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Real Time Energy Monitoring and Control Model for Peer-to-Peer Integrated Hybrid Supply System

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Abstract— *Energy wastages arising from isolated households operating on standalone or hybridized energy systems constitute major source of economic losses. Application of formidable energy management, monitoring and control schemes is a remedy. This research designed a real time energy monitoring and control model for peer-to-peer integrated hybrid supply system. Five co-located households in semi-estate scenario, each connected to a central grid supply; renewable energy supply and individual standby generators with associated loads formed the network. A central controller was designed to monitor and control the network generation and consumption of energy. Excess power from individual household generators and or renewable energy sources during grid down time are accumulated by the central controller and shared in equal proportion to the remainder of the households with automatic overload control. The system was designed and simulated with Proteus simulation software and Arduino Integrated Development Environment (IDE). Results obtained from the simulation showed effective elimination of power wastages and improved efficiency of generators. Subsequent research will explore the transformation of the design to a physical model.*

Index Terms—Energy Monitoring, Energy Control, Integrated Supply, Peer-to-Peer System, Real time Model

I. INTRODUCTION

Access to reliable, affordable and sustainable energy is essential for industrial development and economic growth. To improve living standards in developing countries, it is essential to expand access to reliable and clean energy. Smart home energy management system is a system capable of exchanging commands between households and energy providers to optimize energy consumptions. Collaboration between energy stakeholders result in a minimal consumer electricity cost and better management of the peak loads by the utility providers. Another key feature is to enable consumers and utility providers to communicate with each other while sharing the responsibility of managing the power flow and consumption. Clean, efficient, affordable and reliable energy services are indispensable for global prosperity. Energy demand management system, and optimization solution would help reduce energy costs while improving operational performance. The high demand for energy supply due to rapid population increase leads to the consideration of other sources of energy for optimal performance. The hybridized smart energy connection earlier developed for individual utilization now needs to be integrated into a common mini-grid for cooperative use [1][2]. But the system requires more devices and sensors which would make

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the configuration complex, thereby creating new research challenges. However, recent technological advancements in the energy sector would pave way for thriving clean and renewable energy resources using the Internet of Things (IoT) to handle the envisaged complexity [3].

There is need to develop a clean energy self-regulating system for integrated low-level voltage system in micro-grid configuration. [4] proposed a framework that would ensure effective renewable and clean energy utilization and sustainability in buildings using Internet of Things (IoT), sensors and other smart devices. These would create and exploit innovative energy solutions from clean and renewable resources through remote access monitoring and control activity. Renewable energy resources could only be used as intermittent energy sources, because power generated by them fluctuates randomly. Appropriate measures to mitigate these shortcomings is to integrate clean energy resources with other already existing power sources. Through the use of smart energy controllers, efficient regulation, management, monitoring and control; the reliability of power supply is improved with minimal outages [5]. This research would deploy a design to demonstrate with some household buildings in a semi-estate with five detachable buildings using the application of smart energy sharing arrangement. These buildings are assumed to have integrated their standby generating sets, clean energy system and public power supply under a peer-to-peer arrangement using a smart integration scheme (common bus) with energy priority concept.

The co-located households are connected to a central grid supply, renewable energy supply and individual standby generators with associated loads to form the network. A central controller was designed to monitor and control the network generation and consumption of energy. Individual households have equal priorities of energy allocation with supply from the grid**.** During grid down times, priority shifts to ensure that individual households with running standby generators and or renewable energy resources have enough power allotment to supply their loads. The excess of power from the generator and or renewable energy sources are accumulated by the central controller and shared in equal proportion to the remainder of the households. Any attempt by individual households to exceed their allocated power, results in automatic supply cut-off and reset, thereby allowing loads within allocated capacity. Each household is equipped with a metering system that displays real time energy availability and consumption.

The challenges of standalone and hybrid renewable energy systems already in use have been overcome due to the prevailing energy innovations, but the most recent challenges are in energy integration, monitoring, control, and data management [6]. These are due to the complexity arising from integrating multiple energy sources into a single grid system [7]. More so, remote monitoring and control would minimize intermittent energy fluctuation, which is the primary setback in renewable energy systems that calls for hybridization of resources before integration to form one of the sources among other multiple sources [5][8]. Most of the already experimented integrated system are now facing large data management problems due to application of monitoring and control schemes. Thus, there is the need for smart configuration with Internet of Things (IoT) [3]. The following gaps were identified and solutions were proffered: energy integration complexity problem was resolved using an intelligent system developed to facilitate smart energy integration into the mini-bus after synchronization. Intermittent renewable energy fluctuation challenge was taken care of through hybridization of several renewable energy systems aimed at mitigating the inherent fluctuations in renewable energy supplies due to their seasonal dependence. On the other hand, large data handling challenges were checked through the introduction of Internet of Things (IoT) involving Android devices for remote access of energy information on real time basis. Web-based documentary for energy management, forecasting, energy generation and consumption assessment by regulatory agencies were developed. However physical implementation of the design is a subject of further research endeavors. The aim of this work is to design a real time energy monitoring and control model for peer-to-peer integrated hybrid supply system. The following are the specific objectives to: develop real time smart power controller for collaborative energy monitoring and control with load and generator priority scheduling; adopt an integrated and synchronized scheme for already existing grid system, generator set and renewable energy system; develop circuitries for real time remote monitoring and control of the generated and consumed energy and develop an overall system energy scheduling and balancing scheme.

These would create an era of smart energy management through remote energy, scheduling, monitoring and control in which disputes on quantity of power generated by individual sources and consumed by individuals from the central point will no longer be an issue. With the introduction of real time energy scheduling, monitoring and control using Internet of Things (IoT), the co-located households would be able to access and retrieve energy transaction details remotely. Real time energy access would be achieved by both the consumers and the producers with the capacity to TURN ON/OFF the supply remotely, thereby, reducing the cost of energy.

II. Literature Review

In order to maintain a renewable energy smart-grid inter-connectivity, Internet of Things (IoT) would provide variety of household applications that facilitate sustainable energy delivery. Internet of Things encompasses cloud computing and android devices for real time energy monitoring and control [3]. The challenges in determining the quantity of renewable energy produced has recently led to the development of virtual power operating centre for assisting energy producers and decision makers in the energy market with relevant data. However, adaptive models were used to provide more reliable prediction algorithm [9]. [4] observed large data management as a problem in buildings. Large data emanate from smart metering systems, sensors and other devices associated with Internet of Things (IoT), and as such developed a building data exchange model with algorithm from artificial intelligence to ease data handling. [10] discovered that renewable energy requires adequate management system such as data processing to aid control activities. [11] posited that the universal energy demand by 2050 would be met from renewable energy supply sources integration, these predictions were made from the renewable energy dataset which shows that renewable energy would contribute two-third of bulk energy consumption, and thus would help to reduce emissions from greenhouse gases. [12]

explored the potential of renewable energy for large integration system and provided a guide for its integration in order to form the largest share in energy produced for consumption. [13] x-rayed the potential of renewable energy and explained that for renewable energy to be the leading energy source in the energy sector, smart-grid integration should be encouraged for sustainable energy supply. To attain a complete transition from conventional energy source to renewable energy system successfully, small-scale integration and Internet of Things should be the first step. However, many renewable energy sources were presented in a modelled form, optimized and their integration was virtually demonstrated [14]. [15] and [6] revealed that control issues associated with renewable energy systems include their integration challenges which poses serious threats to the power system stability in the microgrid. Their research showed that connecting renewable energy source to the grid was one of a major way of ensuring a sustainable energy supply, they also suggested that from developed single phase microgrid model, the electric grid should be made to adapt to the generation units before its integration. [16] showed that a control scheme with a DC microgrid simulation model for autonomous control operation under various load conditions may serve household energy needs. The emerging electricity market would be interested in the deployment of a large quantity of renewable energy resources into the microgrid with flexible, controllable and efficient operation.

[17] reported the possibility of integrating renewable energy resources into the Alaska's island microgrid energy system which has over 200 communities as beneficiaries. These microgrid energy systems have operated for many years without interconnectivity, despite available renewable energy resources due to integration and control challenges. [18] attempted to monitor and control an integrated renewable energy system on a real time basis but discovered that the intermittent and random nature of renewable energy resources is a major challenge hampering reliability of the system, thus proposed a new off-line optimization approach to drive the online algorithm. [7] developed a residential feeder of Low voltage microgrid benchmark model for the integration of multiple sources and loads into the grid as measures to increase reliability of renewable energy systems.[19] explored the concept of blockchain in community energy management for smart grid systems, where several self-renewable energy generating users share energy in the community microgrid for optimal community utility. In these cases, every participant applies the best strategy to minimize their energy consumption cost with Internet of Things (IoT) and smart metering system. [20] reviewed current renewable energy status in Nigeria and proposed the use of abundant renewable resources instead of over dependence on fossil fuel. Based on the level of renewable energy endowment in Nigeria, there should be efforts to ensure uninterrupted energy supply through proper harnessing of the resources in order to minimize dependence on fossil fuel with the attendant environmental challenges [21]. Based on facts from the reviewed literature, the challenges of energy data handling, intermittent energy fluctuation and energy integration problems have continued to attract research attention without consideration of energy wastages emanating from the non-scheduling of available energy among collaborating peers [22]. Thus, the need for the design of a real time smart scheduling, monitoring and control model for cooperative energy utilization aimed at curbing the challenges of load scheduling, energy wastages, monitoring and control.

III. Research Methodology

The research applied simulation approach to demonstrate its conceptual model. Software simulation with the underlisted materials was carried out and combination of the components design formed the adopted method. From the experimental setup, whenever any of the power supply sources was ON, connected bulbs with varying specifications (power rating) consumes power representing each household power consumption as recorded by the wattmeter. Similarly, the power generated was also metered, to ascertain the quantity coming in from each source.

A. Research Materials and Equipment

Virtual hardware such as Arduino Uno, Sensors (current and voltage), Switches (Push buttons, Mechanical), IoT Device, Liquid crystal display screen, Resistors, Capacitors, Voltage Regulators, Relays, Transistors, Diode, Synchronizer, Infinite bus bar and Power Supplies (National Grid supply, Renewable energy supply and Generating set supply) were used.

Software: - Proteus, Arduino IDE, Mongo DB, JavaScript, Hypertext Preprocessor (PHP) and HTML & CSS were also used.

B. Research Designs

In this simulation model, three sets of collaborative power supplies were considered to serve five households in a semi-estate. These five households live in five detachable buildings with peer-to-peer energy agreement to control energy wastages on standalone operations. With this architectural model, each household with single generating set, solar energy supply was integrated for central use alongside the public power supply. A central controller was designed to monitor and control the network generation and consumption of energy. Individual households have equal priorities of energy allocation with supply from the grid and renewable energy resources. During grid and renewable energy down times, priority shifts to ensure that individual households with running standby generators have enough power allotment to supply their loads. The excess of power from the generator sources are accumulated by the central controller and shared in equal proportion to the remainder of the households. Any attempt by individual households to exceed their allocated power results to an automatic supply cut-off and reset, thereby allowing for load within allocated capacity. Each household is equipped with a metering system that displays real time energy availability and consumption.

Figure 1 shows the architectural model for real time energy monitoring and control scheme from the peer-to-peer hybrid integrated supply system: The architecture has three power supply sources; the peer-to-peer mini-estate smart energy

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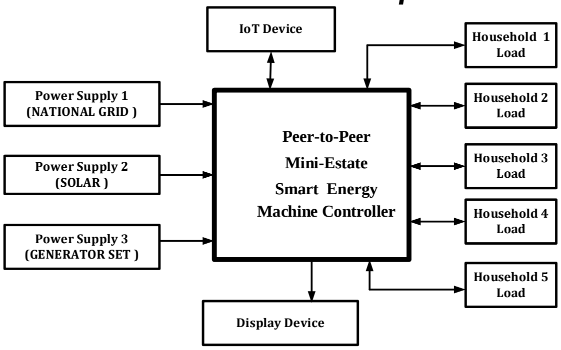

Figure 1: The Integrated Energy Architectural Model

controller with relays, Arduino microcontroller, transistors, IoT device, liquid crystal display, synchronizers and busbar and five detachable households as load centers.

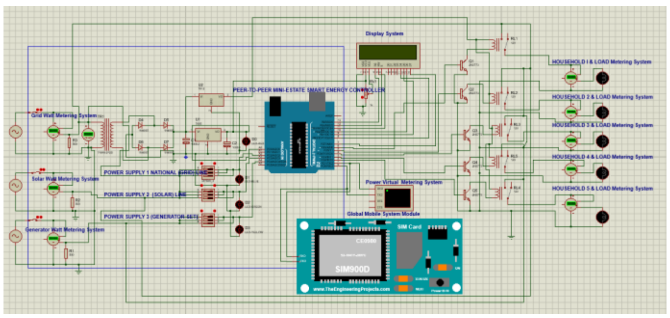

Figure 2: Proposed circuit diagram for Peer-to-Peer Mini-estate Smart Energy Monitoring and Control Model

In Figure 2, the schematic of the smart energy controller shows the input from the three power sources are regulated for the five detachable households in a mini-estate. The microcontroller action of scheduling is achieved with the programming code written with C++ in the Arduino IDE. Real time communication of system status dynamics was achieved through IoT device (GSM module) for remote monitoring and control via android application. The display system gives the energy management details virtually for both supplied and consumed energy. This energy data is captured for each household corresponding to the available supply from their individual power metering system. The individual household power demand data were collected, the data revealed that each of the household require 16100W to power their respective loads. The simulation to represent these loads were carried out and result were obtained by varying the power rating of each household bulbs(lamp) and the corresponding wattage recorded as seen in Fig, 2. These result values were scaled using a software program and simulated to reflect a real-life data scenario, and documented in section IV.

IV. Results Discussion and Analysis

A. Virtual Hardware Simulation Results

Table 1 shows that household A, C and E generated (15000W) from 3000W, 5000W, and 7000W of power from their generators into the common tie. Table 2 shows that household A, B, C, D, and E got a total grid supply (40000W) from

Table 1: Power Supply Status in Generator Mode

Household	Generator Power Status (W)	Power Demand Level (W)	Consumption Power Level (W)	Power available for sharing (W)
A	3000	2300	2300	700
B	-	2300	**1600**	-
C	5000	4000	4000	1000
D	-	2000	**1600**	-
E	7000	5500	5500	1500
Total	**15000**	**16100**	**15000**	**3200**

8000W each from the common tie. Household B and D did not generate any power supply to the common tie. The power demands for A, B, C, D and E were (16100W) from 2300W, 2300W, 4000W, 2000W, and 5500W, power consumption for A, C and E were (11800) from 2300W, 4000W, and 5500W, the excess power available for sharing for B and D was (3200W) from 700W, 1000W, and 1500W. With this peer arrangement, household B and D were supplied with the excess power from the other collaborative household to the magnitude of 1600W each.

Table 2 Power Supply Status in Grid Mode

Household	Grid Power Status (W)	Power Demand Level (W)	Consumption Power Level (W)	Excess available Power(W)
A	8000	2300	2300	5700
B	8000	2300	2300	5700
C	8000	4000	4000	4000
D	8000	2000	2000	6000
E	8000	5500	5500	2500
Total	**40000**	**16100**	**16100**	**26900**

The power demands for A, B, C, D and E were (16100W) from 2300W, 2300W, 4000W, 2000W, and 5500W, power consumption for A, B, C, D, and E were (16100) from 2300W, 2300, 4000W, 2000W and 5500W, with an excess energy available from A, B, C, D, and E was (26900W) from 5700W, 5700W, 4000W, 6000W, and 2500W. With this peer arrangement, all the households were supplied as demanded, but excess from all the households were to the magnitude of 26900W. This excess suggests that the estate could accommodate more loads to the tune of 26900W from the grid supply.

Table 3 Power Supply Status in Renewable Mode

Household	Renewable Power Generation Status (W)	Power Demand Level (W)	Power Consumption Level (W)	Power available for sharing (W)
A	2500	2300	2300	200
B	2400	2300	2300	100
C	4500	4000	4000	500
D	-	2000	**1300**	-
E	6000	5500	5500	500
Total	**15400**	**16100**	**15400**	**1300**

Table 3 shows that household A, B, C, and E generated (15400W) from 2500W, 2400W, 4500W, and 6000W of power from their renewable energy sources into the common tie. Household D did not generate any power into the common tie. The power demands for A, B, C, D and E were (16100W) from 2300W, 2300W, 4000W, 2000W, and 5500W, power consumption for A, B, C, and E were (11800) from 2300W, 2300W, 4000W and 5500W, with an excess energy available for sharing for D as (1300W) from 200W, 100W, 500W, and 500W. With this peer arrangement, household D was supplied with the excess from the other collaborating households to the magnitude of 1300W.

B. Mobile Application Interface

In order to achieve real time energy monitoring and control, Hyper Text Markup Language (HTML) and Cascading Style Sheet (CSS) program was written for the development of the frontend user interface on the mobile application. Fig. 3 shows the landing page of the user interface of the mobile application. Similarly, the backend was developed with Hypertext Preprocessor (PHP), and sequential query language (MySQL) aided in the database creation. For individual household remote access to their allocated power, the mobile application sends command to the firebase system through the Global System Mobile (GSM) module.

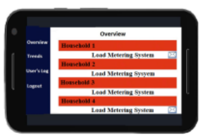

Figure 3: Front-end Users interface

The GSM module on receiving commands from the firebase feeds the controller for scheduled action initiation and the control action goes back to the GSM module for feedback on the mobile apps through the firebase system. From the program code, although individual households have no capacity to alter the design configuration, they can toggle to view power supply and consumption status of the network. The novelty in this research is the smart real time cooperative monitoring and control system for sustainable energy resources utilization in semi-estate power network with minimal wastages.

V. CONCLUSION

Real time smart energy monitoring and control model for integrated collaboratives supply system was demonstrated with five households in a semi-estate. The proposed system encourages and initiates energy collaboration; a contributory network for cohabited households to cope with energy wastage and guarantee continuous energy availability. Any group of household planning for contributory energy network would not have any reason to design any system, but to embrace this real time energy control panel and connect their system for use at ease with the associated advantages of energy availability with minimal wastages.

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