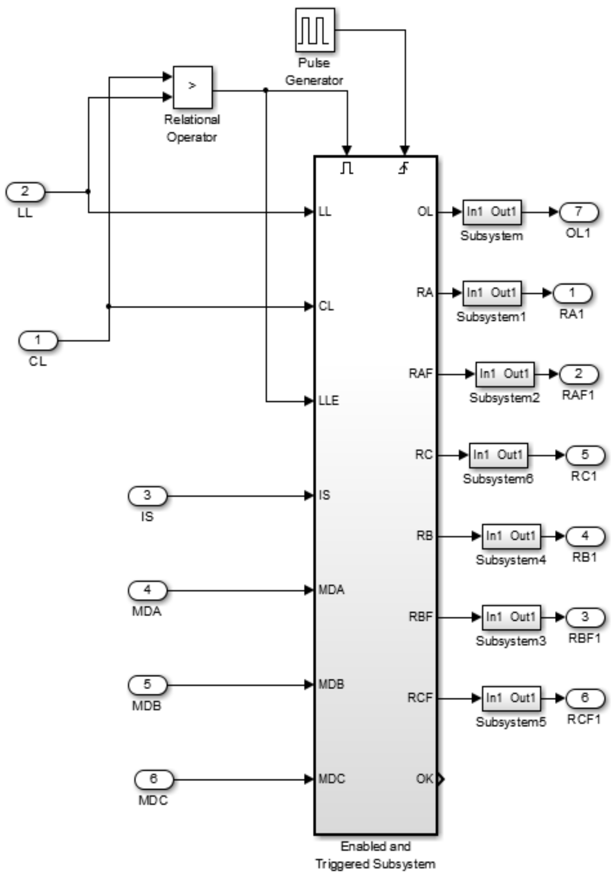

Figure 4.0: Simulink Implementation of DRMA Using Enable/Trigger Subsystem and other Interconnected Components

V. INCORPORATING DRMA INTO HYBRID AC/DC MICRO-GRID

The modeling of AC/DC hybrid system is shown in figures 5.0 and 6.0. To produce a hybrid AC/DC, the DC subsystem shares the same PV, charge regulator and battery storage with the AC subsystem. All the plug loads such as televisions and refrigerators are modeled as AC load while the lightings and fans were modeled as DC load. The submersible pump was modeled as a DC load because of its high efficiency. This setup is shown in figures 5.0 and 6.0 and the loads were lumped together. A Demand Response Management System which executes an algorithm that helps in consumer side energy management was introduced into the Hybrid AC/DC system to improve energy management in the DC sub-grid. This algorithm relies on user defined priority level and load limit by assigning priority levels to the various loads and shutting down loads of less priority when a preconfigured load limit is exceeded.

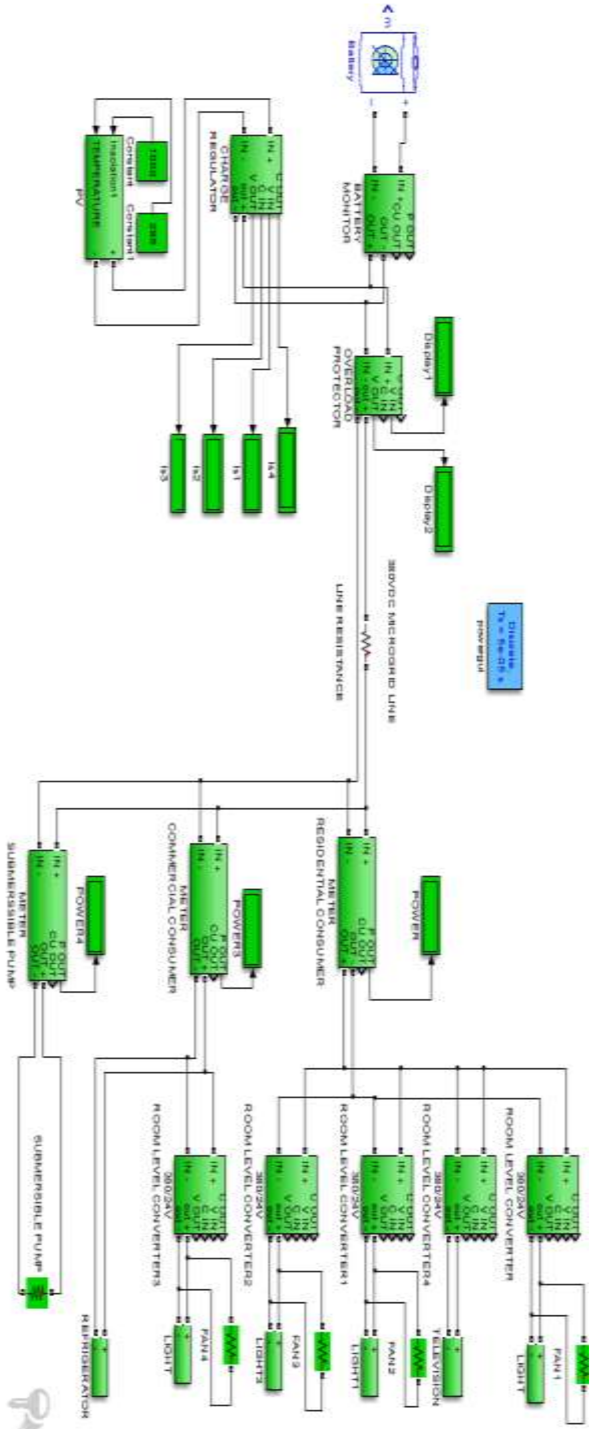

Figure 5.0: Simulink Implementation of DC Micro-Grid System

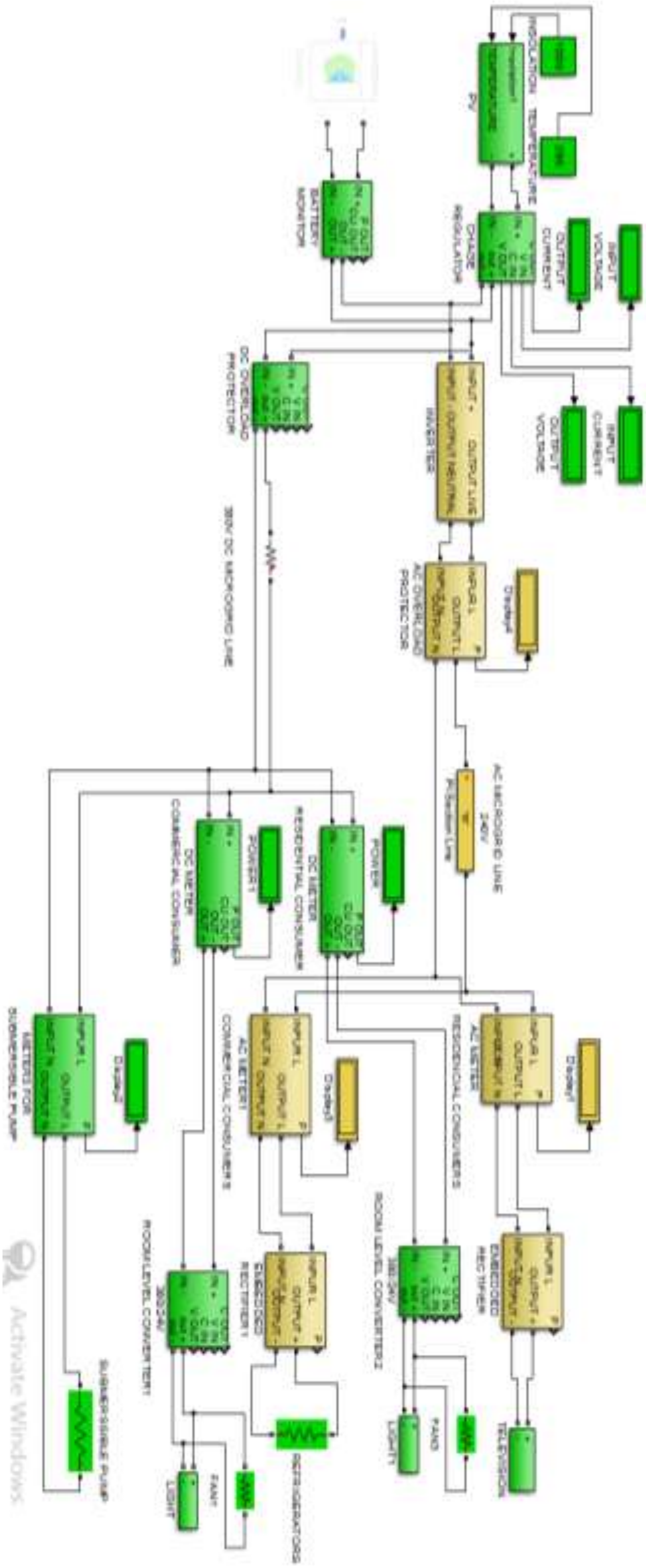

Figure 6.0: Simulink Implementation of Hybrid AC/DC Micro-Grid

VI. RESULTS

In order to determine voltage drop on the grid network having load of 9000watts connected to both grids, the voltage levels along the line length was measured and expressed in percentage. Figure 7.0 is a graph of the percentage voltage level as the length increases. The red line indicates the 5% allowable voltage drop.

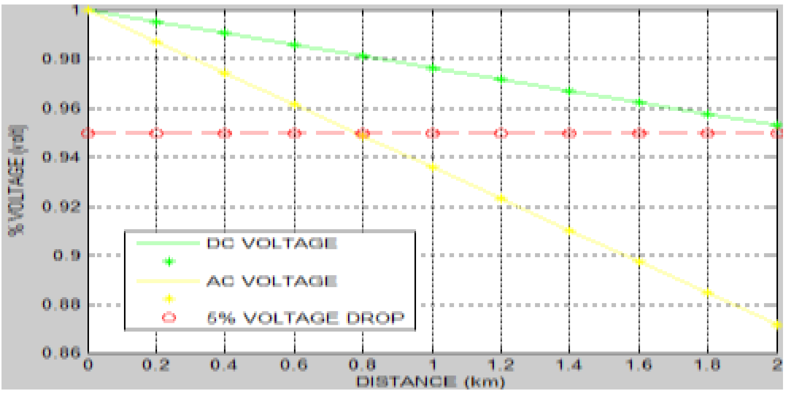

Figure 7.0: Graph Showing Percentage Voltage Level as Conductor Length Increases in AC and DC Grid.

To determine power loss along the line, watt meter was placed along the length of the AC and DC distribution line and the change in total power was computed and plotted against the corresponding length. This is presented in figure 8.0

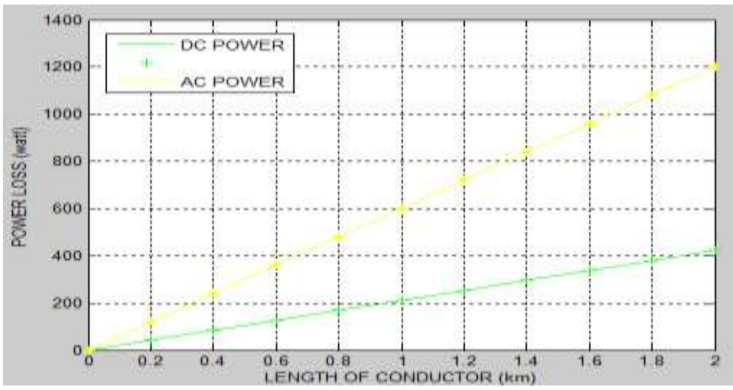

Figure 8.0: Graph of Power Dissipated Along the AC and DC Distribution Line as Line Length Increases.

The power loss obtained for the two grid infrastructures were plotted against the load ratings as shown in Figure 9.0.

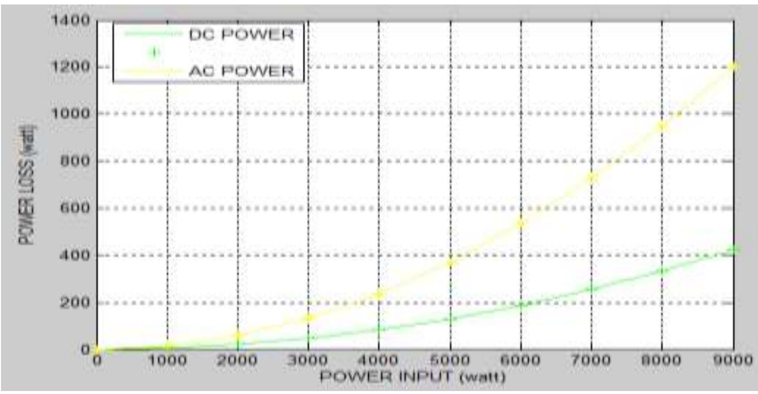

Figure 9.0: Graph of Power Loss Against Input Power for a Distribution Length of 2km

Tables 1.0 - 4.0 presents the outcome of DRMA with all possible status of the sensors at various DC load limits. The column for meter reading was developed from DC meter reading during simulation. From the tables, the Boolean value "0" with white background indicates that the load was turned off by the sensors while the value "0" with red background indicates that the load was turned off by the load monitor due to exceeded load limit and priority value. The value "1" indicates that the load is on. Illumination sensor value of "1" means that the environment is dark hence the outside lights are turned on while "0" indicates otherwise. Motion Detector value of "0" means that there is no occupant within the room hence the need to turn off the light and fan or only the light based on priority level of the room while "0" indicates otherwise.

Table 1.0: All Possible Status of Sensors and Corresponding Status of DC Load when Maximum Load Limit is Set above the Peak DC Load Per Residential Building

	SENSORS				ROOM A		ROOM B		ROOM C			
S/NO	MD A	MD B	MD C	IS	FAN A	LIGHT A	FAN B	LIGHT B	FAN C	LIGHT C	OUTSIDE LIGHT	TOTAL LOAD
1	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	1	0	0	0	0	0	0	1	26
3	0	0	1	0	0	0	0	0	1	1	0	43
4	0	0	1	1	0	0	0	0	1	1	1	69
5	0	1	0	0	0	0	1	1	0	0	0	43
6	0	1	0	1	0	0	1	1	0	0	1	69
7	0	1	1	0	0	0	1	1	1	1	0	86
8	0	1	1	1	0	0	1	1	1	1	1	112
9	1	0	0	0	1	1	0	0	0	0	0	43
10	1	0	0	1	1	1	0	0	0	0	1	69
11	1	0	1	0	1	1	0	0	1	1	0	86
12	1	0	1	1	1	1	0	0	1	1	1	112
13	1	1	0	0	1	1	1	1	0	0	0	86
14	1	1	0	1	1	1	1	1	0	0	1	112
15	1	1	1	0	1	1	1	1	1	1	0	129
16	1	1	1	1	1	1	1	1	1	1	1	155

Table 2.0: All possible Status of Sensors and Corresponding Status of DC Load when Maximum DC Load Limit is Set 150 Watt Per Residential Building

	SENSORS				ROOM A		ROOM B		ROOM C			
S/NO	MD A	MD B	MD C	IS	FAN A	LIGHT A	FAN B	LIGHT B	FAN C	LIGHT C	OUTSIDE LIGHT	TOTAL LOAD
1	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	1	0	0	0	0	0	0	1	26
3	0	0	1	0	0	0	0	0	1	1	0	43
4	0	0	1	1	0	0	0	0	1	1	1	69
5	0	1	0	0	0	0	1	1	0	0	0	43
6	0	1	0	1	0	0	1	1	0	0	1	69
7	0	1	1	0	0	0	1	1	1	1	0	86
8	0	1	1	1	0	0	1	1	1	1	1	112
9	1	0	0	0	1	1	0	0	0	0	0	43
10	1	0	0	1	1	1	0	0	0	0	1	69
11	1	0	1	0	1	1	0	0	1	1	0	86
12	1	0	1	1	1	1	0	0	1	1	1	112
13	1	1	0	0	1	1	1	1	0	0	0	86
14	1	1	0	1	1	1	1	1	0	0	1	112
15	1	1	1	0	1	1	1	1	1	1	0	129
16	1	1	1	1	1	1	1	1	0	1	1	125

Table 3.0: All Possible Status of the Sensors and the Corresponding Status of DC Load when Maximum DC Load Limit is Set 120 Watt Per Residential Building

S/NO	SENSORS				ROOM A		ROOM B		ROOM C		OUTSIDE LIGHT	TOTAL LOAD
	MD A	MD B	MD C	IS	FAN A	LIGHT A	FAN B	LIGHT B	FAN C	LIGHT C		
1	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	1	0	0	0	0	0	0	1	26
3	0	0	1	0	0	0	0	0	1	1	0	43
4	0	0	1	1	0	0	0	0	1	1	1	69
5	0	1	0	0	0	0	1	1	0	0	0	43
6	0	1	0	1	0	0	1	1	0	0	1	69
7	0	1	1	0	0	0	1	1	1	1	0	86
8	0	1	1	1	0	0	1	1	1	1	1	112
9	1	0	0	0	1	1	0	0	0	0	0	43
10	1	0	0	1	1	1	0	0	0	0	1	69
11	1	0	1	0	1	1	0	0	1	1	0	86
12	1	0	1	1	1	1	0	0	1	1	1	112
13	1	1	0	0	1	1	1	1	0	0	0	86
14	1	1	0	1	1	1	1	1	0	0	1	112
15	1	1	1	0	1	1	1	1	0	1	0	99
16	1	1	1	1	1	1	0	1	0	1	1	95

Table 4.0: All Possible Status of Sensors and Corresponding Status of DC Load when Maximum DC Load Limit is Set 100 Watt Per Residential Building

S/NO	SENSORS				ROOM A		ROOM B		ROOM C		OUTSIDE LIGHT	TOTAL LOAD
	MD A	MD B	MD C	IS	FAN A	LIGHT A	FAN B	LIGHT B	FAN C	LIGHT C		
1	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	1	0	0	0	0	0	0	1	26
3	0	0	1	0	0	0	0	0	1	1	0	43
4	0	0	1	1	0	0	0	0	1	1	1	69
5	0	1	0	0	0	0	1	1	0	0	0	43
6	0	1	0	1	0	0	1	1	0	0	1	69
7	0	1	1	0	0	0	1	1	1	1	0	86
8	0	1	1	1	0	0	1	1	0	1	1	82
9	1	0	0	0	1	1	0	0	0	0	0	43
10	1	0	0	1	1	1	0	0	0	0	1	69
11	1	0	1	0	1	1	0	0	1	1	0	86
12	1	0	1	1	1	1	0	0	0	1	1	82
13	1	1	0	0	1	1	1	1	0	0	0	86
14	1	1	0	1	1	1	0	1	0	0	1	82
15	1	1	1	0	1	1	1	1	0	1	0	99
16	1	1	1	1	1	1	0	1	0	1	1	95

VII. DISCUSSION

A. Voltage Drop

Figure 5.0 shows voltage drop along the DC and AC distribution line at 9000watt load as the length of the line increases. It can be observed that the voltage level on the AC grid dropped to 95% at 800m while the voltage level on the DC grid remained above 95% even at 2000km. This shows that the DC grid has improved performance in terms of voltage drop and hence, the distribution line can extend to greater distance if DC distribution is adopted. Moreover, because of this reduction in voltage drop over larger length, it was possible to integrate the DC grid of the three sites since synchronization is not required for DC grid integration unlike the case of AC grid integration. This improved the reliability of the system. If one site fails, the other site can easily manage the loads. However, control method must be implemented to manage the energy flow.

B. Loss in Distribution Grid and Converters

Figure 6.0 shows power dissipated along the distribution line (at 9000watt load) as the length of the line increases. Power lost along the AC grid at a length of 2000m is 1200watt while that of DC at same length is 420watt. Figure 3.0 shows a graphical comparison of the power dissipated in both grids at different load level with a constant distribution line length of 2000m. The value obtained from the graph at 9000watt input from the source corresponds to the value obtained from figure 2.0 This graph demonstrates that tremendous amount of energy could be saved if DC distribution is implemented. The grid length of each site is 833m. From figure 2.0, line loss for AC grid of 9000watt load at this distribution length is 500watt while the loss on DC grid is 180watt. The net saving when DC is implemented is 320watt (500watt - 180watt). Hence, for the three sites, the net saving on the DC grid is 320*3=930watt. Furthermore, DC to AC conversion loss on the inverter for the three site (27000watt) =1,242watt. The net saving associated with the direct DC appliances for 27000watt lump load is 2,662watt. The net saving on the distribution line when DC grid is implemented is 930watt.Total net saving associated with the implementation of DC micro-grid equals (1242+2662+930 =4834watts).
This is 17.9% of the total power.

VIII. ANALYSIS OF THE DRMA RESULT

From table 1.0, the status of all the lights and fan are dependent on the sensors since the maximum load limit (LL) is set above the peak DC load which is 155watt as can be seen from the last row (row 16) of the table. (Note that row 16 has all the sensor status as “1” hence all the load are turned on since the LL is not exceeded). In the case of table 2.0, the load limit (LL) was set to 150watt. Row 1 to row 15 has all the light and fan controlled by the sensors. However, in row 16, all the sensors had the status as “1” but the fan in Room C was turned off. This is because the load limit was exceeded at this point and the DRM system turns off the fan due to its priority level thereby reducing the load from 155wats to 125 which is within the set limit. (Note that Room C has the least priority of 1). Also, in table 3.0, the load limit (LL) was set to 120watts. It can observed that for row 16 with all the sensors set to “1”, Room C fan and Room B fan were turned off to reduce the load to a value of 95watts. Note that room C has the least priority of 1 followed by room B with priority level 2. Also note that the lights in the entire building were assigned a higher priority than the fans. For row 15, the external lighting was turned off based on the sensor status of “0” yet the available load exceeded the LL. Subsequently, Room C fan was turned off based on priority level. Similarly, in table 4.0, the motion detector in Room A had a status of “0”. Hence, both light and fan in Room A were turned off but the available load was still above the load limit (LL) of 100watts. Subsequently, Room C fan was turned off based on priority level. The same logic applies to Row 12, 14, 15 and 16.

IX. CONCLUSION AND RECOMMENDATION

The Hybrid AC/DC micro grid presented in this work demonstrated that tremendous amount of energy can be saved from the use of DC distribution and DC appliances. The energy lost in the Hybrid AC/DC grid and appliances were analyzed. Furthermore, DRMA was developed and implemented to influence energy consumption without compromising the comfort of electricity consumers. Although the DC micro-grid offered the greatest energy saving potential, the Hybrid AC/DC micro-grid is recommended to serve as a transition phase since it will be very difficult to adopt pure DC micro-grid due to cost. However, DC appliance will gradually become cheaper if fully adopted as a result of less electronic waste associated with it and economy of scale. The cost of transition to DC micro-grid might be very expensive in terms of capital expenditure but has a very attractive operating cost. This cost analysis is recommended for further research. The work can be extended to grid-tied and stand-alone distributed generation systems, only off grid systems were considered.

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