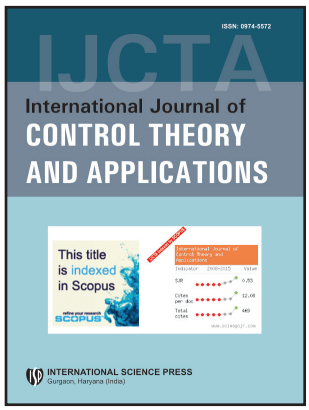

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Control and Monitoring of an islanded Microgrid with Renewable Energy Sources

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Abstract: Today's world is in search of new energy sources for power generation, as the non renewable energy sources are depleting at a faster rate. Nuclear energy, hydro power, etc., cannot be a proper substitute for the non renewable sources because of the negative impact made by them in the environment. The mankind is planning to reduce the global carbon footprint due to the adverse effects of it, in the form of global warming. One of the main contributors of the carbon footprint is the electricity generation using fossil fuels, which should be reduced gradually. Maximum utilisation of renewable, green and sustainable energy sources will be a major step towards that aim. This paper proposes a control algorithm for an islanded micro-grid for a residential building, which is charged by photovoltaic cell (PV), fuel cell (FC) system and an IC engine with a combined heat and power (CHP) system, where energy extracted from biomass is playing an important role. The source and load management of the system will be done based on the availability of the biomass, hydrogen, sunlight, load profile etc. The proposed algorithm has been validated using MATLAB© and C Programming software.

Keywords: Microgrid; biogas; biomass; hydrogen; load profile.

1. INTRODUCTION

There is a tremendous increase in the greenhouse gases in the atmosphere after the industrial revolution, which is forcing the world to rethink about its emission. Technically, the total set of greenhouse gas emission to the atmosphere in all forms is defined as 'Carbon footprint'. A major contributor of carbon footprint is the electric power generation using fossil fuels. The Paris Agreement, which will come into action by 2020 mainly aims to hold the increase in global average temperature to below 2^{o}C. Recently India has also agreed to be a part of the mission, for which we have to find more efficient energy extraction methods from renewable energy sources. Apart from these environmental considerations, the fossil fuel reserves around the globe are depleting fast, and it may last only up to some decades. These leads to a unique mind among the global population to switch into clean, renewable, green and sustainable energy sources.

Renewable energy sources mainly include solar, wind, hydro power, biomass energy, geothermal energy, tidal energy, etc. As a major renewable energy source, solar energy technologies have developed into a wide field of study, and leading the renewable energy extraction mission with the highest contribution. Wind energy is also considered as a potential global green energy source which is also a well established area of study and implementation. Hydro power, as the largest renewable energy source, supplies almost 50% of national electricity production in 63 nations, and 90% in 23 nations [1],[2]. As an emerging power generation technology, geothermal energy is also contributing to the green energy generation. Energy from biomass, which is a term used for all organic materials obtaining from living beings, has great potential in the present scenario. Waste treatment, water purification, biological carbon fixation, etc are the bonus benefits from biomass energy technology.

The impact made by buildings can be reduced by making them greener i.e., they will be completely a green building with self sustained energy generation without any negative impact on the environment, eco-friendly building materials, more intelligent technologies for comfort and safety, waste management systems, etc [3], [4]. The energy requirements of the building will be fulfilled by energy from biomass and solar energy. The energy management systems, which will be the basis for any microgrid control system, are discussed in [5], [6], [7], [8], [9]. The objectives and operations of a supervisory control system in a micro grid has been well discussed in [10], [11].

This paper proposes a control algorithm for the aforementioned power system which includes the load side and source side management. The algorithm also considers a load shedding strategy, which will execute whenever the sources cannot meet the demand. The rest of the paper is organised as follows : Section II deals with the proposed system. Section III deals with the electrical load profile and its generation. Section IV is about control and monitoring system and the proposed algorithm. Section V showcases the simulation results of the load profile generation and the control algorithm including the load shedding. The conclusions of the work are briefed in section VI and the future works has to be carried out based on this work are given in section VII.

2. OVERVIEW OF PROPOSED SYSTEM

A residential building where 4 persons are residing is considered as the load in this paper. The building's power system has not connected to the utility grid. The proposed system with renewable energy sources, load and control and monitoring system is shown in Figure 1. It is a stand alone DC power system, where all devices in the building are DC devices whose details are given in Table 1. The block lines represent the power flow and dashed lines represents the communication and control signal flow.

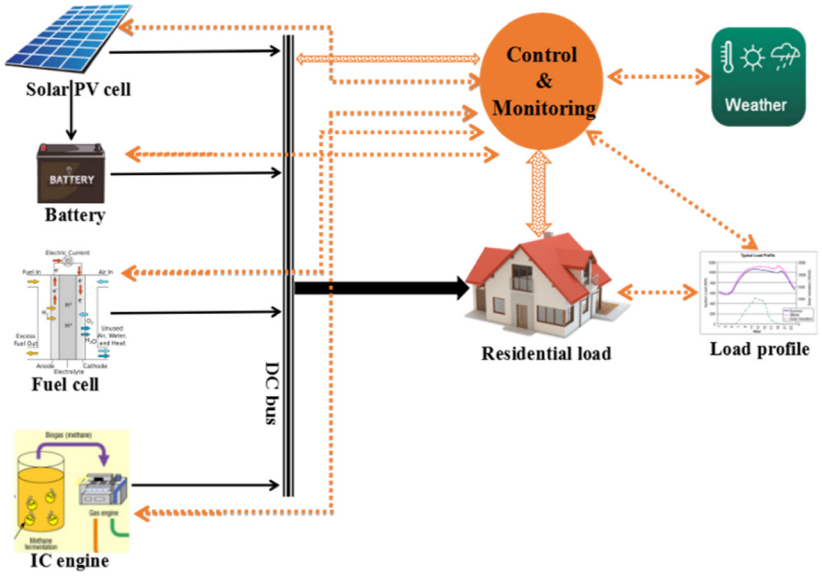

Figure 1: Proposed system

A PV source, Fuel Cell and an IC engine will be the power sources for the building. The fuel cell will be supplied with hydrogen, which is obtained from biomass. The fuel cell used in this system is a Proton Exchange Membrane Fuel Cell (PEMFC). Hydrogen rich gas will be obtained from biomass after a sequence of process such as dark fermentation, sulphur deprivation etc. There will be a fuel processor associated with the bioreactor, to carry out and control the hydrogen generation for the fuel cell. An IC engine is considered to be powered by the biogas, which will be coupled with a synchronous generator to get the electric power. There will be dedicated local controllers associated with both fuel cell and IC engine, which will have communication with control and monitoring computer. As the source used for the power generation is biomass, the negative impact on the environment will be negligible. Even though the IC engine has the exhaust gas, by designing a proper heating system for the proposed building or a combined heat and power system, we can utilise the exhaust gas in a better way which will not harm the environment much.

As considering a residential building in this work, the availability of power throughout the day is a necessity. The sources IC engine and fuel cell are not much reliable, as they are directly dependent on the biomass treatment process. So, in order to get a continuous power supply some other sources have to be considered like solar photovoltaic cell with battery. Thus the SPV system become a part of this hybrid system.

A control and monitoring computer is connected to the three sources. The availability of the energy sources, i.e., hydrogen level in the storage system, biogas level in the storage tank and availability of the irradiance level of the fuel cell, IC engine and the PV respectively, will be continuously monitored by the computer. The localised controllers of the sources update the status of each source as ON/OFF, which will be used by the computer for the energy management. Similarly, a communication will be provided in between the computer and the devices in the building. This communication will be used for the load shedding of the system and to monitor the instantaneous demand of the load on the system.

Table 1
Devices In The Proposed Residential Building

Device	*Voltage (V)*	*Wattage (W)*
Refrigerator	24	72
LED lamps	12	7 (4 no.)
CFL lamps	12	12 (4 no.)
Fan	12	20 (3 no.)
Computer	12	170
Water Purifier	24	11
TV	12	30
AC	48	800 (2 no.)
Water Pump	24	350
Sandwich Maker	96	550
Cell Phone	12	4
Hair drier	24	425

The specifications of the power sources are designed based on the total and connected load of the building. A solar PV array of 2 kW is considered, which will have a backup battery of 306 Ah rating. The limits for the SOC of the battery are kept as 30 and 80 for minimum and maximum respectively. Highest priority among the sources is given to PV, keeping the cost minimisation and energy conservation as the main objectives. Fuel cell of 1.24 kW capacity is taken as the secondary source and an IC engine considered as third source with potential of 1 kW power, which has given least priority among the three sources. Battery is kept as an emergency backup.

The status of the sources will be decided by comparing the base load value and the instantaneous power of each source.

3. LOAD PROFILE GENERATION

The behaviour of a power system can be analysed based on the variation of the load for a specific time period with equal intervals of time such plots are known as load profiles, which can be hourly, daily, weekly, monthly or even yearly load profiles. The load profile varies according to the consumer behaviour, environmental variations and social impacts. Load profile can be considered as the first step in the design of an energy management system.

In this work, four scenarios of the load profile has been considered i.e, summer week day, summer weekend, monsoon week day and monsoon weekend. The scenarios are selected based on the climatic conditions in Kerala, where rainy season and summer season predominates throughout the year. The temperature variation between these two seasons makes great impact on the typical load profile of Kerala houses. Likewise week days will have less power consumption than weekends (holidays are considered to be of the same profile as the weekend).

The load profile can be obtained by using the Bottom-Up approach [12]. The load profile generation loop is shown in Figure 2.

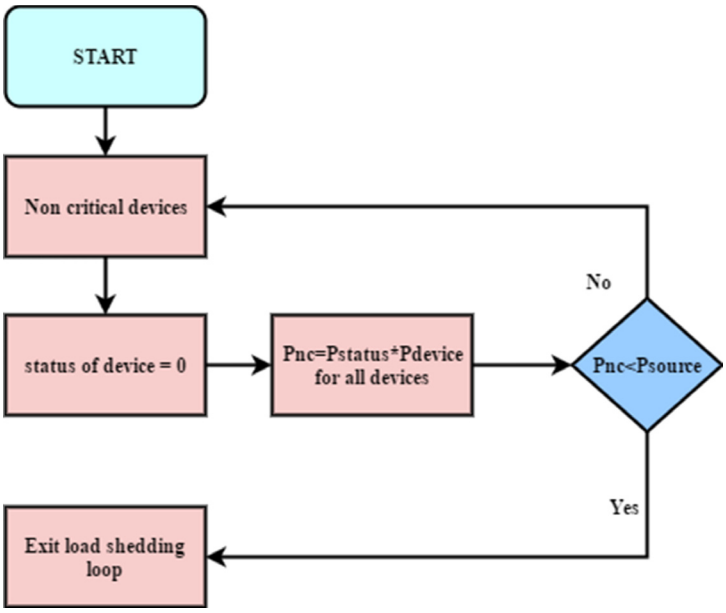

Figure 2:Load profile generation loop

The load profile for 24 hours is calculated and plotted by using the following equation (1):

$$P = \frac{3600 \times 24 \times W_{standby} + f \sum_{n=1}^{12} W_{nom} \times t_{cycle}}{3.6 \times 10^{6}} \quad (1)$$

Where P is the total power, $W_{standby}$ is the power consumed by the devices in their standby mode of operation, f is the frequency of switching of the devices in the entire time period, W_{nom} is the rated wattage of the device and t_{cycle} is the time of operation of each device in the total time period.

This loop will execute for all 12 devices, calculate their individual power for each hour and then accumulate those powers to get the complete load profile for 24 hours with one hour interval.

4. CONTROL STRATEGY

Even though the power system is provided with reliable energy sources, the reliability of the entire system may not be guaranteed without the planning of a control and monitoring system. Control algorithm development is one among the crucial steps in designing a stand alone microgrids. The main objectives of control and monitoring system can be listed as : high reliability, best economic operation, reduced carbon emission, conservation of energy, quality of supply, etc.

A control algorithm is developed in this paper, which will have the following strategies.

- Priority order of the sources is PV, fuel cell, IC engine and then the battery.
- Status of the devices in the system, sources, load profile of the system should be available.
- The load is divided as critical and non critical. First 6 devices in TABLE I are critical devices and the rest of them are non critical.
- The power consumed by the devices should be available continuously.
- IC engine will power only the critical devices, if no other source is available.
- Battery will supply load only when its SOC is above a safe level.
- Battery will supply only critical load if no other source is available.

The proposed control algorithm is given in Figure 3. The blocks to limit FC generation and IC generation in Figure 3 will be carried out by the respective localised controllers for the flow control of hydrogen and biogas respectively. The instantaneous power demand of the system will be communicated to the localised controllers by the control computer, based on which the limiting of generation will be done by the localised controllers.

Load shedding algorithm will consider only the non critical devices. Each device will be considered in the priority order, which is defined by the consumer, and the status of the first device will be made 0. Then the load of the system will be calculated with the devices having status 1. If the load still exceeds the supply, then the next device will be cut, and this will go on until the source can meet the load. The load shedding algorithm in the main control algorithm is given in Figure 4.

Where,

Pc	Critical load
Pnc	Non critical load
Ppv	Power supplied by PV
Pfc	Power supplied by fuel cell
Pic	Power supplied by IC engine
SOCmin/max	SOC limits of battery

5. SIMULATIONS AND RESULTS

Load profile generation algorithm discussed in section III has executed in MATLAB© software. The frequency operation of devices and time cycle of devices varies with the seasonal variations. Similarly, the time of the

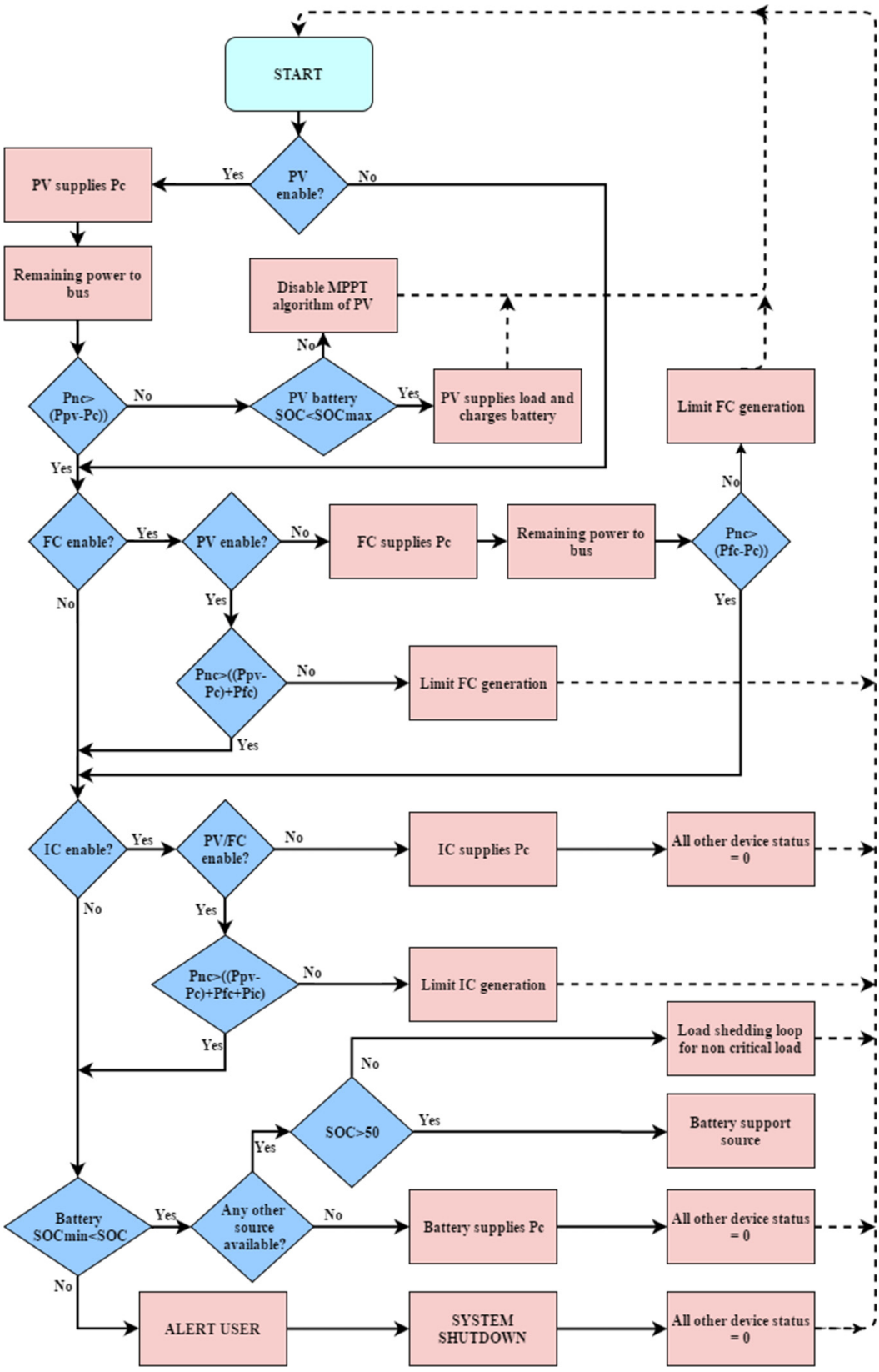

Figure 3: Control algorithm for the proposed system

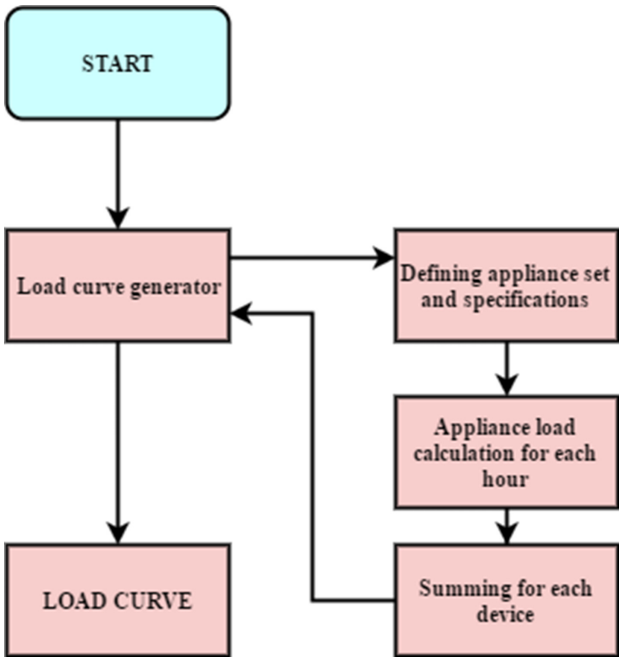

Figure 4: Load shedding algorithm

presence of the consumers in the building varies among weekdays and weekends/holidays. The base load of 0.38 kW has kept constant by considering the continuous 'ON' status of the first 6 devices in Table 1. Input data for the simulations have taken from public technical reports. Figure 5 shows the load profile for summer and monsoon season.

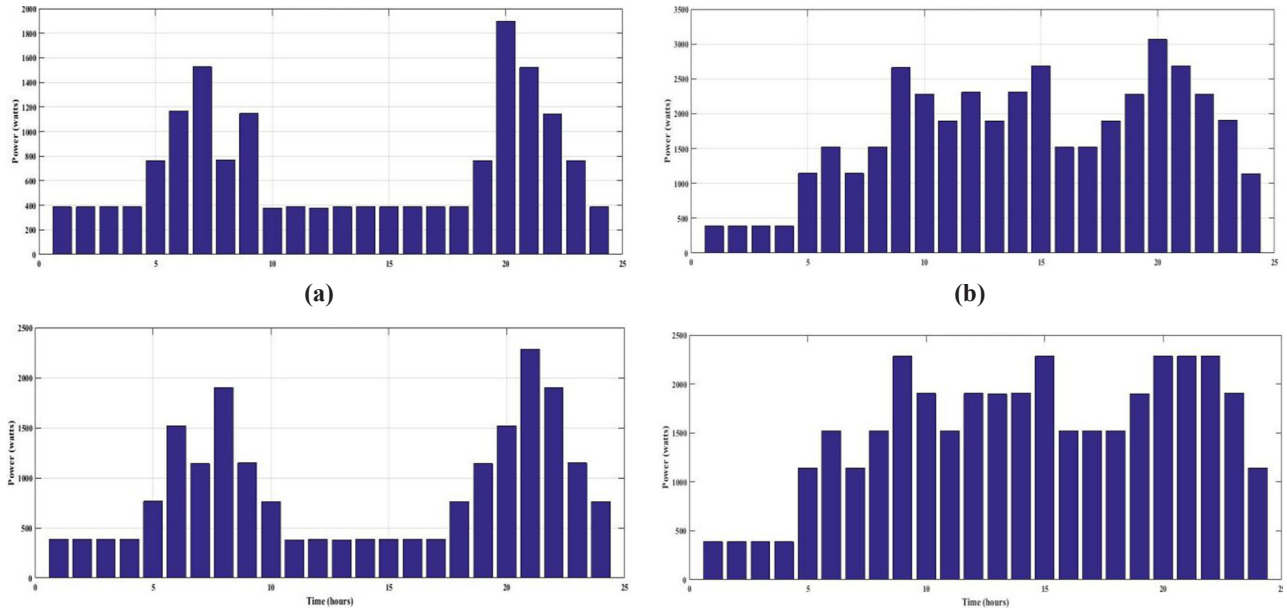

Figure 5: Load profile : (a) summer week day and (b) summer holiday(c) monsoon week day and (d) monsoon holiday.

The results obtained from the load profiles of the four scenarios are used to execute the control algorithm, proposed in section IV, in C programming. The results are tabulated for the four load profiles and given in Table 2-5, where F, P, I, B are FC, PV, IC and battery,↑-surplus, ↓-deficit, C-charging, D-discharging.

Table 2
Control Algorithm Simulation Results : Summer Weekday

Hour	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*	*16*	*17*	*18*	*19*	*20*	*21*	*22*	*23*	*24*
Source	F	F	F	I	I	I	P	P	P	P	P	P	P	P	P	P	P	I	I	I	F+I+B	F+I+B	F	F
Load shed	–	–	–	✓	✓	✓	✓	–	–	–	–	–	–	–	–	–	–	✓	✓	✓	–	–	–	–
FC status	↑	↑	↑																		↓	↓	↑	↑
PV status							↓	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑							
IC status				=	=	=												=	=	=	↓	↓		
Battery	–	–	–	–	–	–	–	–	–	C	C	C	C	C	C	C	–	–	–	–	D	D	–	–
Limiting	F	F	F	–	–	–	–	P	P	–	–	–	–	–	–	–	P	–	–	–	–	–	F	F

Table 3
Control Algorithm Simulation Results : Summer Holiday

Hour	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*	*16*	*17*	*18*	*19*	*20*	*21*	*22*	*23*	*24*
Source	F	F	F	I	I	I	P	P	P+F+I+B	P	P	P	P	P	P+F+I+B	P	P	I	I	I	F+I+B	F+I+B	F+I+B	F
Load shed	–	–	–	✓	✓	✓	✓	✓	–	✓	–	✓	–	✓	–	✓	✓	✓	✓	✓	–	–	–	✓
FC status	↑	↑	↑						↓						↓						↓	↓	↓	↓
PV status							↓	↑	↑	↑	↓	↑	↓	↑	↑	↑	↑							
IC status				=	=	=												=	=	=	↓	↓	↓	
Battery	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	D	D	D	–
Limiting	F	F	F	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–

Table 4
Control Algorithm Simulation Results : Monsoon Weekday

Hour	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*	*16*	*17*	*18*	*19*	*20*	*21*	*22*	*23*	*24*
Source	F	F	F	I	I	I	P	P	P	P	P	P	P	P	P	P	P	I	I	I	F+I+B	F+I+B	F+I+B	F
Load shed	–	–	–	✓	✓	✓	✓	✓	–	–	–	–	–	–	–	–	–	✓	✓	✓	–	–	–	–
FC status	↑	↑	↑						↓						↓						↓	↓	↓	↓
PV status							↓	↓	↑	↑	↑	↑	↑	↑	↑	↑	↑							
IC status				=	=	=												=	=	=	↓	↓	↓	
Battery	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	D	D	D	–
Limiting	F	F	F	–	–	–	–	–	P	P	P	P	P	P	P	P	P	–	–	–	–	–	–	F

Table 5
Control Algorithm Simulation Results : Monsoon Holiday

Hour	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*	*16*	*17*	*18*	*19*	*20*	*21*	*22*	*23*	*24*
Source	F	F	F	I	I	I	P	P	P+F+I+B	P+F+I+B	P	P	P	P	P	P	P	I	I	I	F	F	F	F
Load shed	–	–	–	✓	✓	✓	✓	✓	✓	✓	–	–	–	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
FC status	↑	↑	↑						↓	↓											↓	↓	↓	↓
PV status							↓	↓	↓	↓	↑	↑	↑	↓	↓	↓	↓							
IC status				=	=	=			↓	↓								=	=	=				
Battery	–	–	–	–	–	–	–	–	D	D	C	C	C	–	–	–	–	–	–	–	–	–	–	–
Limiting	F	F	F	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–

The status of the three sources has set according to the availability of the energy source. Depending upon the priority given to the sources, load will be supplied by the corresponding source. If the load is beyond the instantaneous capacity of a source, then next source will be considered and this will goes on until the load can be met by the sharing of sources. If any source's generation is exceeded the requirement, the algorithm will limit the generation. For PV, if the generation is exceeded, the excess power will be used for charging the battery. If the battery cannot be charged more, and still PV is excess, then the MPPT will be disabled and the generation will be limited to the required power. Similarly the excess power generation of fuel cell and IC engine will be limited by regulating the flow rate of hydrogen and biogas respectively.

Load shedding will be performed whenever the sources cannot meet the demand. For load shedding, only the non critical devices will be cut down in a predefined priority order. IC engine will power the non critical devices only, if no other sources are available. Battery will support other sources only if the SOC is above the pre-set value. In the simulations it has been taken as 60. Battery will power the critical devices only if all other devices are not available and battery SOC is within the limits. The algorithm has a worst case where no source is available and battery SOC is not in a safe range, then the entire system will be shut down. The simulation results of the load shedding algorithm is given in Table 4.

Table 4
Load Shedding Algorithm Simulation Results

Hour	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*	*16*	*17*	*18*	*19*	*20*	*21*	*22*	*23*	*24*
PV	0	0	0	0	0	0	400	500	800	1500	1600	1900	1700	1400	800	500	400	0	0	0	0	0	0	0
FC	500	500	500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	500	500	500	0
IC	0	0	0	950	950	950	0	0	0	0	0	0	0	0	0	0	0	950	950	950	0	0	0	0
Load	447	447	447	447	447	447	389	447	447	1377	1377	1377	1377	1377	447	447	389	447	447	447	447	447	447	0
Status	Pc+11,12	Pc+11,12	Pc+11,12	Pc+11,12	Pc+11,12	Pc+11,12	Pc	Pc+11,12	Pc+11,12	Pc+Pnc-7	Pc+Pnc-7	Pc+Pnc-7	Pc+Pnc-7	Pc+Pnc-7	Pc+11,12	Pc+11,12	Pc	Pc+11,12	Pc+11,12	Pc+11,12	Pc+11,12	Pc+11,12	Pc+11,12	0

Where the numbers 7-12 indicates the non critical devices. By integrating the load shedding algorithm with the control algorithm, the slots where load shedding is needed can be decided.

6. CONCLUSION

The need for a sustainable and greener solution, for the energy deficiency and environmental problems that the entire globe is facing, has given light to the system proposed in this paper. The residential building which will be powered by biomass energy and solar energy, will not cause any harm to the environment. The load profile of the proposed residential building power system has obtained for two different seasons. The seasonal variations in Kerala have been considered for the simulation. Maximum demand occurs in the summer season (3.1 kW) weekend profile. A base load of 0.38 kW is maintained throughout the simulation. Demand is more in the summer season than in the monsoon season for both weekdays and weekends. Considerable variations in the load profile can be seen in the weekday and weekend profiles, which has distinguishable effects in the control algorithm sequence.

The proposed control algorithm has simulated and validated in C programming and obtained a tabular data of the available sources, load shedding, battery status, etc for 24 hours with the results obtained from the four load profiles. Almost all objectives defined in section IV has met by the proposed algorithm. All conditions have validated using the simulations like, only one source available, sharing of sources, excess generation of sources, load excess than supply, load shedding of non critical devices and shut down of the entire system as a worst case.

7. FUTURE SCOPE OF THE PROPOSED SYSTEM

The dedicated localised controllers for the three power sources has to be co-ordinated by the control and monitoring computer. The time interval taken for the simulation should be modified from one hour to 15 minutes to make the system more reliable. An advanced communication system for the control and monitoring has to be implemented with the proposed building.

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