Load Curtailment in the BVRIT Campus Microgrid System, Fed with 440 KWp Decentralized Rooftop Solar PV System

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Received: 13.08.2023, Accepted: 16.09.2023

Abstract- This paper presents a novel load curtailment mechanism for a campus Microgrid with integrated photovoltaic (PV) systems, employing MATLAB Simulink and Stateflow. The Conventional demand response (DR) methods are not efficient for achieving rapid responses in today's context, where a significant number of consumers have PV systems installed. Conventional methods like Volt-Var Optimizations are computationally expensive and necessitate low response times. To achieve the net load curtailment, load profiles of different academic blocks are acquired from the campus energy monitoring system (CEMS). Load curtailment was performed on a single day, employing Simulink and Stateflow in MATLAB without an Energy Storage System, which would typically be used to smoothen the load curve.

Keywords- Demand response, load curtailment, phasor, microgrid, photovoltaic system, stateflow.

1. Introduction

B V Raju Institute of Technology (Autonomous), Narsapur campus in India, experiences a continuous growth in student intake and technological advancements each year. As a result, the management consistently upgrades the infrastructure to accommodate these changes. However, this increasing demand has led to a rising connected load in electrical terms. Managing the load to ensure it remains within the contracted maximum demand from the grid operator has become a challenge due to the varied and discrete nature of loads in an engineering college. To address this issue, the objective of this work is to develop a response mechanism that can effectively fulfil the load management criterion without disrupting the regular functioning of the institute. Specifically, the focus is on simulating a Load Curtailment mechanism for the BVRIT Narsapur campus, which currently lacks a demand-side management system. The goal is to create a scalable and integrable Load Curtailment system in conjunction with the existing net metering setup. The Load Curtailment model aims to optimize electricity consumption, ensuring that the load never exceeds the maximum demand contracted by the grid operator.

To achieve energy efficiency within the smart grid [1, 9-14] of the campus, it is essential to have control over the load activity. This can be accomplished through Demand Response (DR), a popular method for load curtailment. DR involves motivating changes in customers' power consumption habits, and it is organized into two categories: elastic and inelastic loads. Inelastic loads, such as computers and fans, have constant power requirements, while elastic loads, like pumps and motors, can be adjusted. The BVRIT Narsapur campus utilizes a grid-tied photovoltaic supply, without an Energy Storage System (ESS). Consequently, load and supply matching strategies dependent on PV and battery conjunction are not suitable for this scenario. Instead, a simpler load curtailment approach using Stateflow can be implemented. Existing literature offers load-shedding mechanisms for demand response, but these strategies might not be easily adaptable. Demand side management (DSM) approaches leverage flexible energy sources, but not every Microgrid can install an energy storage system. Load scheduling strategies are cost-friendly but may lack flexibility in responding to changing priorities. This paper aims to address this specific gap in the literature by designing an adaptive Load Curtailment system that does not require an energy storage system and can be adjusted according to the operating conditions without significant hardware redesign. Load scheduling and load-shedding mechanisms are covered in detail in [2-3] and [4], respectively, while demand-side management mechanisms with energy storage solutions are explored in [5-8].

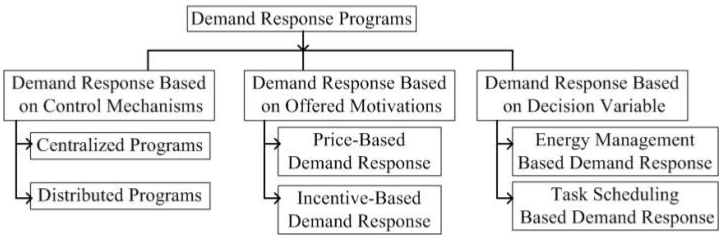

Fig. 1. Classification of Demand Response Strategies [1]

2. Considerations for Load Curtailment System

The objective of this work is to perform Load curtailment on a single day in a BVRIT campus Microgrid with integrated photovoltaic (PV) systems, employing Simulink and Stateflow in MATLAB. The load curtailment system, PV array modelling, and control algorithm for load balancing. All these are explained clearly before going to the proposed MATLAB Simulink model in section three. The Load Curtailment System model was created using Simulink. The crucial elements of our implementation include:

- State Charts
- Controlled Current Source
- Three-phase Current Load

A. Phasor Simulation of a Three-Phase Microgrid

The model described in [8] presents a comprehensive simulation of a full-scale microgrid incorporating a grid-tied PV farm and an Energy Storage System (ESS). Irradiance data from a public time series data (TMY3) and publicly available residential load data are used to track the system's behaviour minutely throughout an entire year. The microgrid is powered by an IEEE utility grid, and to expedite the simulation, the area of the PV farm is provided as input to the irradiance data, enabling the calculation of power fed to the grid. Fault protection is also incorporated in this model, and the system's response to faults is tested. Furthermore, the model facilitates the construction of other grid-connected PV farms without the need for complicated Maximum Power Point Tracking (MPPT) algorithms. This is because the simulation employs a phasor mode that requires a constant frequency in all its components during operation, simplifying the simulation and focusing on signal magnitude changes rather than the entire curve. The ESS is also modelled using a controlled current source, and the model verifies the availability of the battery under various parameters. Adequate compensations are provided based on these parameters. The model is visually depicted in figure 2 titled "ESS One year Simulation in one minute". This model serves as a foundational model due to its use of phasor mode simulation, which offers advantages such as simplified implementation of control algorithms and scalability. It allows for focusing on the changes occurring in the simulation without significantly affecting the overall results in a microgrid. Considering these benefits, and the ease of implementation, this model was selected as the basis for the current work.

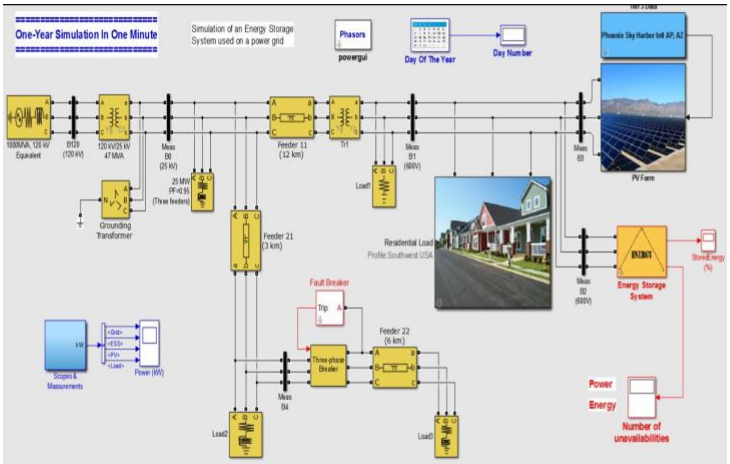

Fig. 2. Simulink model of Sample Grid

B. Working of the Load Curtailment System

As previously stated, the Load Curtailment system builds upon the foundation of the Simulink model introduced in [8], incorporating specific essential functionalities into the system. The load profiles.slx file contains all the three-phase loads, serving as a template for setting up the three-phase grid. These loads were simulated using data from the load values variable within the load data.m script, which initialized these variables in the workspace. The modeling process follows the steps outlined below:

- The active power of the load is extracted from the load_values variable.
- The load data variable provides the average power factor of these loads at 30-minute intervals.
- The next step involves the calculation of apparent power, which is done as follows:

Apparent Power (kVA) = Active Power (kW) / (cosϕ) (1)

- Subsequently, the reactive power is computed as

Reactive power (kVAR) = Apparent Power (kV A) × sin(cos-1(cos(Φ))) (2)

These active and reactive powers are then passed through a multiplexer (mux) to the three-phase dynamic load, generating its profile. This profile can be monitored through the measurement port of the block. Once the loads are modelled, they are connected to a 440V, 630kVA, 50Hz 3-phase supply provided to the BVRIT Narsapur campus from the Narsapur substation

Sno.	Name and Location	Capacity
1	Solar at Visweswarayya Block	83 kWp
2	Solar at Mechanical Block	194 kWp
3	Solar at APJ Block	63 kWp
4	Solar at Aryabhatta Block	100 kWp
	Total	440 kWp

Fig. 3. Installed PV capacity in BVRIT Narsapur

C. PV Array Modelling

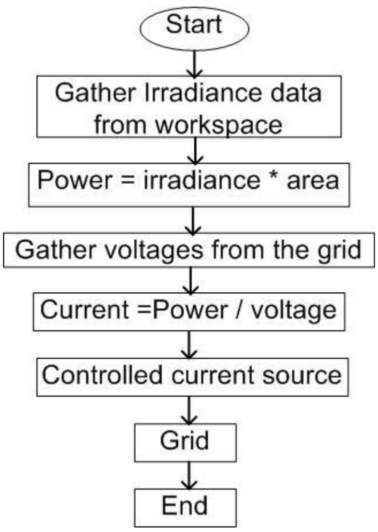

Fig. 4. Modelling of PV array in phasor mode

The PV Array is simulated using the following approach. As mentioned earlier, to expedite the modelling process for data forecasts ranging from hours to years, the phasor mode is utilized. The campus houses a 441 kWp PV installation, comprising two types of modules: 315Wp and 250Wp, with 60 cells each. The Visveswaraya Block is equipped with the 315Wp modules, while the other five locations have the 250Wp modules, as depicted in Figure 3. To calculate the total area of the PV installation, the peak output, irradiance data obtained, areas derived from peak power and module power ratings, and the arrangement of 19 modules per string with an average of 20 strings per block are considered. The azimuth is assumed to be 180 degrees, and the inclination is set at 150 degrees. Based on these parameters, the incident area of the PV installation exposed to solar rays is computed, and this data is used to model the PV array for each block, as shown in Figure 4. Since load data for other blocks in the campus's Central Energy Monitoring System (CEMS) was not available at the time of modelling this work, only data from two blocks with available information was included in the model.

D. Control Algorithm of Load Balancing System in BVRIT Narsapur

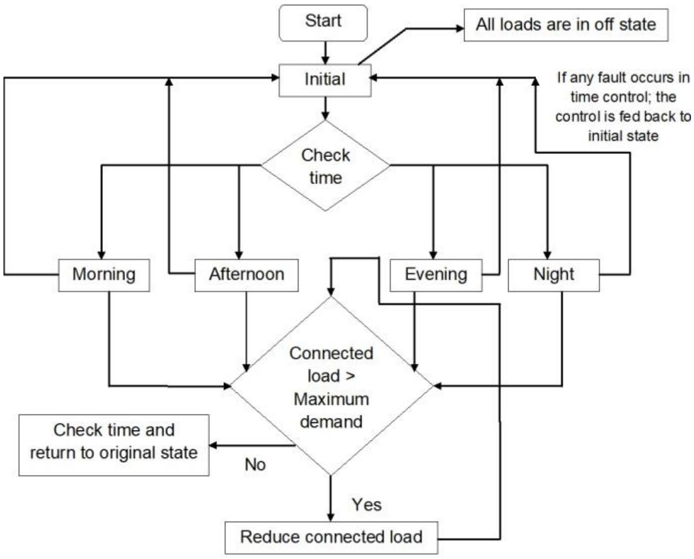

Fig. 5. Control algorithm of Load Balancing System in BVRIT Narsapur

Because of the timing requirements and the computational intricacies involved in managing the grid using optimization techniques, this project has opted for a Schedule-based Demand Response (DR) control approach for the campus microgrid. The operational procedure of the control algorithm is as follows –

- Three inputs are considered: Current load, contracted Maximum Demand, and Time of Day (TOD).
- The system distinguishes between four states based on the TOD: Morning, Afternoon, Evening, and Night.
- The control algorithm transitions to the relevant state, and within each state, a restricted set of loads are activated to optimize efficiency.
- While operating within each state, the algorithm evaluates the present cumulative load against the contracted maximum demand (typically set slightly below it).
- If the connected load surpasses this threshold, the control shifts into the maximum demand state.

- In this scenario, only essential loads are engaged until the connected loads fall below the designated threshold of the contracted maximum demand. The operational procedure of this control algorithm is depicted in the flowchart illustrated in Figure 5.

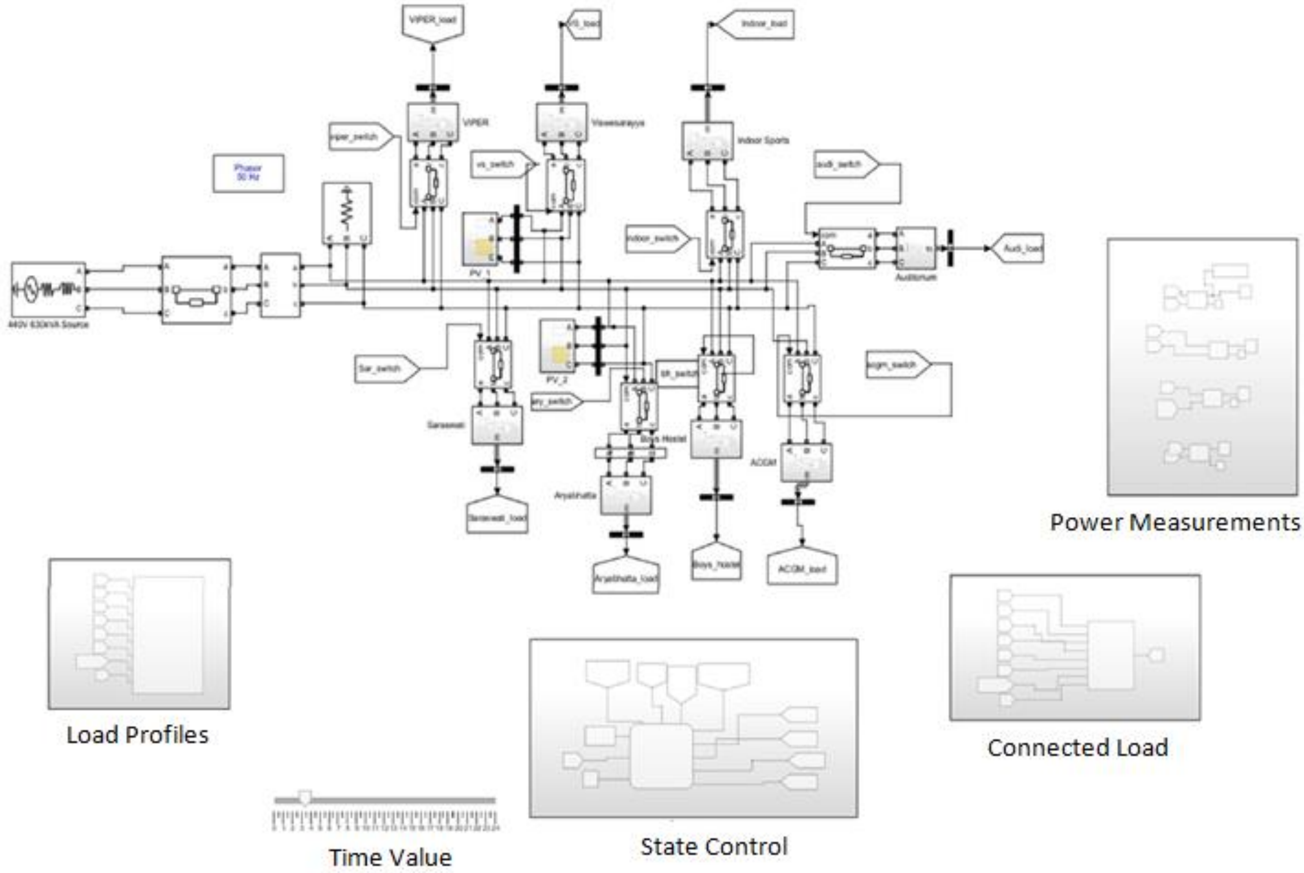

Fig.6. Simulink model of three phase campus microgrid

3. Proposed Simulink Model

This section first developed a MATLAB Simulink based three-phase campus microgrid system based on the objective mentioned in section two. Later, it illustrates how a State machine uses six different states: initial state, maximum demand state, morning, afternoon, evening, and night, followed by acquiring data from eight load blocks in the campus microgrid in section four. Simulating the aforementioned components involving switches within the converters necessitates the utilization of a discrete mode of operation. However, this choice contributes to a slowdown in simulation time, and within microgrid contexts, this delay holds significant implications, given the variable simulation durations spanning from hours to potentially years. This delay proves less advantageous, especially when frequent demand response events within the microgrid require timely forecasts. To address this, we have opted to substitute discrete components with their corresponding power outputs and meticulously synchronize these conversions to closely mimic plant behaviour. Furthermore, to enhance both control Precision and model scalability, we have adopted State Charts to govern the Simulink model. This approach proves especially valuable when grappling with intricate and complex grids, where translating coding into a clear visualization becomes a laborious and tangled task. The Simulink model of the proposed system is shown in Figure 6.

3.1 Simulink Model of the Load Balancing System in BVRIT Narsapur

The model comprises three primary components:

- Three phase grid
- State flow controller
- Measurement of parameters

A. Three Phase Grid

The system is powered by an 11kV, 630kVA three-phase, 50Hz supply. It encompasses eight loads, each with

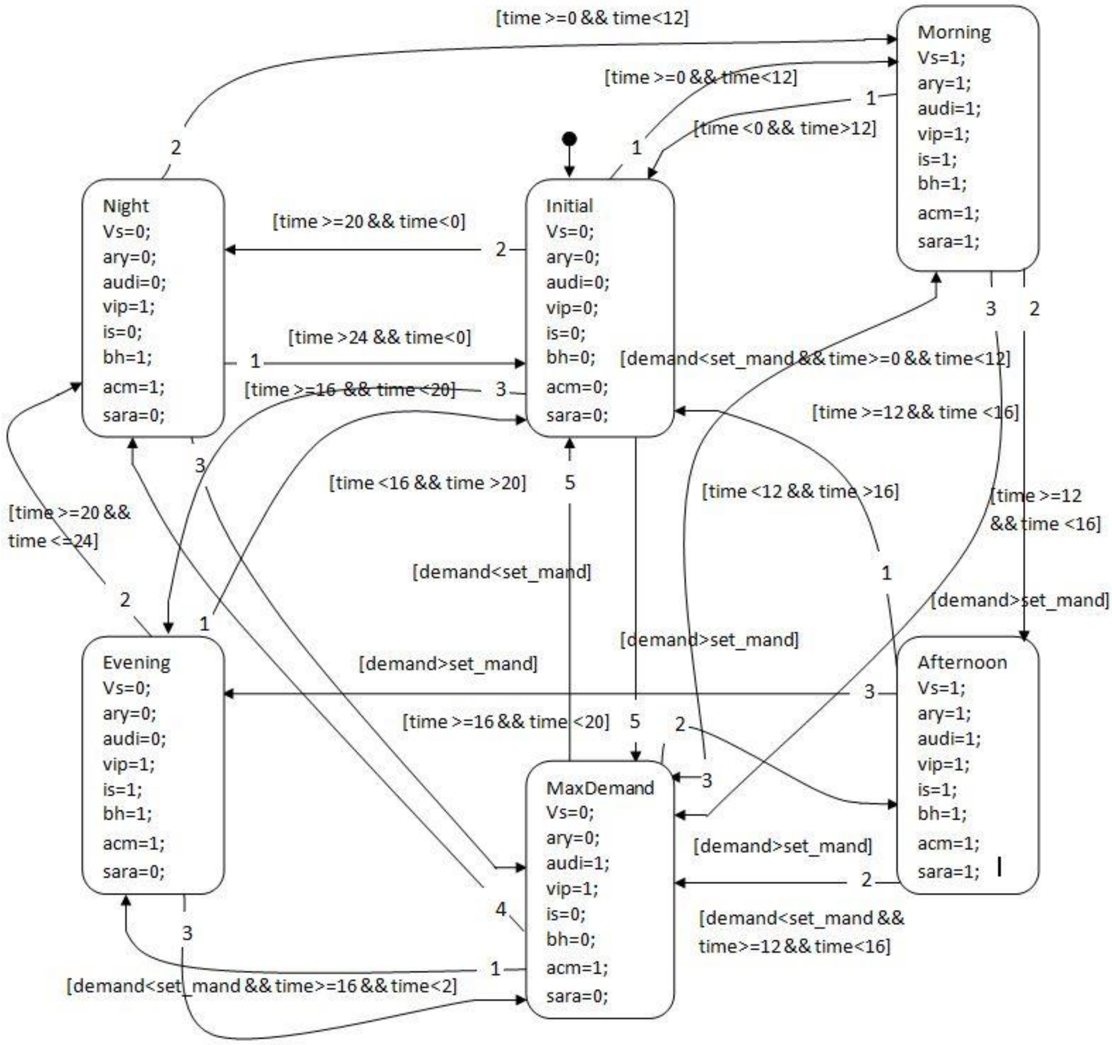

Fig.7. Moore State machine used for implementing DR

predefined profiles, which are simulated through three-phase dynamic load blocks. These profiles are provided as time series via a repeating sequence, with necessary repeating sequence values drawn from the MATLAB script named "load_data.m," located in the main directory. Reactive power calculations for load control are carried out using the function "cal_react.m. To input the data into each load, a repeating sequence block and multiplexer (mux) are employed according to equations (1) and (2). Profiles are extracted from the measurement port of the three-phase dynamic load using a bus selector. The power profile of the respective block during grid operation is visualized through three-phase V-I measurement blocks coupled with instantaneous three-phase phasor power calculation blocks, collectively represented as the power measurements block.

The campus microgrid encompasses two powerhouses: an older powerhouse receiving a 500kVA supply from the substation, and a newer powerhouse with a 630kVA supply input. The input voltage of 11kV is stepped down to 440V phase to phase. For the sake of simplification in design and control, the model omits the transformer and higher voltage lines preceding it. Notably, the inclusion of these elements separately tested for control and simulation does not introduce any errors. This approach enhances clarity in comprehending modelling concepts. Each load within the three-phase grid is initially equipped with a breaker. While the original intention was to model complete load entities and gather data, constraints such as transients induced by the model's inductive elements led to a focus on the powerhouse data alone. This approach accentuates the control mechanism, as elaborated in the subsequent section.

B. Stateflow Chart

The Stateflow diagram depicted in Figure 7 illustrates a machine with six distinct states. The following are brief descriptions of these states:

- **Initial State:** This marks the starting point of the model. In this state, all loads are deactivated. It also serves as the state where a system reset can occur, triggered by any detected faults in the system or persistent controller issues.
- **Maximum Demand:** This state is entered when the instantaneous connected load, computed from grid data, surpasses a predefined threshold. In this state, essential loads are activated, while the non-essential ones are deactivated.
- **Morning:** The system operates within this state between 0 and 12 hours.
- **Afternoon:** The system remains within this state during the time span of 12 to 16 hours.
- **Evening:** The system remains within this state during the time span of 16 to 20 hours.
- **Night:** The system remains within this state during the time span of 20 to 24 hours.

For the purpose of ensuring a comprehensible view of the control mechanism and facilitating effective demonstrations, the state control receives a manual time constant value. This value can be adjusted during simulation through the utilization of a Slider block, allowing variations within the range of -1 to 25. The inclusion of the values -1 and 25 is intended to simulate scenarios involving faulty time control. To generate the connected load, which acts as another input, the load profiles generated by each three-phase dynamic load block are aggregated in connection to the three-phase grid. By incorporating these three inputs, the model's behaviour is regulated. In this simulation, the employed state machine follows the Moore type. This choice is due to the algebraic loop error that arises in Stateflow when using Mealy type state machines. The interference with the load profile loop triggers this issue. In contrast, Moore machines are chosen here to circumvent this problem. It is imperative in Moore machines that the present state remains independent of the preceding state output. Additionally, the state must not possess entry, during, or exit scenarios that directly impact the output of the subsequent state during transitions. These adjustments and principles are crucial for proper functioning. These modifications find practical application and can be more comprehensively grasped when implementing hardware circuits, specifically using Field Programmable Gate Arrays (FPGAs). These applications and their results will be explored further in the subsequent results section.

4. Results and Discussions

4.1 Load Profiles

The subsequent load profiles originate from the data retrieved from the campus energy monitoring system (CEMS) [15] concerning the eight load blocks situated within the BVRIT Narsapur campus microgrid. While these loads exhibit variable magnitudes, they can be categorized according to their designated usage patterns. These categorizations are aligned with the campus operating hours, potentially offering avenues for algorithmic refinement in subsequent developments. By incorporating the campus scheduling details, the initially seemingly erratic load profiles reveal a semblance of coherent behaviour. This phenomenon is subject to deeper analysis in the subsequent section. Comprehensive descriptions of these load profiles are provided below.

A. Auditorium And Motoring Load

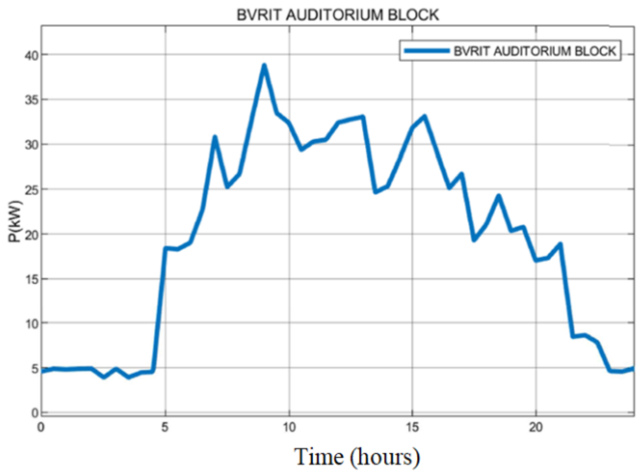

Fig.8. Load profile of BVRIT Auditorium Block

The figure below, designated as Figure 8, illustrates the load profile for both the auditorium and motoring load. An evident pattern emerges where the pumps are engaged multiple times throughout the day due to the substantial resource demands inherent to an engineering campus. This pattern results in a load profile that exhibits an overarching dome-like shape. Broadly, the load experiences heightened utilization during the morning hours, followed by a gradual decrease in usage towards the late hours of the night. This decreasing trend signifies a reduced demand for resources as midnight approaches. Upon closer examination of this load profile, a distinct bi-hourly pattern of peaks and troughs becomes apparent. Traditional power system analyses typically depict load curves with a steady ascent until mid-day, followed by another rise in the evening, particularly in the context of residential loads. In this context, the observed load profile stands out due to its unique behaviour. Instead of a continuous and gradual rise, the load demonstrates a cyclic two-hour increment and decrement. This distinctive pattern is attributed to the scheduling of motors and the timing of events in the auditorium. The peak load occurs approximately at 9:30 am, indicating that at the beginning of the academic day, all pumps, motors, and auditorium lights are activated to ensure an adequate water supply. Additionally, a noticeable peak in the figure corresponds to a morning event hosted in the Auditorium at the BVRIT Narsapur campus, contributing to this observed spike.

B. Academic Blocks Load

The loads originating from the academic blocks exhibit a consistent pattern. The academic buildings included in the load analysis encompass VIPER, Visveswaraya, Aryabhatta, and Saraswathi. These buildings consistently contribute to the load profile with a steady demand stemming from lighting and fan systems. However, a noteworthy shift occurs during the hours spanning 11 to 14. During this timeframe, the activation of laboratory sessions prompts the simultaneous operation of electrical block motors and the computer systems within the Aryabhatta and Visveswaraya blocks. Additionally, various equipment on the other floors of the buildings becomes operational. Consequently, this specific period represents the phase of peak load consumption, demanding meticulous control. A visual representation of these load variations can be observed in Figures 9, 10, 11, and 12. Let's proceed to examine the load profiles of each academic block in the following sequence:

- Aryabhatta Block
- VIPER
- Visveswaraya Block
- Saraswathi Block

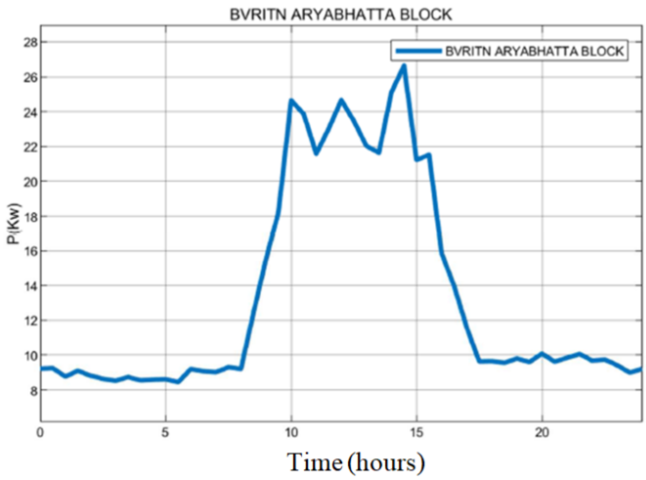

Fig.9. Load profile of BVRIT Aryabhatta Block

Initiating with the Aryabhatta Block, a consistent no-load output of approximately 10kW can be observed. This fixed load allocation caters to server maintenance within the block. As the clock approaches 8, the load begins to increment, reaching its initial peak around 9. This initial peak is among several such peaks evident within the load curve. Between approximately 13 and 14, a reduction in load consumption becomes apparent, attributed to break periods and the deactivation of resource-intensive loads. The period post lunch witnesses resurgence in load consumption due to laboratory activities. Subsequently, after the 15th hour, load consumption commences its decline, marking the conclusion of the day's classes. The load consumption stabilizes to a consistent level around 16. Beyond the general load pattern, additional factors contribute to load spikes during working hours. Firstly, the chemical department engages in various ongoing laboratory experiments and research initiatives, separate from regular academic laboratories. These endeavours necessitate a notable power supply, significantly influencing the load profile. Furthermore, conference halls within the block host frequent talks and discussions. These spaces incorporate extensive lighting arrangements, thus adding to the overall load profile.

C. VIPER Block

While designated as an academic block, the VIPER block distinguishes itself with a distinctive load consumption pattern that notably resembles the load pattern of the auditorium's motoring load. This peculiarity arises from the fact that VIPER isn't merely a block but encompasses an entire campus. Within VIPER, a diverse range of loads including motoring, heating, and pumping loads are encountered. Consequently, the load profile exhibits distinct characteristics. In the early hours of the morning, the dominant load component is attributed to fan usage. A dip in power consumption occurs due to a utility supply fault or interruption. Subsequently, the load experiences a rapid increase, particularly evident from around 9 am onward. This upward trajectory persists between 9 and 13, occasionally punctuated by troughs. These troughs may correspond to peaks in pumping and motoring loads, causing temporary load reductions. At 13, the heavy loads remain operational, sustaining the elevated consumption level. As the day progresses, load activity gradually decreases, only to pick up again around 18. This resurgence aligns with evening activities within the hostels, contributing to increased consumption. This heightened activity prevails through midnight, accompanied by load fluctuations attributed to people moving across facilities. A noteworthy observation is the considerable load activity that persists even at midnight, underscoring the sustained demand within this distinct campus environment.

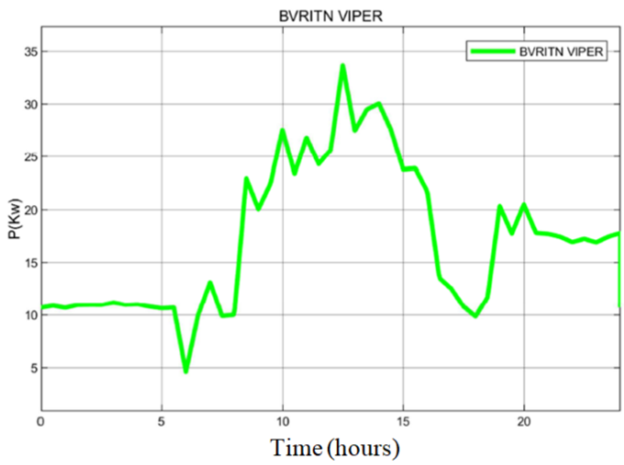

Fig.10. Load profile of VIPER Block

D. Visveswaraya Block

The Visveswaraya block displays a load profile similar to that of the Aryabhatta block, albeit with a simpler pattern characterized by fewer troughs and crests in its load profile. The block maintains a consistent power consumption of approximately 5 kW due to the continuous operation of the Lift situated within the block. The load in this block becomes noticeable around 8 hours and gradually intensifies until 12 hours, driven by increasing activity in the labs. After 13 hours, the load gradually decreases as class-related loads diminish during afternoon lab sessions. Unlike the Aryabhatta block, the Visveswaraya block experiences fewer fluctuations in its load due to a lower presence of computer peripherals. Additionally, the block's solar installation incorporates higher capacity modules, contributing to enhanced load stability. During the approach to midnight, minor load fluctuations are observable, likely attributed to supply variations. These fluctuations might also indicate intermittent engagement and disengagement of backup power supplies for the computers.

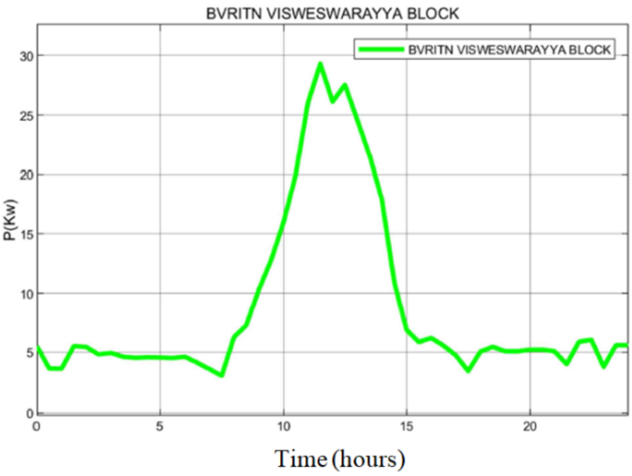

Fig.11. Load profile of BVRIT Visveswaraya Block

E. Saraswathi Block

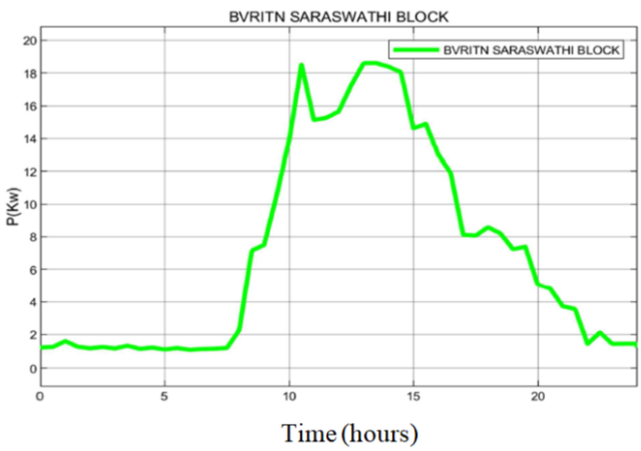

Fig.12. BVRIT Saraswathi Block Load

This building serves as the central library block, with its operational hours spanning from 9:00 to 20:30. As a result, we can observe a gradual rise in power consumption commencing at 9:00, peaking around 11:00. This trend correlates with the inclusion of civil department laboratories within the block, indicating that the load is influenced by the lab schedule. A similar consumption peak is evident between 13:00 and 14:00 due to the afternoon session schedule. As the day progresses, lab loads diminish, and departing day scholar students lead to a reduction in overall consumption. Subsequently, only lighting and fan loads remain active within the library. This shift prompts a gradual decrease in the load profile, and by approximately 20:30, the load returns to its baseline of approximately 1.5 kW.

F. Sports Block and Hostels

These two blocks share a nearly identical nature stemming from the predominant utilization of their facilities by students during the morning, evening, and into the night. As a result, their consumption patterns exhibit comparable fluctuations and troughs due to synchronized usage. Let's delve into a detailed examination of their profiles.

1). Indoor Sports Complex

Within the indoor Sports complex, there is a gymnasium that opens early in the morning, leading to an abrupt surge in power demand that persists until 8:00. Subsequently, the bakery within the indoor complex becomes operational, coinciding with the deactivation of the gymnasium facilities, resulting in a decline in load consumption. Classes commence, and access to the complex for sports activities resumes at 14:30, leading to another peak as both resident and day scholar students engage in its use. After the day scholars leave around 16:00, the load diminishes once again. This pattern then reverts to the morning consumption level as hostellers utilize the facilities until dinner is served. Subsequently, non-essential loads are powered off, leaving only constants such as restroom lighting. This represents the load profile of the sports complex.

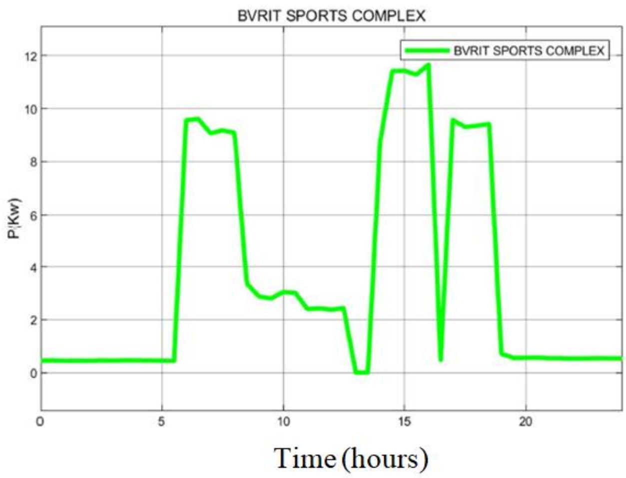

Fig.13. Load profile of BVRIT Indoor complex

2). Boys Hostels

Similar to the Indoor Sports complex, the boys' hostel has an early start as well. The pumps are turned ON to fulfil the water requirements of the hostels and also the heaters are turned ON in the morning. This leads to the peak consumption in the morning. Then as the classes start around 9:30 hrs the consumption decreases drastically and only some stray loads are turned ON at this time. As the time approaches 16hrs, the academic day ends and the load starts to increase gradually again. This load reaches its night peak before the meals are provided in the college canteen and then as people begin to take rest for the day, the load starts decreasing slowly and then it comes to steady state at midnight as people are taking rest and only the fans in the hostels are operating at full speeds and constant loads such as the restroom facilities are operating at this point.

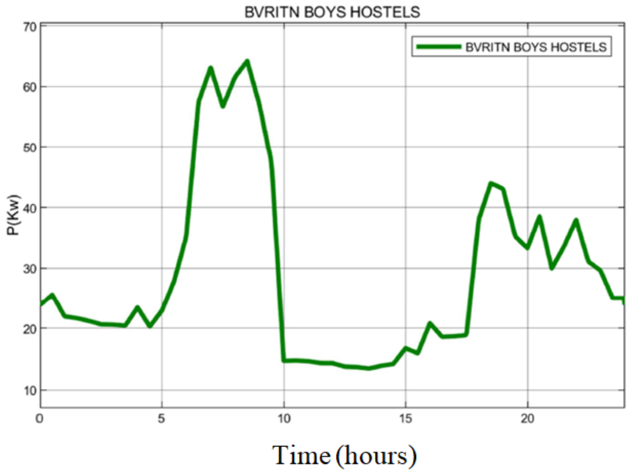

Fig.14. Load profile of Boys Hostels

3) ATL, Guest Quarters and Mango Gardens Load

Predicting these loads presents significant challenges due to their random and unpredictable nature. While Mango gardens may have a more consistent schedule, the guest house and ATL (Advanced Technology Lab) tend to be active during the daytime. The irregular behaviour of these loads is evident in the graphical representation. Within the guest quarters, certain fixed loads remain switched on for convenience, resulting in an initial curve position higher than the typical loads observed thus far. The continuous switching actions in these three areas lead to a load curve characterized by constant troughs and peaks. Fluctuations within the load profile are likely influenced by the air conditioning load in these regions. However, during the evening period, when the ATL and mango garden loads are mostly inactive, overall consumption significantly reduces compared to the afternoon peaks. Managing the load in this sector becomes particularly crucial due to the erratic nature of these loads throughout the day. This importance stems from the observation that the combined peaks of these loads align with the peaks of the academic block loads, raising the possibility of surpassing the maximum contracted demand during these instances. Consequently, control systems deactivate these loads during such peaks, underscoring the necessity of implementing stabilizing equipment. While the initial investment in safety apparatus could lead to higher costs, these expenses can be offset by long-term savings when load consumption decreases or becomes more stable through improved consumer practices. Additionally, considering that academic schedules also impact the load due to the presence of an academic block, the load experiences its own peaks and troughs, which might not be ideal for efficient power usage. Nevertheless, with the passage of time and the development of better forecasting techniques, these load curves can be smoothed out and made more predictable.

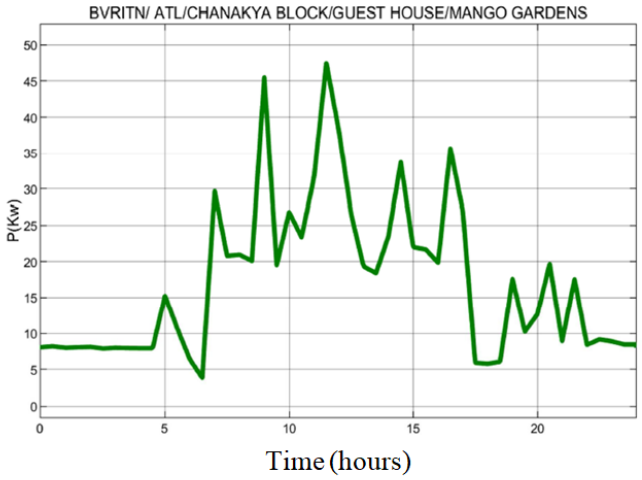

Fig.15. Load profile of ATL, Guest Quarters and Mango Gardens combined

4.2 State Changes

Throughout its 24-hour operational cycle, the system transitions through numerous states, with corresponding controls established to manage the system's output within each state. The timings, behaviours, and certain limitations of these states are outlined below. The load balancing system encompasses four primary operational states along with two emergency states, which are as follows:

Operating States

- Morning State
- Afternoon State
- Evening State
- Night State

Control States

- Maximum Demand State
- Initial State

The operation of the load balancing system in these states is described in the same order below.

A. Morning State

In this particular state, the operational period spans from 0 to 12 hours. This time range encompasses a broad array of timings, prompting the activation of all loads. The incorporation of nearly two time frames within this state serves the purpose of simplifying the control mechanism. In practical real-time implementation, these states can be adjusted based on the operator's preferences and requirements, aimed at enhancing the load profile. During this period, all loads, including entities like Auditorium motors, are switched on. This approach ensures that pumping loads occur during off-peak hours, leading to substantial cost savings. The campus employs a high-capacity pumping system for daily operations, which involves significant initial power draw and can exert strain on the utility grid while also affecting the power factor.

B. Afternoon State

During this specific state, the designated timeframe extends from 12 to 16 hours. This span corresponds to the peak consumption phase, and as per our prerequisite of preserving the campus microgrid's routine operation alongside the load balancing model, all loads remain active. This period typically generates the highest demand, which will be addressed through the maximum demand state for momentary control. It is crucial to exercise caution when scheduling heavy loads, such as motors, within this interval. The initiation of motors demands a substantial starting current, impacting the power factor significantly and leading to additional penalties. However, as the clock approaches 15:00 hours, the load generally begins to taper off, allowing for a slight recovery period in the evening for the power system.

C. Evening State

Within this state, the established time frame spans from 16 to 20 hours. During this phase, the academic block loads are deactivated, while loads essential for the residents' campus activities are activated. Simultaneously, the control system deactivates the remaining loads. This configuration leads to significant savings by facilitating peak shaving, allowing the utilization of motoring loads during this timeframe. In comparison to the peak consumption observed in the afternoon and morning states, this state can be regarded as a cooling-off period. This interlude enables both the grid to recuperate and the photovoltaic arrays to cool down from their prior peak operations.

D. Night State

Within this state, the defined time frame spans from 20 to 24 hours. While this could be expressed as timing intervals like {20,24} and {0,5}, doing so at this point increases complexity, which could hinder the clear demonstration of the control mechanism, as initially intended for the project. This state serves as another cool-down period, characterized by the deactivation of most loads while keeping loads like hostels switched on. Certain pumping loads are permitted to remain active to address emergency water requirements. In this state, the peak load attained is not excessively high and remains within the boundaries of the contract demand. To enhance the load conditions within this state, adopting proper electrical practices, such as turning off stray lighting loads during midnight, holds potential for cost savings. However, it's important to note that street lights continue to operate for reasons of institutional and individual security and safety concerns.

E. Initial State

This state is entered when the model is started and is also an emergency state for the control of the model. The model enters this state during running when it encounters a fault. Hence fault control can be modelled to return to initial state so that loads are not destroyed. To generate initial state control, the timer limits are set to -1 to 25. So that whenever timer is at these limits the model stays at this state. This state can be modelled as an emergency state using a MATLAB function which switches value of this constant to out of range values whenever the system is under duress. This multifaceted usage of each state is what provides simplicity and flexibility for the load balancing system.

F. Maximum Demand State

The system enters this state from any of the other states whenever the set demand or the maximum demand is exceeded by the system during an hourly period. In this state for a momentary period, only the blocks and hostel loads are kept intact for server maintenance to prevent deletion of campus data due to a reset caused by the operation and the rest of the loads are shut off. As soon as the system demand is lower than the set demand according to the forecast data, the system enters its previous state. This is an emergency state but it is not a faulty control state like the initial state of the system. There is a possibility that the system enters this state quite regularly and this implies that the time has arrived for the grid operator to increase the contract maximum demand to ensure uninterrupted operation of daily activities.

5. Conclusions

This paper successfully implements a load curtailment mechanism using Stateflow within Simulink. The graphical representation of this implementation offers a more precise grasp of demand response, particularly when incorporating forecast data instead of real-time usage in the load profile. This modification facilitates the creation of demand response event windows, allowing grid operators to take necessary measures to keep the maximum demand within the contracted maximum limit. Integrating PV installations also leverages net metering, reducing grid operation costs further. Nevertheless, achieving highly effective deployment of this system necessitates a greater quantity of measurement devices that exhibit heightened sensitivity. These devices are essential for monitoring various types of loads across each phase of a block. Further, optimization of the Stateflow using AI and ML techniques is recommended for more advanced control and load scheduling. The procedural charts, like the one employed in this implementation, can complete their sequence rapidly, and including advanced techniques can extend their capabilities and enhance load management.

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