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Control Design and Management of a Distributed Energy Resources System

Moses Oluwafemi Onibonoje[1*], Oluwafemi Oladipupo Alegbeleye[1],
Adedayo Olukayode Ojo[1]

[1]*Department of Electrical/Electronics and Computer Engineering, Afe Babalola University Ado Ekiti, Km 8.5 Afe Babalola Way, Ado-Ikare Road, Ado Ekiti, +234 Nigeria*

Abstract. Energy generation, distribution, and transmission are crucial to the development and advancement of humans and their environment. Therefore, the need for a sustainable environment is essential. This study focuses on designing, building, testing, and commissioning an intelligent grid solar-powered distributed energy resource system to serve as an alternative to powering loads with conventional energy sources, creating a pollution-free and self-dependent system that can be built to the capacity of the required load. The solar panels, voltage regulator, microprocessor, solar charge controller, and batteries are all interconnected to automatically switch between the three solar substations. The simulation of the DER network system was executed with MATLAB, Simulink, and Simscape Electrical. The management system was created using the Visual Studio 2019 and ASP.NET MVC software. The management system was designed to keep tabs on the daily sales of the DER components to various clients. The results are achieved by subjecting a load (21W rated headlight bulb and a 5W rated fluorescent bulb) at specified time intervals (10, 20, 30 minutes). The results showed us a particular set threshold voltage for the sub-station switch. This project gives an insight into how good and reliable the distributed energy resource system can be as it provides a constant power supply to the equipment.

Keywords: Distributed energy; Inventory system; Modelling; Solar panel

1. Introduction

Energy has always been an essential factor in human civilization. However, Energy generation and utilization are critical to ensuring rapid economic growth. With the accelerating advancement, the energy demand is also increasing (Oyedepo, 2012). Since conventional energy sources are limited, the inability to effectively handle the increasing demand often leads to the energy crisis.

The global population of about 7.674 billion people has about 940 million with out access to electricity, and Sub-Saharan Africa has the most significant percentage. The total world energy was 80% fossil fuels, 10% biofuels, 5% nuclear, and 5% renewable as of 2016 (Motjoadi, Bokoro, and Onibonoje, 2020; Liang *et al.,* 2019). There is a crucial need to start considering renewable energy sources because of the continuous exhaustion of limited fossil fuel supply and environmental friendliness. The distributed energy system design helps create a small-scale unit of power generation that operates locally and is connected to a larger power grid at the distribution level, which saves electric energy by moderating

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[*] Corresponding author's email: onibonojemo@abuad.edu.ng, Tel.: +2348069531521

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the usage of grid energy, saving oil expenses sustained in using a generator (Ronak and Shah, 2018).

Nigeria's total electricity generating capacity hovers around 13000 MW, out of which about 4000 MW can be dispatched to its over 200 million people, which is insufficient for the demands. Alternative means of electricity such as solar energy could compensate for the deficit and provide cleaner and safer energy (Bolawole, Onibonoje, and Wara, 2020; Folorunso, Onibonoje, and Wara, 2020; Ayamolowo *et al.,* 2019).

This study aims to model a smart grid solar-powered system, simplify the abstract modeling components, construct the system, and implement a robust and adaptable inventory management system. The study also intends to evaluate the performance of the system. The scope of the paper includes modeling and simulating a distributed energy system, in this case, a nodal solar system, aiming to produce alternative energy means through automated switching among three different solar nodes occasioned by present conditions.

Distributed energy resources can be in different forms, including natural gas-fueled generators, solar panels, and electric vehicles (Pallett, 2017). The demonstrable prototype of any of the forms can be modeled as a small-scale energy source, such as a small-scale biofuel system or a geothermal plant, to the proportionate consuming loads while the management is also highlighted (Münz and Wu, 2021; Qurrahman *et al.,* 2021; Smirnova *et al.,* 2021).

1.1. *Distributed Generation*

Distributed generation (DG) is usually referred to as a small-scale electricity generation located near the local load area or connected to distribution grids. DG may be self-dispatched or dispatched by network operators. DG includes reciprocating engines, combustion turbines, micro-turbines, fuel cells, etc. In general terms, DG refers to using stand-alone or grid-connected small, modular electric generation devices located close to the point of consumption (Allan *et al.,* 2015). The key defining characteristics of DG technologies include the power production size of the technology, as well as its location and applicationDG systems are generally located close to the power demand, on the customer side of the meter or the distribution network, rather than on the transmission network (Allan *et al.,* 2015). A typical example of a distributed generation system is shown in Figure 1.

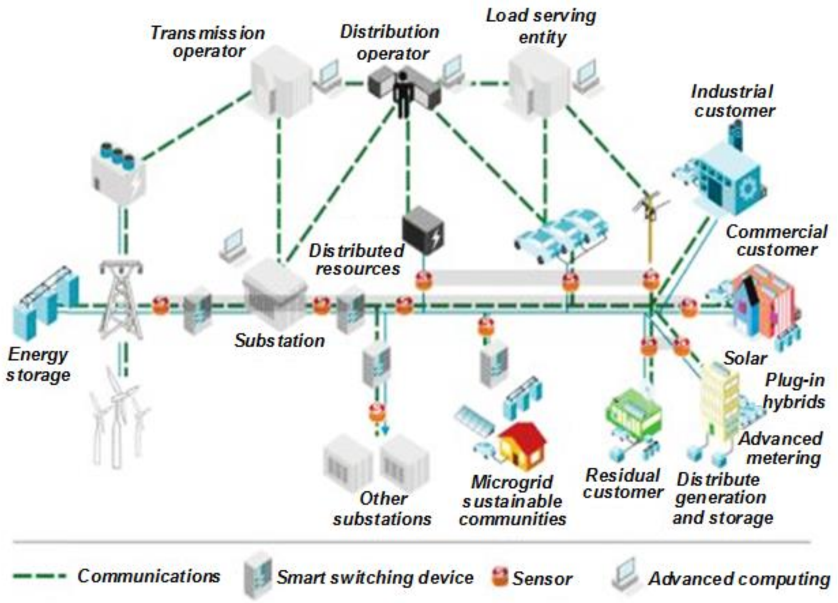


Figure 1 Distributed generation (Colmenar-Santos *et al.,* 2016)

The systems mainly produce between 1 kW and 5 MW power supply (Ibhaze *et al.,* 2017). Furthermore, some systems include stand-alone rural or remote applications (such as areas with grid access constraints), grid-connected devices that export electricity to the grid, utility-owned devices (aimed at improving power quality and reducing power losses in specific areas), and combined heat and power (CHP) devices.

1.2. *Distributed Energy Resources Technologies*

The exact definition of distributed generation (DG) can vary depending on the source and capacity. Nevertheless, it is commonly and concisely described as any limited-capacity electric power source directly linked to the power system distribution network, where the end customers consume it. DG is not a new notion in the growth of the power business. Micro-turbines, combustion engines, fuel cells, wind turbines, geothermal systems, solar systems, and other technologies can power DG. DG occurs on two levels: the local level and the end-point level (Qurrahman *et al.,* 2021).

1.3. *Distributed Energy Resources Management System*

Distributed energy resource management system (DERMS), is a software platform that manages a group of distributed energy resource (DER) assets such as rooftop photovoltaic solar panels, behind-the-meter batteries, or a fleet of electric vehicles to deliver vital grid services and balance demand with supply to help utilities achieve mission-critical outcomes (Wong *et al.,* 2018). DERMS are used to communicate simultaneously with, control, and coordinate DER devices in different geographic locations. For example, when excess energy is being injected into the grid due to plentiful solar energy being produced during the day, a DERMS can control batteries in the grid to charge using that excess energy. On the other hand, suppose there is a lack of energy to meet demand. In that case, DERMS can control batteries to inject energy into the grid and control intelligent thermostats to reduce the temperature in buildings, so the energy demand is reduced (Münz and Wu, 2021). The benefits of the DERMS software include creating multiple, arbitrary groupings of DER and subgroups of DER for dispatch based on whatever criteria are presented at the time, grouping DERs and groups of DER using a recursive architecture, and providing status and forecasting of capacity to upstream DERMS and distribution management systems

1.4. *Reliability of Distributed Energy Resource System*

An entire section dedicated to energy system reliability is warranted because it is a crucial aspect of ensuring the sustainability of an energy system. Reliability refers to the ability of an energy system to provide electricity at a reasonable cost. It can be seen in how energy systems respond to problems with energy supply. Let us examine two scenarios that frequently cause problems. In the first scenario, a unit is rendered unable to function due to a natural disaster or a war. The supply of imported energy is stifled in the second scenario (Aluko, Onibonoje, and Dada, 2020; Onibonoje, 2019; Onibonoje and Olowu, 2017). It is reasonable to assume that a unit's failure primarily affects each consumption node that the unit serves. The effect can manifest directly in the form of disruptions in electricity networks or indirectly in increased electricity prices. In the worst case, a region may remain without electricity (Alanne and Saari, 2006). Because the use of domestic primary energy sources in the case of a centralized reference energy system is only 1% of total primary energy use, the shutdown of a single local primary energy source is not likely to cause significant problems. Instead, if the import of primary energy is blocked, problems will also occur in the case of a decentralized reference energy system. The investigations of the dynamic modeling, stability and control of power systems with distributed energy resources for optimal trade-offs and optimization have been conducted by (Farizal, Dachyar, and Prasetya, 2021; Onibonoje, Ojo, and Ejidokun, 2019; Sadamoto *et al.,* 2019)

The absence of a load monitoring application was the only drawback. The work also worked on the best design and operation of distributed energy resource systems for residential communities. However, the main drawback was that it did not include a switching process for selecting a distributed energy resource.

2. Methods

The design layout of the distributed energy resource system is described here, with its block diagram and that of the solar substation shown in Figures 2 and Figure 3, respectively.

2.1. *Operating Principle of the DER System*

The intelligent grid solar distributed energy resource system is an automated power generation system that regulates the switching operations of various substations. Whenever a nodal substation runs low, the system switches to another nodal substation while recharging the previous one. This system creates an endless loop of power supply to the load with a minimal delay time. A preprogrammed interconnected hardware unit, including the microprocessor, relay, battery, charge controller, solar panels, and voltage regulator was designed to achieve the objective.

2.2. *The Software Unit*

The modeling and simulation of the DER network system were executed with MATLAB, Simulink, and Simscape Electrical. The management system was created using the Visual Studio 2019 and ASP.NET MVC software. The management system was designed to keep track of the daily sales of the DER components to various clients. The development process of the application, from planning and designing to testing, is herewith highlighted.

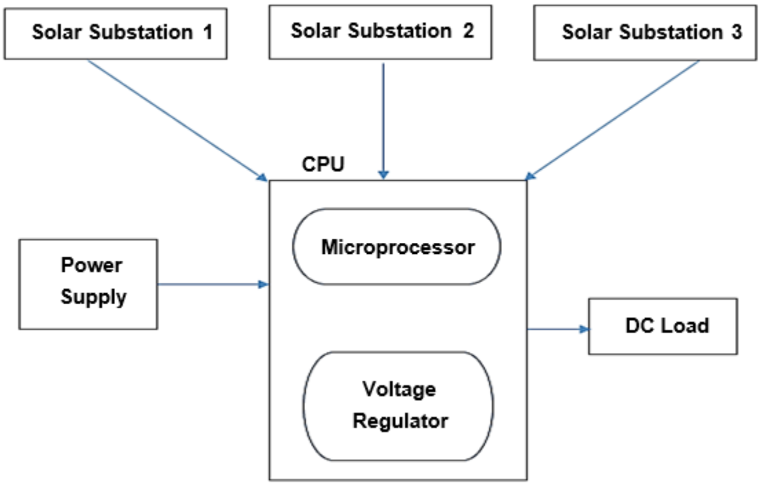


Figure 2 The block diagram of the DER system

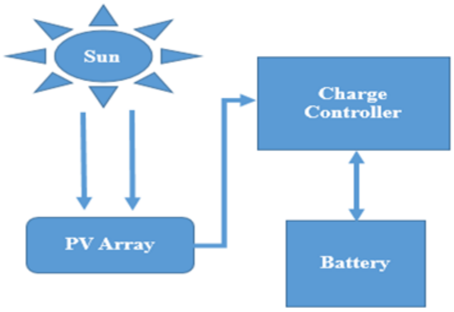


Figure 3 Composite blocks of the solar substation

Planning: the features of the application are organized, and these include pages, a database, and navigation.

Environment Setup: the environment is set up for development by following the guidelines in the Visual Studio documentation. The documentation includes creating a new project, setting up the environment for growth, and linking the project with the database.

Writing/Coding Application: After setting up the environment, coding is carried out using the different components of the C# Programming Language and the ASP.NET MVC framework CRUD function to implement the functions of the inventory system.

Debugging, Testing, and Running the Application: this phase was iterative. Each time the code is updated, it is debugged immediately to check for bugs that need fixing. Thus, local testing was done using the iterative model after minor changes or updated implementations in the code. Also, different types of tests were carried out to validate the correctness and robustness of the application.

2.3. Solar Modules Specification

The heart of the photovoltaic system is the solar module. Considering the efficiency and price of solar modules on the market, the mono-crystalline type being the most appropriate for this project, three panels were used to analyze the system. The PV modules typically do not require any further improvement aside from maintenance, such as regular cleaning. Therefore, for this project, three 30W/24V panels were chosen.

3. Results and Discussion

The performance metrics of the DER system and its peripherals were measured and compared to the simulated and expected values derived from modeling and calculations.

3.1. Simulated Results of the DER System

The island and main utility micro-grid were subjected to dynamic disturbances by disconnecting the island grid entirely from the primary utility grid and opening the island grid breaker for 10 seconds. Then, at 40 seconds on the variable load, a 300 kW load was added.

The frequency disturbances, as shown in Figure 4, occurred due to the islanding of the microgrid at 10 seconds and the additional load added at 40 seconds. The microgrid's distributed resources change over time depending on how it operates. The solar array (PV) tracks the irradiance over time. The diesel generator (GenSet) tried to hold everything steady by making up all the additional power output (maintaining unity frequency and unity voltage) as islanding occurs at 10 seconds. At 40 seconds, an extra load of 300 kW was added to the microgrid. In addition, the energy storage system maintained a steady power output of 100 kW. The microgrid voltage, however, was a flat or steady line instead of the expected three-phase AC waveform due to the use of a phasor simulation type in the simulation.

3.2. Results of the DER hardware

3.2.1. Continuity test

Results showed that continuity was achieved in all the components and the overall system, so electrical connection exists and current flows through the system.

3.2.2. Switching speed test

Results showed that the switching time interval between substation 1 and substation 2 was faster than the switching time interval between substation 2 and substation 3. The result showed that the switching duration of sub-station 1 to sub-station 2 was 3 seconds, while the switching duration of sub-station 2 to sub-station 3 was 5 seconds.

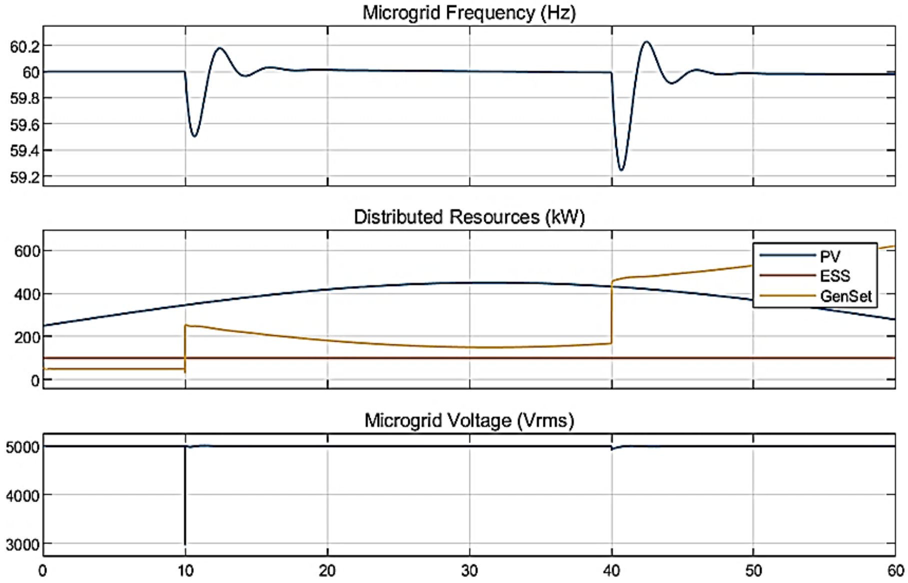


Figure 4 Simulation Result

3.2.3. Charging and discharging rate tests

Results showed that the solar panel would take approximately 4 hours to recharge the battery from 11.4V to 12V. Also, the result showed that the 26W car headlight bulb and 5W fluorescent bulb would take 30 minutes to discharge the battery from 12V to 11.4V.

3.3. Evaluation Procedure

After installation, the measured output of the DER system gave the expected results. Table I presents the run-down of the system and battery bank results we obtained. A 12V/26W car headlight and 5W fluorescent bulbs were used as load. A stopwatch was used to record the time at batteries got drained. The system is designed so that when the battery voltage drops from 12.1V to 11.4V, it switches to the next substation. The average values obtained were computed in the table.

Table I shows how the DER system works with load; it is observed that when the sub-station passes the set threshold, the system automatically switches to the next sub-station within a millisecond. However, when sub-station 3 is low, the system is switched off entirely.

Table 1 Evaluation results

Station	Sub-station 1	Sub-station 2	Sub-station 3
Threshold (V)	11.5	11.5	11.5
Load (V/W)	12/26	12/26	12/26
Starting Voltage	12.1	12.0	11.9
Time (0 min)	11.9 V	standby	standby
Time (10 mins)	11.8 V	standby	standby
Time (20 mins)	11.7 V	standby	standby
Time (30 mins)	11.4 V	standby	standby
Time (0 min)	standby	11.7 V	standby
Time (10 mins)	standby	11.6 V	standby
Time (20 mins)	standby	11.4 V	standby
Time (0 min)	standby	standby	11.8 V
Time (10 mins)	standby	standby	11.6 V
Time (20 mins)	standby	standby	11.4 V

3.4. Installation of the DER System

The most important part of the system is the first installed solar panels. The installation of the battery bank quickly followed that of the panels. During the battery installation, careful attention was paid to the possibility of a short circuit. The batteries and their terminal voltages were also carried out during installation. This ensures that the overall output would give us the expected output.

The output of the terminal of the battery bank was connected to the charge controller. Tight connections were all ensured in the process. After successfully installing the solar panel, battery bank, and voltage regulator, the completed project was simulated and analyzed. Pictures of the distributed energy resource system during coupling were shown in Figure 5(a); and the assembled unit with the solar panel was shown in Figure 5(b).

(a) (b)

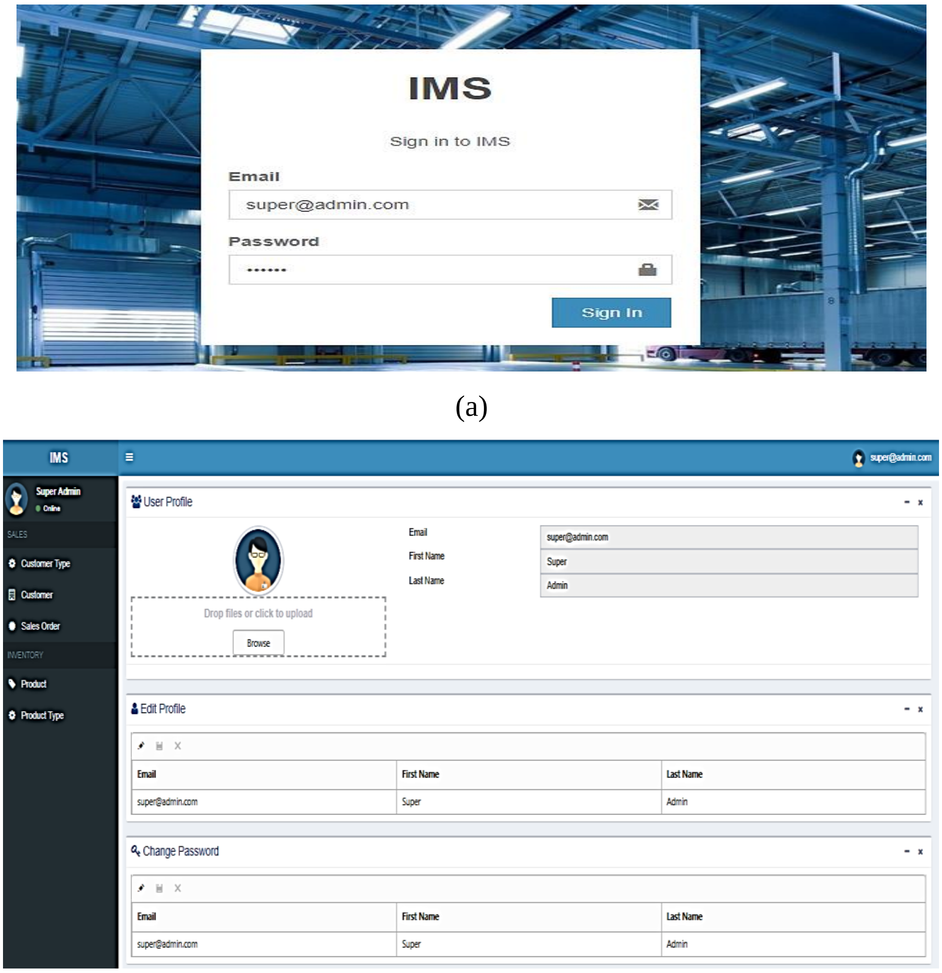
Figure 5 The hardware units: (a) Solar Charge Controller; and (b) Assembled unit with Solar Panels

3.5. Inventory Management System

The login page developed is shown in Figure 6(a), where an email and password are required to access the inventory system. A login page is necessary to protect the application from unauthorized users. A User Profile page was also developed to include functions such as profile picture upload, changing passwords, and editing profiles, as shown in Figure 6(b). The sales order page was also created to include functions such as retrieving, creating, updating, and removing sales orders, as shown in Figure 7.

4. Conclusions

Renewable energy generation is replacing conventional means of power generation worldwide. In this study, we have presented an independent, environmentally safe, and progressive design of an intelligent grid solar system. This underscores a solution to the lack of clean and safe electricity availability by devising a means of switching between two or more power generation sources to eliminate the power outage cycle. This study finds application in rural and urban communities, domestic houses, and industries. The results also show that the DER system effectively switched between three power generation sources (solar energy) intelligently without human interaction. The implication of this study is that small to medium load users can have access to constant power supply to their facilities without interruptions. However, the limitation of the study is that there is a necessity for scaling up the experimental prototype into a deployable level for the end users. This study concludes that the future of Distributed Energy Resource system implementations using solar energy will get better and more efficient. It gives an insight into how good and reliable the distributed energy resource system can be as it provides a constant power supply to the equipment.



Email
super@admin.com
Password
••••••

(a)

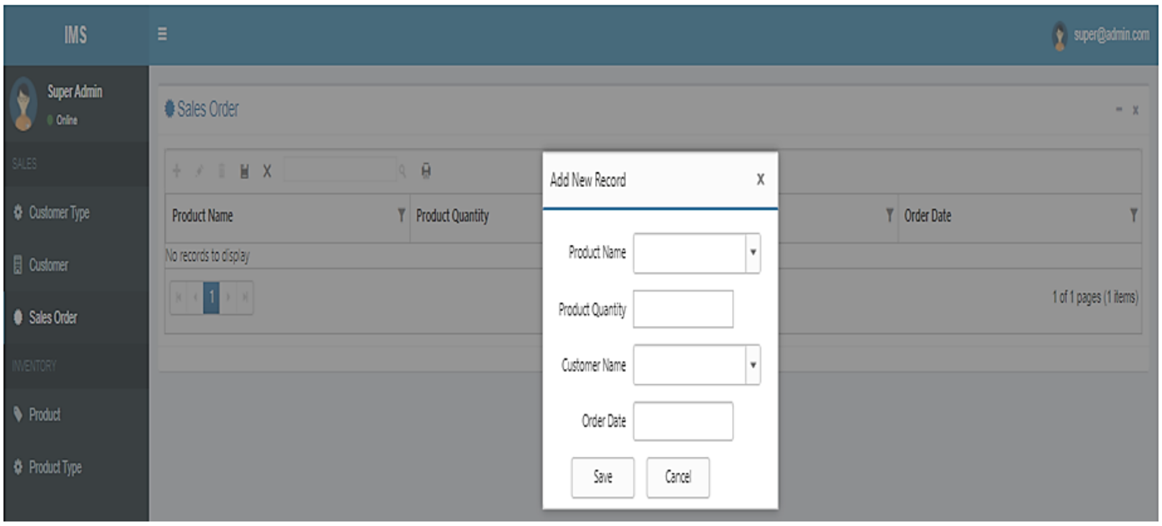
Email: super@admin.com
First Name: Super
Last Name: Admin

Email	First Name	Last Name
super@admin.com	Super	Admin

Email	First Name	Last Name
super@admin.com	Super	Admin

(b)

Figure 6 The hardware units: (a) Home login page; and (b) User profile page



Product Name	Product Quantity	Order Date
No records to display		

1 of 1 pages (1 items)

Add New Record
Product Name
Product Quantity
Customer Name
Order Date

Figure 7 Sales order page

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