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Implementation of an Intelligent Energy Management System for Optimized Microgrid Performance

Abstract— Energy management in microgrids has become indispensable for the optimal functioning and efficient operation of the microgrid system. The primary objective of this project is to develop a novel energy management architecture model, taking in to account the various constraints on the operating loads and the supply to these loads. The application of this operational model will be restricted to domestic loads. The connected loads are categorised, load scheduling is performed, and the mode of supply is decided. Load scheduling is achieved by linear programming in MATLAB and mode of supply for the loads is decided by implementing ladder logic in MATLAB Simulink.The hardware has been implemented by using a Programmable Logic Controller (PLC), which switches between the various sources powering the Smart grid.

Keywords: MATLAB, constraints, domestic, microgrids

I. INTRODUCTION

Environmental concerns and economic factors have influenced the way in which the appliances operate. They have augmented the widespread usage of renewable energy systems. The management of the various power supply modes can be accomplished by implementing a divide and monitor approach. This can be facilitated by means of microgrids that provides greater information flow, flexibility and control to both electricity consumers and electricity suppliers. Microgrids serve as essential tools in this project and also in meeting the rising demand for electricity in an increasingly electrified world. They gain attention due to their ability to sell excess electric- ity to the utility grid, act as a buffer during energy demand surges, and provide power during natural disasters. Grid-connected microgrids can run in "island mode" independently but remain synchronized with the main grid, enhancing supply security and providing emergency power. The two-way flow of information between consumer and electricity producer in smart grid has efficient control of the grid system and the scheduling of appliances to optimize the cost. The objective is to classify loads into diverse categories based on the constraints in operating them and develop an optimization algorithm which is based on a mixed linear programming approach to schedule the appliances based on user requirements. After this, the mode of supply to the loads connected to the micro- grid must be decided. The microgrid is operated in a grid connected mode and is supplied with power from the main grid or from the battery powered by the Photovoltaic system. This project aims to minimize the household electricity bill and reduce the dependence on main grid which is achieved by classification of loads (shiftable or non-shiftable) based on operating constraints, scheduling the shiftable loads using linear programming, and developing a ladder logic to decide the mode of supply for the non-shiftable loads. The primary idea behind the algorithm used is to operate the shiftable loads when the hourly tariff is minimum, provided there's few constraints and to run the non-shiftable loads during the time of high tariff, provided there is enough energy stored in battery or to run the loads on grid supply.

II. DEMAND SIDE MANAGEMENT (DSM IN DOMESTIC MICROGRIDS)

Demand Side Management (DSM) plays a crucial role in optimizing energy consumption in domestic mi- crogrid systems. To effectively schedule various load types within such a system, comprehensive data on each load type's characteristics, including cycle times and energy usage in different modes, is essential. Furthermore, DSM also involves Demand Response (DR), a set of initiatives aimed at encouraging end-users to reduce their short-term energy consumption in response to price signals from the electricity market or triggers set by grid op- erators. There are two primary strategies employed by utility energy providers to adjust demand response and align it with energy supply and generation. Direct load control is one strategy, in which the utility or an operator and the consumer agree to directly manage the functioning of appliances to shift or shed the load. The second strategy is to employ dynamic smart pricing, where customers are urged to manage their loads independently and voluntarily. Load shifting and load reduction are two areas where DSM has an major impact. The future of energy management is shifting towards the increasing use of small-scale dispersed energy resources Demand dispatch is a key DSM strategy, offering deployment and assessment capabilities across a 24-hour duration and is important for efficiently integrating intermittent renewable energy sources, ensuring a smooth and reliable energy supply.

A. DEMAND RESPONSE VISUALIZATION TECHNIQUES

Demand Response techniques are highly effective in reducing operating expenses and minimizing unwanted emissions. The six standard techniques used for the load shaping strategy in demand side management are repre- sented in the Fig 1

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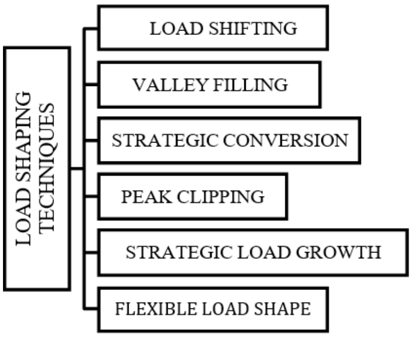


Fig. 1. Load Shaping techniques

Out of these, the three major aspects of Demand Response are :

- **Peak Clipping**: This technique focuses on reducing peak demand, ensuring that the supply capacity of substations remains within safe limits. By staying within thermal limits of transformers and feeders, significant cost savings can be achieved for consumers.
- **Valley Filling**: Encouraging energy consumption during off-peak times is the goal of this strategy. It can be achieved through energy storage devices like batteries and vehicle-to-grid systems. Plug-in electric vehicle batteries can function as both loads and energy sources, offering flexibility in demand management.
- **Load Shifting**: Load shifting is commonly used when multiple loads are connected to a microgrid system. It involves scheduling flexible loads to operate during low tariff hours, optimizing energy costs.

B. ENERGY SOURCES FOR THE MICROGRID

Domestic microgrids can operate in two modes: grid-connected and island mode. While the island mode offers self-sufficiency, it has the drawback of load interruptions when the microgrid supply fails. In contrast, grid-connected mode allows for continuous power supply, even during contingency conditions. The two main categories of power sources for microgrids are the traditional power grid provided by utility companies and re- newable resources like solar and wind. The increasing integration of distributed energy resources (DER) into the grid, particularly on-grid renewable energy sources necessitates transition to smart grids that requires durable and stable infrastructure capable of handling the transition from one-way energy flow to two-way communication and energy flow. Hybrid renewable energy systems (HRES) , such as those combining distribution grid energy, autonomous power generators like fuel cells and combined heat and power systems, renewable sources like solar panels and wind turbines, and energy storage devices like batteries, also offer substantial advantages.

C. TYPES OF LOADS

In a residential energy management system, loads can be categorized as manageable (shiftable) or non- manageable (non-shiftable). Manageable loads can further be divided into:

- **Shiftable Load**: These loads offer scheduling flexibility for demand response based on specific consump- tion cycles with defined energy consumption profiles. Examples include appliances like washing machines and water heaters.
- **Non-shiftable Loads**: These loads have rigid schedules and must operate during specific time periods. They are not flexible in terms of demand response and include items like lighting and fans.

During peak hours when electricity tariffs are high, the cost of electricity increases significantly. To reduce costs, two modes of supply are used: battery storage systems and the main grid. A simulation has been devel- oped using programmable logic controllers (PLC) that determine the mode of supply based on two key criteria: remaining charge in the battery and the tariff per hour.

III.APPLIANCE SCHEDULING

This section briefly discusses about the appliance scheduling problem solved using MATLAB solvers by incorporating a linear programming structure in solving for the minimized cost. The cost is modelled as an objective function. This objective function is optimized by formulating a MILP technique by using decision variables and auxiliary decision variables to decide the operating times for appliances during the day.

A. *PROBLEM DEFINITION*

The operating times of an appliance can be 24 hours which is a single day. These hours are divided into 96 slots. The time duration of each slot being 15 minutes. The problem can be defined based on the number of appliances which are in the form of loads that are connected to the microgrid system. The collection of un-interruptible load profiles for each appliance is denoted by nj for j = 1, 2, 3, and so on, whereas the set of appliances for scheduling is represented by N. When a same appliance is utilized on multiple occasions or at various times, it will be handled differently, either with the same load profile as appliance-1 and appliance-2, or a different load profile. The number of load phases y in usage of appliance j during time slot x is what we can now define as appliance use by name (with its fixed 19 matching load profile). Here,

P^{x}_{yj} represents load variable assigned to an appliance j having load phase y during time slot x. The parameters used in modelling the objective function has been specified in the Table 1 Binary decision variable having a value 1 when appliance with a particular load phase in a particular time slot is being used .

TABLE I

NOTATIONS OF OBJECTIVE FUNCTION

SYMBOL	DEFINITION
j	Appliance to be scheduled
x	Time slot in the day
y	Load phase associated with each appliance
n_j	No. of un-interruptible load phases associated with an appliance
N	Total count of appliances for scheduling
m	Maximum slots of operation
P^{x}_{yj}	Load variable for a particular appliance
S^{x}	Tariff price per time slot
Q^{x}_{yj}	Binary decision variable

B. DECISION TO SCHEDULE THE APPLIANCES

The unit for the load variable which is initially assumed to be kW is now modified to kWh by multiplying the kW value with a time scaling factor of 0.25. These load variables are considered as decision 20 variables which along with the auxiliary variables indicate the operating

status of a particular load profile. The binary decision variable, Q^{x}_{yj}, has two values; 0 and 1. When the load is being serviced or during the operating time slot for that particular appliance the value of the binary decision variable is 1 and the value is 0 otherwise. In the same way, a

complimentary binary decision variable can be formulated. They define the primary operating constraint for the objective function for the optimization of the cost. Let the complimentary binary decision variable be, R^{x}_{yj} then,

$$Q^{x}_{yj} + R^{x}_{yj} = 1 \qquad (3.1)$$

This equation poses a common understanding that either one of the binary decision variables can be 1. Both cannot be 1 at the same time.

C. COST MODELLED AS AN OBJECTIVE FUNCTION

The primary intention of the appliance scheduling algorithm is

to optimize the resources as well as the cost of power supply to the microgrid. The tariff that is to be implemented is a TOU tariff. The dynamic pricing will be applied to curb the unnecessary usage of power. Sx denotes the TOU tariff for a particular time slot x. The summed-up cost of electricity consumption can be modelled as,

$$g(c)=\min \sum_{x=1}^{m} S^{x} \left(\sum_{j=1}^{N} \sum_{y=1}^{N} P_{yj}^{x}\, Q_{yj}^{x}\right) \qquad (3.2)$$

Here g(c) denotes the objective function formulated to minimize the cost. The optimization is realized by using the binary decision variable Q^{x}_{yj} ,x for all values of {y,j,k} in which the appliances j and their load phases y are known and the time slot of operation is the 21 unknown. This will allow for the best arrangement of appliances with respect to start and end times, lowering and levelling appliance peak demand while minimizing energy costs under TOU tariff. If a microgrid is taken into the picture for modelling, then the objective function varies with slight modifications. It is given by

$$g(c)=\min \sum_{x=1}^{m} \sum_{j=1}^{N} \sum_{y=1}^{n_j} (S^{x} P_{yj}^{x} Q_{yj}^{x} - d^{x} T_{yj}^{x} Q_{yj}^{x}) \qquad (3.3)$$

where S and d represent TOU tariff and feed-in tariff. Tyj X is the power produced by PV panel consisting of different phases y at time x. The objective function's micro-grid component is constant because it only has fixed starting and ending times. Appliance scheduling will be the only method used to achieve the optimization. The demand curve for the appliances will be superimposed with the PV profile. When PV supply load is greater than the appliance demand, it is simple to identify when to supplement appliance demand to lower load or export electricity when feasible. Optimizing Microgrid Operation Through Linear Programming

D. OPERATING CONSTRAINTS

1)Power Constraints

In our domestic microgrid setup, we have modelled four different loads, which can be further categorized into shiftable and non-shiftable loads. The four loads include:

Air Conditioner: 3.5 kW Washing Machine: 1.4 kW Water Pump: 1.2 kW Water Heater: 4 kW

The power constraints are determined based on the maximum power rating of these appliances. The operation of the microgrid is directed by these constraints, ensuring that the total load does not exceed the system's capacity during each hour of operation.While shiftable loads can operate at any time, non-shiftable loads are restricted in their operation time due to various constraints. [1]

Table II CONSTRAINTS ON THE MAXIMUM POWER

HOUR	AIR CONDITIONER(KW)	WASHING MACHINE(KW)	WATER PUMP(KW)	WATER HEATER(KW)	TOTAL
1	3.5	1.4	1.2	4	10.1
2	0	1.4	1.2	4	6.6
3	0	1.4	1.2	4	6.6
4	0	1.4	1.2	4	6.6
5	0	1.4	1.2	4	6.6
6	0	1.4	1.2	4	6.6
7	0	1.4	1.2	4	6.6
8	0	1.4	1.2	0	2.6
9	0	1.4	1.2	0	2.6
10	0	1.4	1.2	0	2.6
11	0	1.4	1.2	0	2.6
12	0	1.4	1.2	0	2.6
13	0	1.4	1.2	0	2.6
14	0	1.4	1.2	0	2.6
15	0	1.4	1.2	0	2.6
16	0	1.4	1.2	0	2.6
17	0	1.4	1.2	0	2.6
18	0	1.4	1.2	0	2.6
19	0	1.4	1.2	0	6.1
20	3.5	1.4	1.2	4	10.1
21	3.5	1.4	1.2	4	10.1
22	3.5	1.4	1.2	4	10.1
23	3.5	1.4	1.2	4	10.1
24	3.5	1.4	1.2	4	10.1

2)Operating Time Constraints

Uninterruptible load phases refer to loads that, once started and completed, cannot be restarted. This con- straint is represented mathematically as ${}_{yj}{}^{X} = 0$, ensuring that loads do not restart after their operation has ended. Additionally, the concept of sequential processing of appliances is crucial. A load phase cannot begin processing loads in a load profile of an appliance until all its previous phases have ended. This principle is known as sequen- tial processing of loads.The user's time preferences play a significant role in developing the load schedule. Time preference restrictions specify the time window within which an appliance must complete its operation, allowing users to define when their appliances can be used. [1]

Air Conditioner: Cannot operate between 2:00 AM and 6:00 PM
Washing Machine: Can be operated at any time
Water Pump: Can be operated at any time
Water Heater: Cannot operate between 8:00 AM and 7:00 PM

E. LINEAR PROGRAMMING SOLUTION

Our objective function contains both integer and non-integer values, making it suitable for mixed integer linear programming (MILP) techniques. MILP allows us to minimize the cost of operating our microgrid while satisfying the given constraints. We divide a day into 96 time slots, each representing 15 minutes. Using binary decision variables, we identify which time slots are being utilized during the operation. Solving this MILP problem presents a challenge because it requires examining every possible combination of binary variables. As the number of variables increases, the computational effort involved grows exponentially. To solve this problem, we employ mathematical solvers and programming software with mathematical functions, such as MATLAB. Additionally, other solvers like IBM CPLEX and GUROBI are available for larger-scale implementations.

1)MATLAB Tools and Functions

In our case, we have utilized MATLAB's linear optimization toolbox which includes solvers for various types of optimization, including mixed-integer linear programming (MILP),to solve the appliance scheduling problem.

2)Load Scheduled Before Optimization

Before optimization, our load schedule for different appliances was determined. The load profiles were created based on the power ratings of the appliances and their specified operation times. Without optimization, this initial load schedule could lead to high costs and inefficient resource usage.

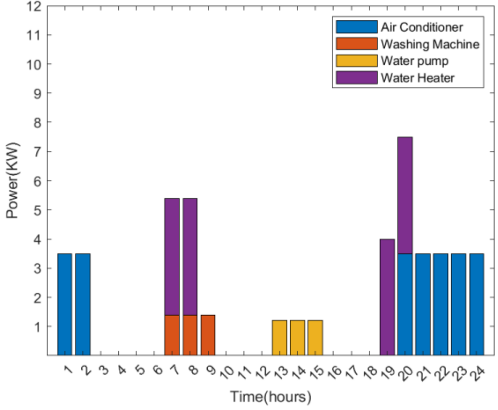


Fig. 2. Load profile of appliances before optimization

3)Load Scheduled After Optimization

After applying linear programming techniques to our load schedule, we optimized it to reduce both costs and peak demand. By shifting the operation of shiftable loads to off-peak hours when electricity prices are lower, we effectively reduced costs.

The optimized load schedule is achieved through the reordering of time slots. Shiftable loads are strategically operated during off-peak hours, while non-shiftable loads are managed during peak hours.

The result of this optimization is not only cost reduction but also an efficient energy management system for the domestic microgrid. It allows for better utilization of locally generated electricity and significant savings, especially during periods of dynamic pricing. [1]

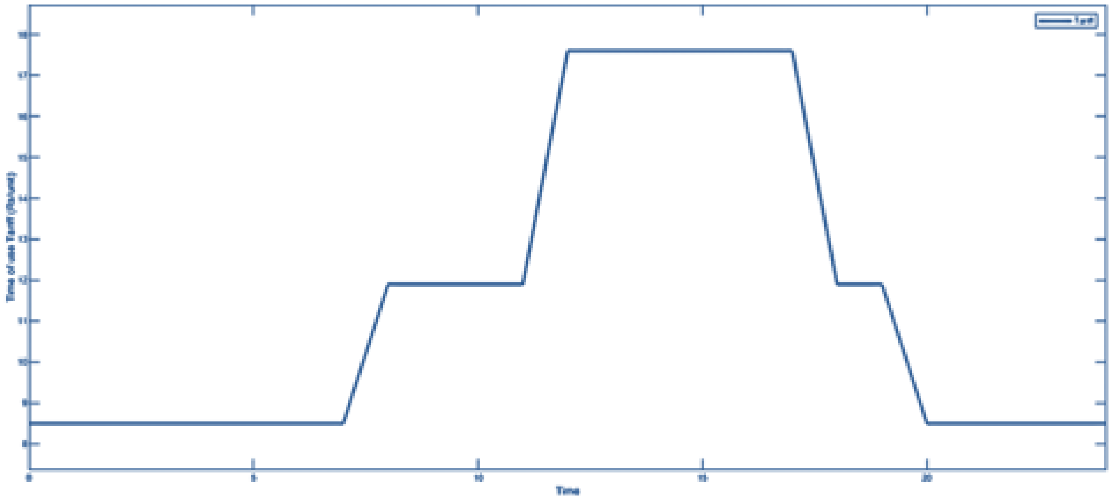
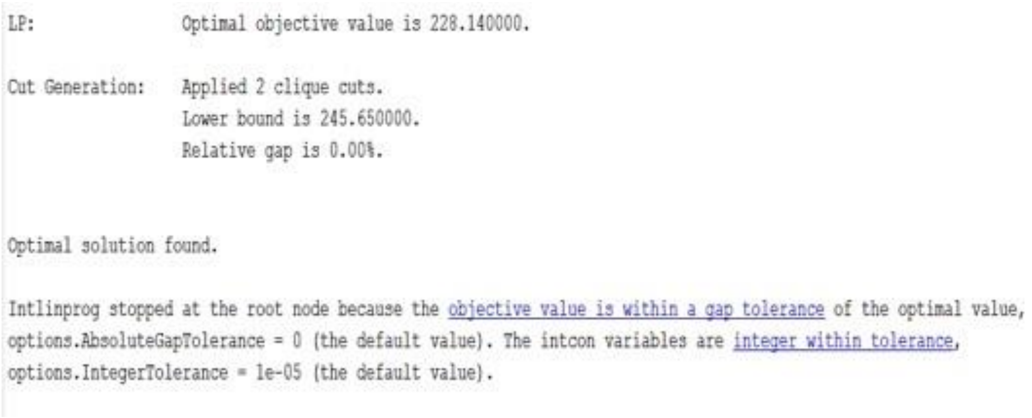


Fig. 3. Time of use tariff pricing



```
LP:                Optimal objective value is 228.140000.

Cut Generation:    Applied 2 clique cuts.
                   Lower bound is 245.650000.
                   Relative gap is 0.00%.


Optimal solution found.

Intlinprog stopped at the root node because the objective value is within a gap tolerance of the optimal value,
options.AbsoluteGapTolerance = 0 (the default value). The intcon variables are integer within tolerance,
options.IntegerTolerance = 1e-05 (the default value).
```

Fig. 4. Optimized cost using LP

It shows the cost of electrical power after scheduling the loads by means of linear programming approach It shows the after optimization load schedule

IV.LADDER LOGIC AND LADDER DIAGRAM

Ladder logic is a graphical programming language that is used to program a PLC (Programmable Logic Controller). It symbolically represents circuit diagrams of relay logic in the form of ladder diagrams.

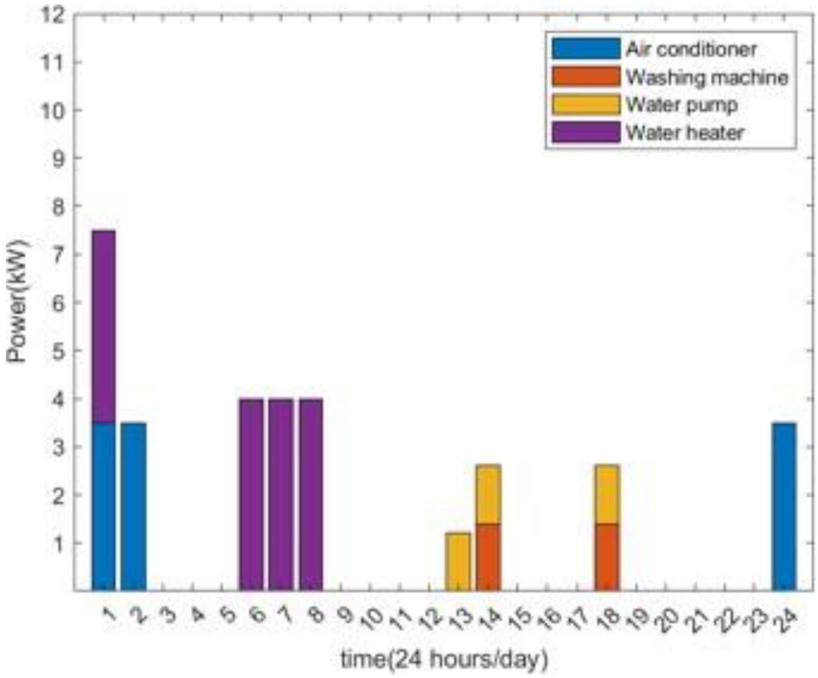


Fig. 5. Load profile of appliances after optimization

Ladder diagrams have horizontal lines of control logic called rungs and vertical lines at the start and end of each rung called rails. Ladder logic works in a similar way of relay logic, but without all the laborious relay control wiring. In simple terms, the field input and output devices are wired directly to the PLC and the ladder logic program decides what outputs to activate, depending on the status of the input signals.

B. COMPONENTS OF LADDER DIAGRAM

- **Rails**

ladder diagram has two long vertical lines called the Rails. One rail represents the positive supply and the other represents the ground of a relay logic circuit.

- **Rungs**

These are the horizontal lines connected between the two Rails and they represent the wires in a relay logic circuit.

- **Inputs**

The inputs are the control signals given in the form of push buttons or analog values. In ladder diagram the inputs are represented as normally open (NO) or normally closed (NC) contact symbol.

- **Outputs**

The external devices like motor that are being controlled represent the output. The output signals are in the form of binary 0’s or 1’s. In a ladder diagram the relay coil symbol represent the output.

- **Logic Expressions**

The logic expressions are used in combination with the inputs and outputs to formulate the desired control operations.

D.LADDER LOGIC IN MATLAB

There are many softwares available for implementing ladder logic. We have demonstrated ladder logic using the ‘PLC Coder’ application available in MATLAB Simulink. [2]

The Ladder Diagram Function Block consists of a ladder diagram and function block variables. In Ladder Diagrams, tags (variables) are used to represent inputs, outputs, and internal memory with attributes such as Data Type, Initial Value, and size. To change the attributes of the Operand Tag, open the Program Variables table within the Ladder Diagram Program block.

E.SIMULATION PROCEDURE

The simulation is carried out for 24 units of time. Each unit of time represents 1 hour.

F.DECIDING INPUT VARIABLE

In the first step the inputs are collected and are given to the 'Battery and Grid Controller' subsystem. The inputs are:

- Battery_SOC – This input represents the state of charge of battery. The battery SOC decreases as and when the load draws power from the battery.or the initial 11 units of time the Battery_SOC remains 100, this implies no power is drawn from the battery.

For the next unit of time the battery supplies power to some of the loads and hence its SOC decreases to 70.

- Tariff – The type of tariff used is Time of use Pricing.

TABLE I

Time	State of charge	Time of use of tariff
1	100	8.5
2	100	8.5
3	100	8.5
4	100	8.5
5	100	8.5
6	100	8.5
7	100	8.5
8	100	11.9
9	100	11.9
10	100	11.9
11	100	11.9
12	70	17.6
13	60	17.6
14	58	17.6
15	55	17.6
16	50	17.6
17	48	17.6
18	48	17.6
19	48	11.9
20	48	11.9
21	48	8.5
22	48	8.5
23	48	8.5
24	48	8.5

G.THE INPUTS ARE GIVEN TO THE AOI RUNNER (BATTERY CONTROLLER RUNNER

Within the AOI runner is the Function Block (AOI). Double clicking the block, opens the 'Block Parame- ters' dialog box which consists of a ladder diagram and function block variables.

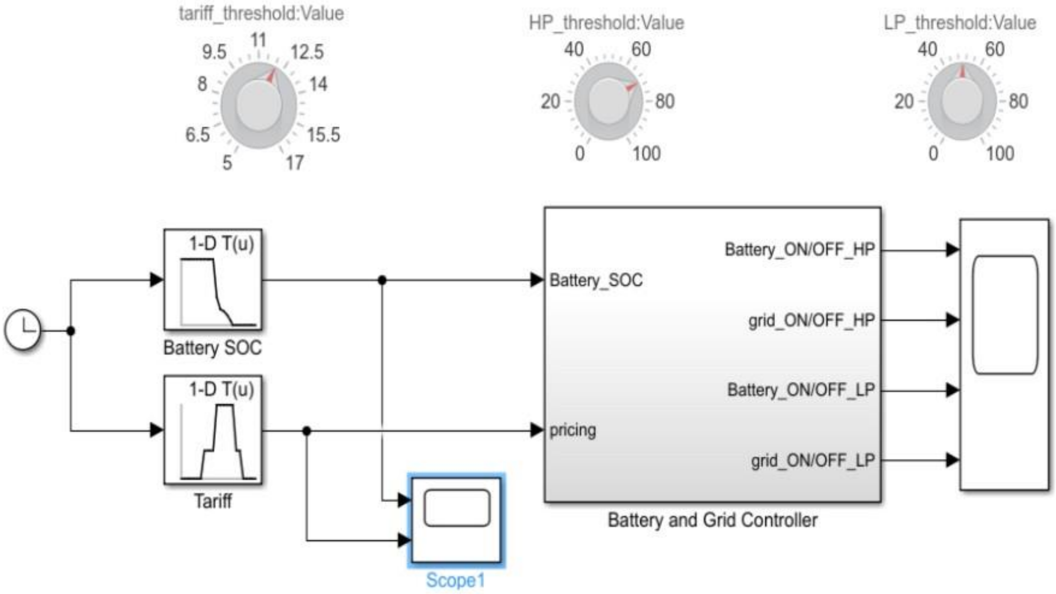


Fig.6: Battery and grid controller subsystem

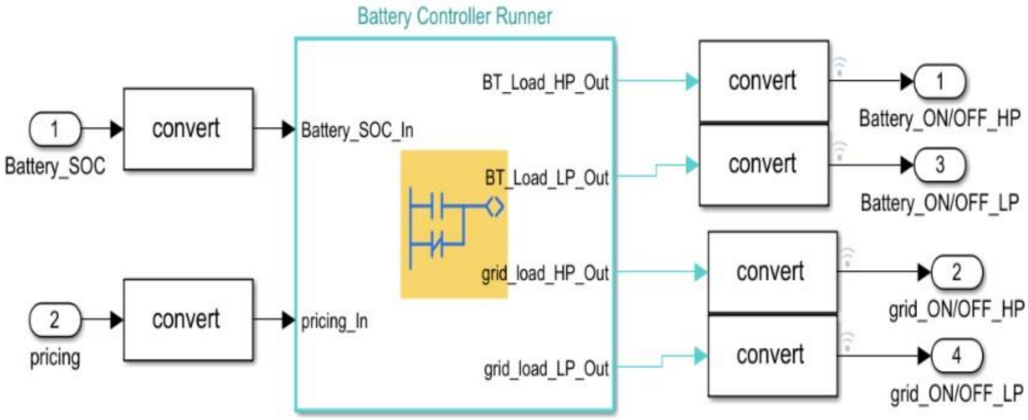


Fig. 7:AOI Runner with I/O

- Function block variable (in the ‘Variable Table’): Function block variables consists of all the variables that are used to implement ladder logic.

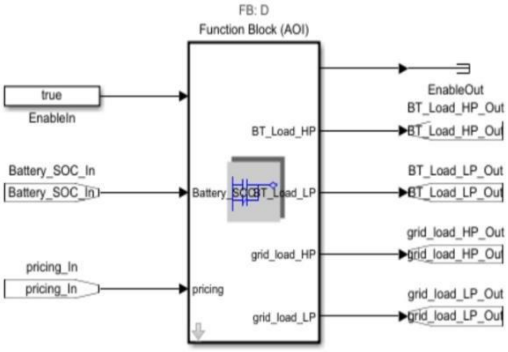
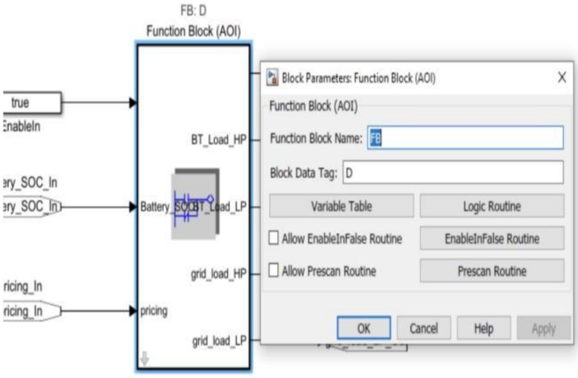


Fig. 8. Function Block (AOI)



Block Parameters: Function Block (AOI)

Function Block (AOI)

Function Block Name: FB

Block Data Tag: D

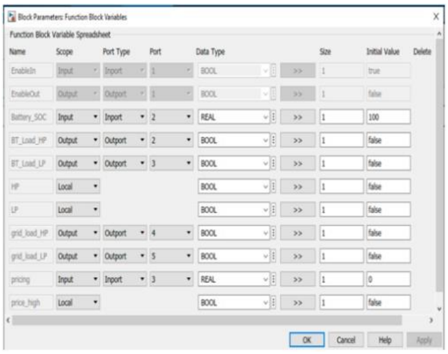
Variable Table | Logic Routine

☐ Allow EnableInFalse Routine | EnableInFalse Routine

☐ Allow Prescan Routine | Prescan Routine

OK | Cancel | Help | Apply

Fig. 9. Block parameters dialog box



Block Parameters: Function Block Variables

Function Block Variable Spreadsheet

Name	Scope	Port Type	Port	Data Type		Size	Initial Value	Delete
EnableIn	Input	Inport	1	BOOL	>>	1	true	
EnableOut	Output	Outport	1	BOOL	>>	1	false	
Battery_SOC	Input	Inport	2	REAL	>>	1	100	
BT_Load_HP	Output	Outport	2	BOOL	>>	1	false	
BT_Load_LP	Output	Outport	3	BOOL	>>	1	false	
HP	Local			BOOL	>>	1	false	
LP	Local			BOOL	>>	1	false	
grid_load_HP	Output	Outport	4	BOOL	>>	1	false	
grid_load_LP	Output	Outport	5	BOOL	>>	1	false	
pricing	Input	Inport	3	REAL	>>	1	0	
price_high	Local			BOOL	>>	1	false	

Fig. 10 Function Block variables.The variables are depicted in Fig 10.

- Function block variable (in the 'Variable Table'): Function block variables consists of all the variables that are used to implement ladder logic.This block gives us access to change the Scope, Port Type,Port, Data Type, Size, and Initial Value of the variable.

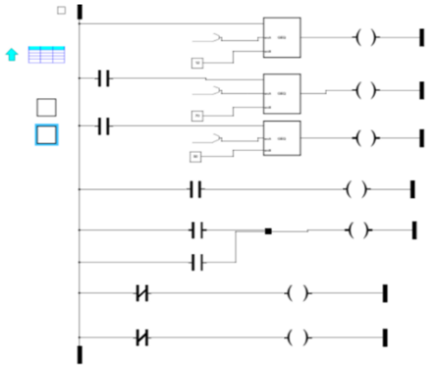


Fig.10(a)

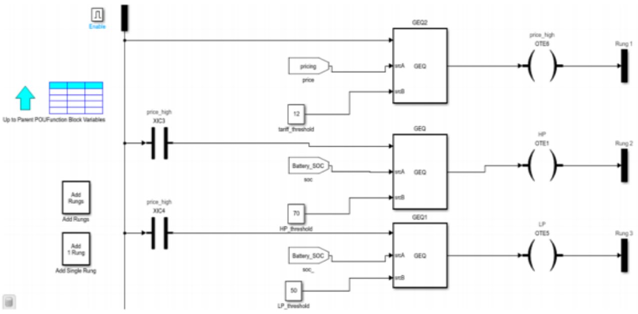


Fig.10(b)

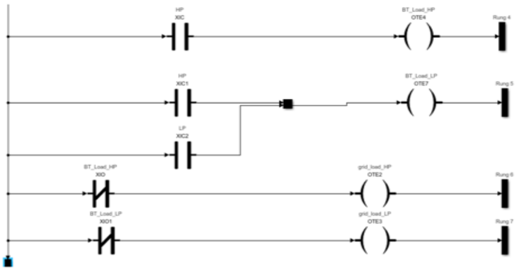


Fig. 10(c)

Fig 10(a)(b)(c) represents the ladder diagrams.

- Ladder diagram (in the 'Logic Routine'):

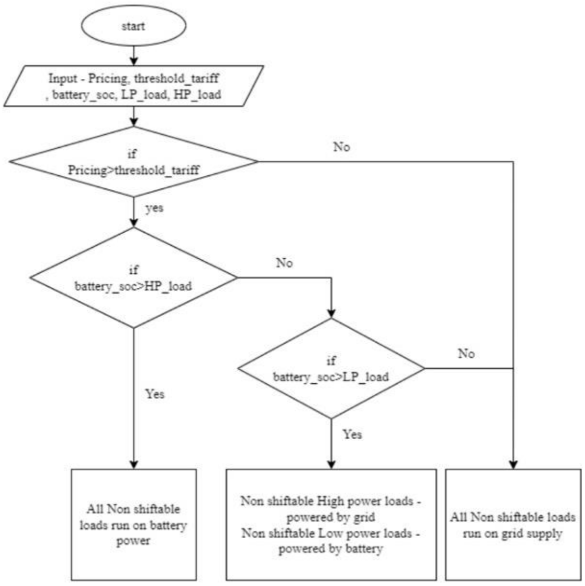
The different inputs that are given to the ladder logic are Pricing which represents hourly time of use tariff, Threshold_Tariff represents Desired threshold value of tariff set by provider, Batter_soc

depicts remaining energy in battery which is calculated using State of 44 Charge of battery. The outputs are BT_Load_HP (OTE 4), BT_Load_LP (OTE 7), grid_load_HP(OTE 2), grid_load_LP (OTE 3).[3]

H. ALGORITHM

The PLC logic must be implemented, such that

- If the tariff is greater than its desired/threshold value, the loads are supplied from the energy stored in the battery.
- Depending on the SoC of battery, it supplies either low power loads or both high and low power loads.
- If the energy of battery is sufficient enough to supply the highpower load, all the non-shiftable loads run on battery.
- If the battery is able to fulfil only the energy criteria of the low power loads, then the non-shiftable low power loads run on battery whereas the high-power loads are powered by the main grid.



If at all, the energy stored in the battery is less than the energy required by the low power loads, then all the non-shiftable loads should be supplied from the main grid.

The different variables used in the flow chart are Pricing which represents hourly time of use tariff, Thresh- old_Tariff represents Desired threshold value of tariff set by provider, Batter_soc depicts47 remaining energy in battery which is calculated using State of Charge of battery, LP_load denote the loads which consume less power and HP_load represent all the loads which consume High power.

I. SIMULATION RESULT

Each step of the simulation is depicted in the following figures:

- When the Pricing is less than threshold tariff, loads must run on grid supply. since Pricing is less than threshold tariff, OTE6 is low and hence Loads run on grid supply. This is depicted by grid_load_HP (OTE2) and grid_load_LP (OTE3) going HIGH. Fig. 11

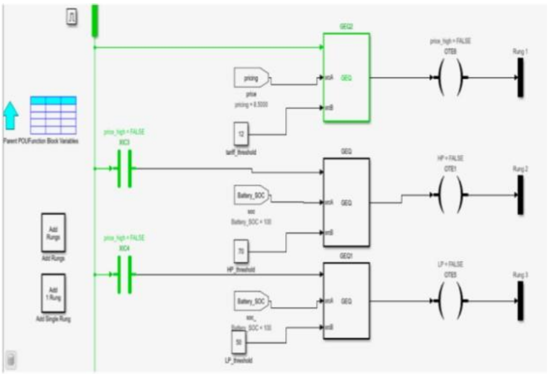


Fig. 12(a)Pricing<threshold tariff

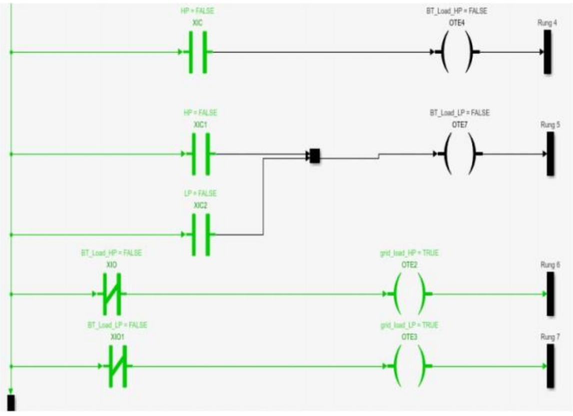


Fig. 12(b)loads run on grid supply

- When pricing is greater than threshold tariff loads must run on battery, provided battery has enough energy. Energy stored in battery is less than what is required to supply high power loads therefore HP (OTE 1) is low. Hence high-power loads run on grid supply which can be seen by grid_load_HP (OTE 2) being high. Low power loads run on battery (as battery energy is sufficient to run the low power loads). This is indicated by BT_load_LP (OTE7) going high

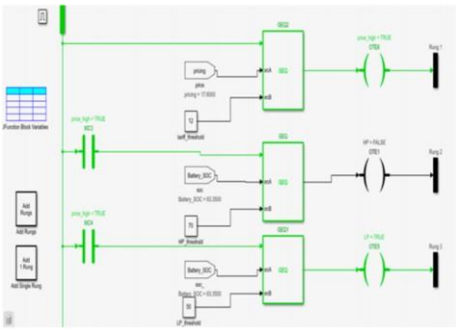


Fig. 13(a)Pricing>threshold tariff

- When Pricing is greater that the threshold tariff, loads must run on battery, but if energy stored in battery is not sufficient to run the loads, then the main grid must be the mode of supply for the loads.
- The hardware setup includes a compact SIMATIC S7-1200 PLC used with various other elements, that in-grid supply.

B.

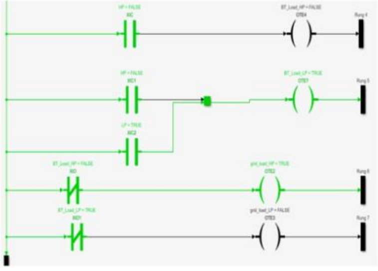


Fig.13(b)Low power loads run on battery and high ones on grid supply

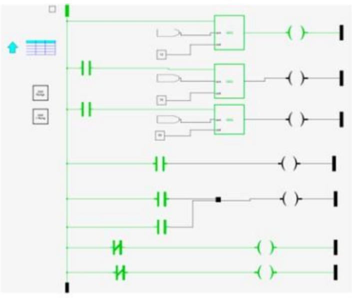


Fig. 14. Battery SOC reaches minimum ,all loads run on grid supply

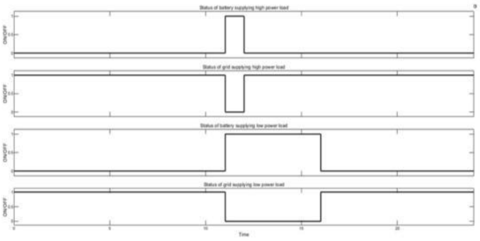


Fig. 15. Output curve

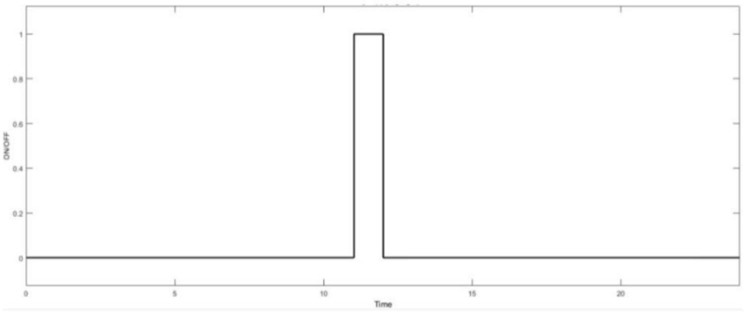


Fig. 16. status of battery supplying high power load

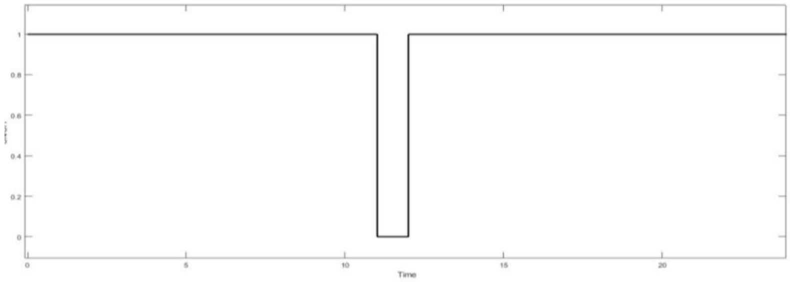


Fig. 17. status of grid supplyng high power load

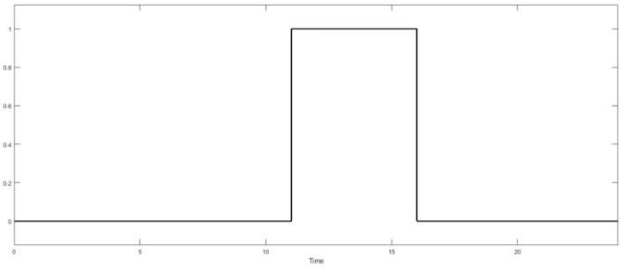


Fig. 18. status of battery supplying low power load

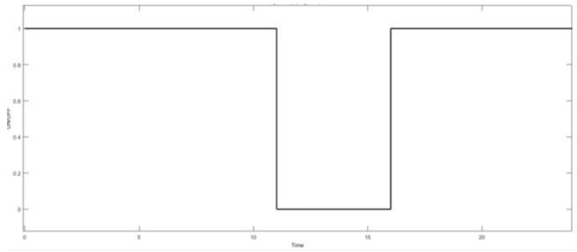


Fig. 19. status of grid supplying low power load

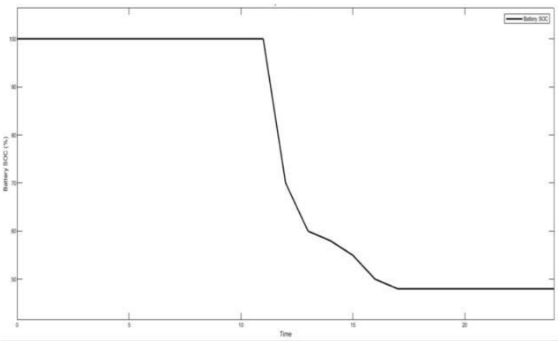


Fig. 20.Battery SOC vs Time

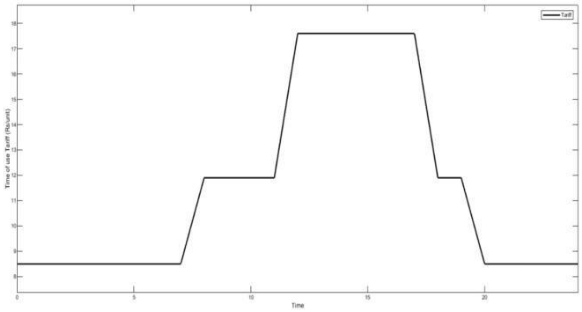


Fig. 21. Time of use tariff vs time

clude RPS, processor, potentiometer. A Programmable Logic Controller (PLC) is composed of several funda- mental components including a CPU, memory, I/O modules, power supply, and communication ports. The major role of the PLC is to control inputs and outputs with specific programming languages such as ladder logic, func- tional block diagrams, and structured text. The SIMATIC S7-1200 is part of the Siemens S7 family of PLCs, which is well-regarded for its reliability and flexible automation solution suitable for a range of industries, offer- ing high-performance capabilities, advanced communication options, and easy installation and expansion. It is a user-friendly PLC that simplifies the programming process using Siemens' TIA Portal software. The SIMATIC S7-1200 product range includes 13 different modules that offer digital and analog signals, 3 compact controllers that provide graded performances in different versions such as wide-range AC or DC controllers, 2 signal boards (analog and digital) that allow low-cost modular controller expansion directly on the CPU while retaining mount- ing space, 2 communication modules, and an Ethernet switch with four ports.

Fig. 22. PLC

The S7-1200 Basic Controller's CPU is responsible for executing the user program and managing communication with the I/O modules and other devices, making it the heart of the S7-1200.The Siemens S7- 1200 offers various models with varying specifications, including the CPU 1211C, CPU 1212C, CPU 1214C, CPU 1215C, and CPU 1217C. The version CPU 1214C is used in this project, and it comes in three versions, each with different power supply and control voltages, DC/DC/DC, AC/DC/RLY, and DC/DC/RLY. The version DC/DC/DC has an integrated power supply/operating voltage of 24V DC [1] .

In this paper, a regulated power supply is used to simulate the working of a renewable battery source for convenience, as the SoC of a battery can be represented as a linear function of its terminal voltage. This is done to gain more control over the engineered system's responses for better demonstration purposes.

I. CONCLUSION

The major outcome from the project is the optimized load scheduling algorithm which minimized the cost of power significantly. It devised a load profile to categorize the shiftable and non-shiftable loads based on the operating constraints. The ladder logic algorithm is used to change the mode of supply (for the non-shiftable loads) from main grid to the Battery system during the peak hours. The scheduling of the various appliances was found to be much more efficient since they were set to be processed during off-peak hours and the shifting of mode of supply during the peak hour minimized the dependence on the main grid. The Brute Force optimization approach can also be used to solve the objective function for lowering the cost of energy in time-varying tariffs and minimizing peak load for levelling the appliance demand curve, but this require significant processing time and memory due to additional constraints. Future studies may also examine other design alternatives to the PV energy sources, including small wind turbines installed in homes. The PV panel system covered in this paper isa grid-tie system with battery management system that stores and conserves energy for use later. Studying the cost-effectiveness of both types of PV panels on-grid and off-grid can help create a comprehensive home energy reserve. In conclusion, the implementation of a microgrid energy management system holds significant promise for achieving efficient and sustainable energy utilization.

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