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Implementation of a Proposed Control Mechanism for Energy Management at Load Points Using MATLAB Algorithm

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Abstract
Energy Management System allows the customers to control, optimize and monitor their energy consumption, which directly translates to a reduction in energy bills. This paper is aimed at addressing such issues, mostly in public places and some other places of interest. The work demonstrates the interaction between the load points referred to as nodes and a central controller, which implements measuring, monitoring, and controlling the energy consumption of various segments of the network, hence conferring on the system operator the powers to regulate the energy consumption of the network from a central point remotely. This work is achieved by measuring and studying the consumption pattern and pegging a threshold, based on a very robust energy allocation plan. The case study is a network of Engineering Students' Hostel University of Agriculture Makurdi, Benue State, Nigeria, which was modelled using a simple MATLAB code to fit the measured consumption curve, which produce the threshold value. These values were programmed microcontroller, representing the central controller, employed to implement the control of energy consumption at the nodes. The results obtained show that the microcontroller was able to control the power consumption by switching ON, when the consumption was below the threshold value and switching OFF, when it was above. The switching action of the microcontroller enabled energy savings, thus translating to reduced electricity bills

Keywords: *Control Algorithm, Energy allocation, Energy Consumption, Energy management,Energy monitoring, Energy Threshold, load points, MATLAB/Simulink, Nodes.*

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I. Introduction

Public University Campuses in Nigeria have seen an increased expansion in physical infrastructure with a resultant increase in electrical energy consumption. Such Universities are burdened by increasing electrical energy cost. To manage this situation, control mechanism has to be built into the energy management system, to regulate the energy consumption at various load points of the Campus distribution network.

Energy management is the realistic, organisational, and systematized coordination of procurement, conversion, distribution and usage of energy to meet requirements, while taking ecological and economic objectives into account[1]. Energy management systems (EMS) comprise the organisational and information structures required to put energy management into practice. This includes the technical resources such as software, hardware and also the human resources, which include trained manpower [2]. Data collection and processing ensure energy transparency, on which energy management, as a process, is based.

II. Problem Formulation

The main objective is to increase the efficiency in the power system network, and to reduce energy wastage using a control mechanism for energy consumption at load points using a MATLAB algorithm for threshold fitting, in conjunction with a microcontroller as the actuator.

A PATTERN OF CONSUMPTION

The pattern of consumption was studied over a range of time long enough to depict the energy consumption pattern of the chosen area.

B BASE CONSUMPTION

The average base consumption was estimated from the consumption pattern.

C. HIKE IN CONSUMPTION

The region where extra consumptions were made was also noted.

D. MARKING OUT A THRESHOLD ARBITRARILY

An arbitrary threshold was chosen, demarcating the areas of high consumption from those of low or base consumption.

III. Literature Review

An EMS balances the sources of energy and consumption of energy to achieve the lowest possible cost. The consumption of energy can be industrial, commercial, manufacturing, or residential.

An EMS generally puts the user in control of energy consumption through monitoring, billing, cost allocation and disconnection. Furthermore, EMS represents a large collaboration of power distribution control products that connect state-of-the-art devices for communication control [3]. It interfaces with communication and intelligent devices such as switchgear and intelligent switching controllers that are connected through an Ethernet network to computer systems equipped with software for collecting, processing and displaying data from the network [4].

A. LOAD PRIORITIZATION

This method ranks loads by priority and assigns a calculated weight for each load in the system. These weights are dynamic (i.e., time dependent), and can be used as an input for any restoration optimization problem. The proposed load prioritization procedure considers the criticality of the load, the amount of energy consumed, the number of connected customers, the cost of interruption, and the practice of demand side management programs. A proposed efficient prioritizing method should be able to quantify the importance of each individual load, and systems' reliability so as to improve the performance of the network [5].

B. STRUCTURE AND FUNCTIONS OF THE ENERGY MANAGEMENT SYSTEM

The structure of energy management system includes the software and hardware components.The energy management system can provide easy-to-access information on energy consumption in real time to control appliances and optimize the energy consumption in the area covered. In the network, the users manage their energy through the smart meter according to the energy consumption information as stated by [6]. The structure of energy management system includes both the hardware and the software components. The hardware includes the physical or tangible components of the network, such as the circuit breakers, relays, the power lines, transformers, and meters. The software consists of the intangible parts such as the control algorithm at the central controller in [7] and [8].

The authors in [9] proposed Energy Consumption Management for Multistage Production Systems considering real time pricing. In their work, they made a demand response model under real-time pricing, considering a generic queuing open production line with multiple single-server stages and finite buffers, for minimizing the cost including both machines and buffers energy consumption. They integrated the work of the authors in [10] and [11] on production systems described by mathematical programming formulation into demand response decision-making problems. They were able to demonstrate the potential of the proposed model in energy efficiency, even though the production cycle was prolonged; it still fell within an acceptable range.

The authors in [12] and [13] considered work on a new model of Distributed System for Data Acquisition and Management of Electric Energy Consumption called power mode. The work presented a solution to energy management, which is designed to increase the electric energy stability of managed consumers. It helped to conceptualize a model of an IT hierarchical distributed system for data acquisition, and also evidences the state of the controlled distributed electric energy consumption. These were achieved by modelling the proposed solutions into the Demand Side Management (DSM) methods of power system balancing called “power modes”. The power modes allow for differentiation of consumer priorities of functions served by their devices, and to remotely and gradually pull off, with the user’s acceptance. The solution presented was designed to increase the electric energy stability of managed consumers. It also allows for introduction of power priorities for consumer’s electrical-equipment considering the importance of their functions.

The authors in [14] presented the intelligent central energy management system for remote community microgrid. Simulations were carried out using MATLAB/Simulink. Parameters were adjusted on the grid to observe control reaction. A Stokvel charge share concept was proposed, wherein the state of batteries' charges and user consumption determined how grid loads should be controlled. A charge share algorithm was designed and tested on MATLAB simulation software. The goal was to share energy between users depending on each user's daily energy consumption. Power measurement determines energy kilowatt hours consumed by each load. The sum of the consumed energy is compared with the state of charge (SOC) of the battery and thereby a percentage calculation of SOC is made. The remaining charge was distributed between the loads according to their respective consumptions. SOC can be set at initial start-up on the simulation. The equation gives the formula structure to produce charge share values to each user.

$$kWh_{per\ user} = \frac{1-(\frac{kWh_{user}}{kWh_{TotalUsers}})\times kWh_{Usable\ Battery\ SOC}}{[N_{users}-1]} \quad (1)$$

The formula forms part of the control structure within the model to derive the quantities of remaining energy to be set aside for grid users according to their level of energy use and battery's charge condition. This mode of control ensures local communities work sparingly with such a limited energy resource. It enables communities to also manage their charge share load patterns.

From the result obtained, it was observed that the charge share values were calculated continuously throughout the day. This confirmed operation, when the most significant user had been allowed the smallest charge portion of the remaining state of charge to be used at night after 6pm; the smallest energy user is allowed a bigger share of energy. This system allowed each user a reasonable energy share during daytime and night, depending on the requirements from users and duration of use.

The authors in [15] introduced the Design of Smart Home Energy Management System (SHEMS) for Saving Energy. An adaptive algorithm was proposed to recognize the activity states of home residents and control the operation of the home appliances accordingly. The proposed SHEMS consists of Home Smart Gateway (HSG), Sensing Units (SU), and End Appliance Unit (EAU). The proposed system mainly depends on employing motion sensors and remote actuators to control the home appliances. It was aimed at reducing the energy consumption by detecting the residents' activity and identifying it among three states: Active, Away, or Sleep. The SHEMS was designed with an algorithm that is based on Hidden Markov Model (HMM) in order to estimate the probability of the home being in each of the three states. The proposed system uses the Wi-Fi technology for data transmission inside home and the GSM technology for external communication. The result shows that the proposed system and its algorithm were successfully tested and 18% of energy saving were obtained. The authors in [16] introduced A New Energy Efficiency Management and Control Strategy of Grid-Friendly-Based Intelligent Electricity, where under the cooperation of the smart gateway, smart socket and smart terminal, the management system could achieve the intelligent control for air conditioning, and make it grid-friendly electrical equipment. This approach introduces the physical deployment within the intelligent system and the interaction with the data scheduling platform of the grid. The system adopts an open design, and gives the overall architecture of the management system, which is based on the hierarchical design method. It also explains the sensing, data, application and control layers of the management system. Secondly, it introduces control strategy of the management system which resulted in the use of electricity equipment for the purpose of achieving the peak load shifting and improving the quality of energy.

IV. Demand Controllers and Management Strategies

The control of energy consumption is performed by means of devices such as sensors, monitoring relays and a microcontroller as the actuator. These devices, manage energy consumption at the node by disconnecting it from the network on the basis of a determined limit. The operation of a demand controller can either be triggered by a "peak energy" signal transmitted by the sensors (through an appropriate communication channel such as GSM, intranet or wirelessly by internet), or in response to variable-on-peak/-off-peak electricity schedules. In this second case, energy limit is set for each node in the distribution network. A near real-time situation was modelled by a table of energy consumption of the Engineering Students'' hostel. This was used in place of a real time database to demonstrate how the simulation will behave in real time condition.

A. SOFTWARE/INTELLIGENCE

The software employed in this work is MATLAB Simulink. It was chosen because of its simplicity, versatility, inbuilt rich library and with many internal functions. MATLAB Simulink is used for the simulation, and an (algorithm) was written to fit the desired consumption curve (threshold value). This in turn, was linked to a microcontroller, representing the central controller, employed to implement the control of energy consumption at the nodes

Resource Management using MATLAB/Microcontroller maintains meaningful data at each node. For instance, each node is assigned an amount of energy to be managed. The management of such energy is carried out by the set instructions as laid out in MATLAB. The programmed MATLAB/Simulink via Microcontroller, was used to analyse the data, and thus the data keeps reflecting physical characteristics of the plugged energy. MATLAB is used to develop a control strategy for the network upon receiving a command signal, by prioritizing energy resources based on some instructions. In addition, it is also used to lay out a predefined strategy corresponding to the command event and executes the control set.

B. SYSTEM DESIGN IN MATLAB/SIMULINK

A simulation was performed in MATLAB/Simulink to illustrate the sensing, control and communication strategies of the proposed energy management system of the distribution network. The system designed in MATLAB/Simulink was done based on the data obtained from the substations under study.

C. ESTIMATING THE THRESHOLD EQUATION FROM THE GRAPH

The graph of the energy consumed for a whole day (24 hour) and covering the entire week, starting from Monday through Sunday were plotted against the time of consumption as shown in Figure 1 through Figure 3. The equation of the curve obtained was estimated using MATLAB and is given as

$F(t) = -12.88\, t^2 + 315.53\, t + 4900.$ (2)

F(t) was used as the threshold value of the energy consumption.

D. MATLAB CODE TO CONTROL THE NODE OF THE CASE STUDY (ENGINEERING STUDENTS' HOSTEL)

MATLAB code was written to generate the equation of the curve as the threshold. When the code is run, values above the curve (Threshold) are seen as excess energy consumption and are denied access by 'opening' the circuit breaker. On the other hand, energy consumption values below the Threshold curve are seen as normal, and as such, and granted access by 'closing' the circuit breaker.

E. MICROCONTROLLER

The PIC18-Q41 family of microcontrollers (MCUs) integrates intelligent analog capabilities with powerful Core Independent Peripherals (CIPs) for small, high-performance data acquisition and sensor interfacing applications. A microcontroller is a solitary chip microcomputer also known as embedded controller. They are basically employed in devices that need a degree of control to be applied by the user of the device. Microcontroller is a compressed microcomputer manufactured to control the functions of embedded systems. Microcontrollers PIC18-Q41 was employed in this work for the control of the relays at the nodes.

V. Result and Discussion

Table 1 presents the summary of the daily power and energy consumption of the Engineering Students' Hostel, and also the percentage energy saved per day as a result of the introduction of a consumption threshold, chosen arbitrarily.

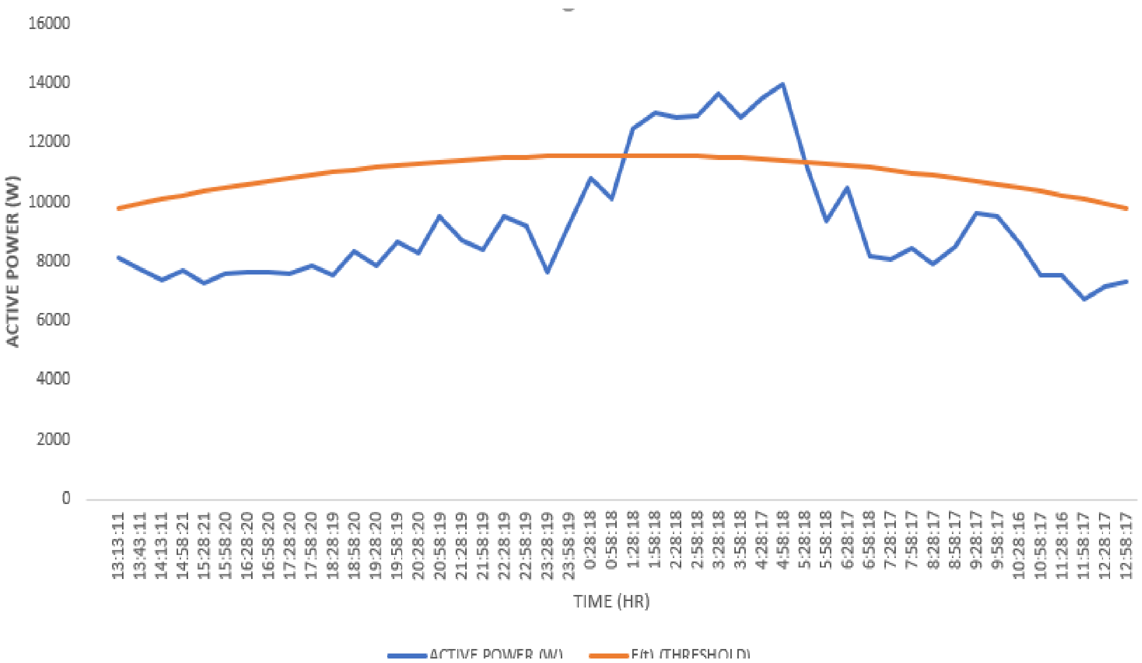

Figure 1. Average Energy Consumption Chart of the Students' Hostel Engineering

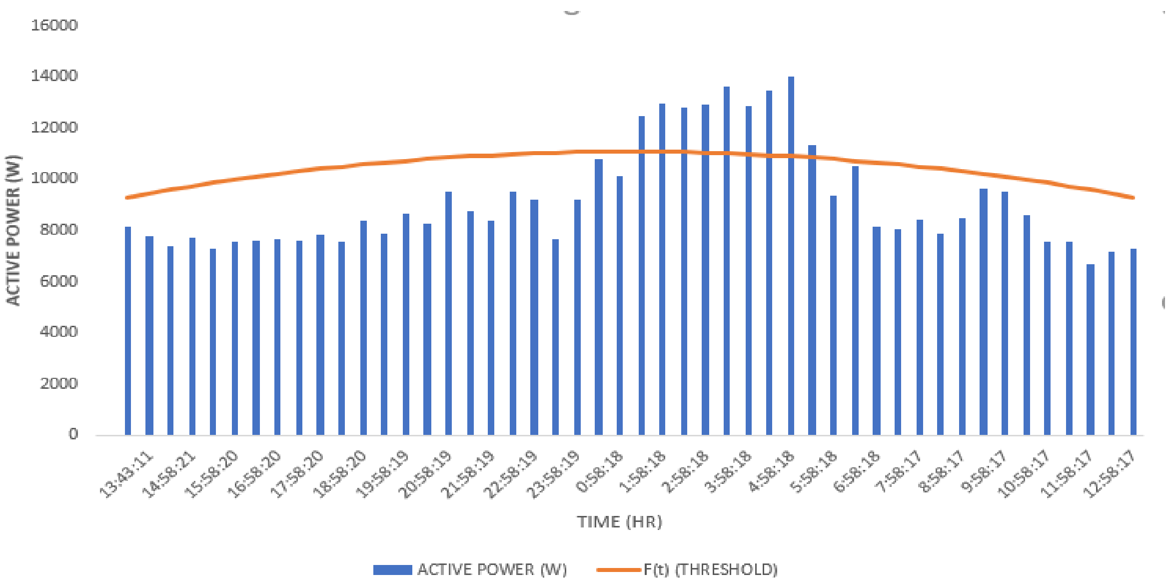

Figure 2. Chart to Estimate the Average Energy Consumption of the Students' Hostel Engineering

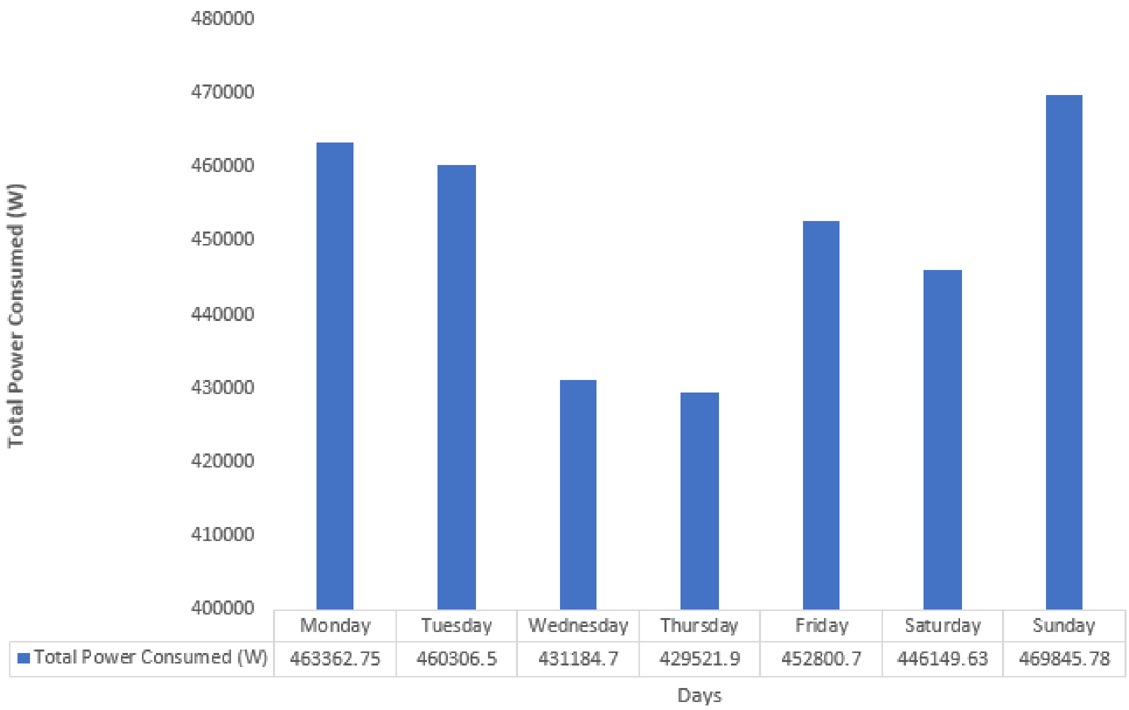

Figure 3. Daily consumption pattern of the students' hostel engineering

Table 1: summary of daily energy consumption and percentage energy saved

Days	Total Power Consumed (W)	Total Energy Consumed (WH)	Power Saved as a Result of the introduction of Threshold (W)	Energy Saved as a Result of the introduction of Threshold (WH)	Percentage Energy Saved as a Result of the introduction of Threshold (%)
Monday	463362.75	231681.38	36997.04	17498.52	7.55
Tuesday	460306.50	230153.25	36812.26	17406.13	7.56
Wednesday	431184.70	215592.35	20283.92	10141.96	4.70
Thursday	429521.50	214760.75	20332.15	10166.08	4.73
Friday	402800.90	201400.45	28956.17	14478.09	7.19
Saturday	446149.63	223074.82	24601.68	12300.84	5.51
Sunday	469845.78	234922.89	23006.16	19503.08	8.30
Total	**3103171.76**	**1551585.88**	**190989.38**	**101494.70**	**6.56**

A. DISCUSSION OF THE RESULT OF THE CASE STUDY, ENGINEERING STUDENTS' HOSTEL

The result obtained from executing the MATLAB code for the threshold, and also introducing a microcontroller for controlling the node at Engineering Students' Hostel is shown in Table 1. It was observed from the table that the circuit breaker was left closed in periods of the day when the consumption was below the threshold, and tripped open when the consumption was above the threshold, with circuit breaker trip signals of '1' and '0' for 'Close' and 'Open' respectively as shown in Appendix 1.

Figure 1 shows the average daily energy consumption. The pattern observed was similar to those of the week days, which showed an increase in power consumption between the hours of 01:28 and 04:28, signifying that students' activities increased during this period as compared to other periods. This may be attributed to the fact that most students prefer to study at night, when it is quiet than during the day time.

When students come back from classes between the hours of 16:00 and 18:00, they rest and possibly engage in sports or other activities, then sleep for a while, before waking up to study and do their assignments. This may account for the low power consumption experienced within these range of time. After 04:28, they rest for a while, before preparing for the activities of the next day.

Figure 2 shows the bar chart used to estimate the average energy consumption of the Hostel. The chart shows a gradual reduction in the students' energy consumption, starting from Sunday until Friday. This may be attributed to the fact that by Sunday, students quickly return back to school to attend to their assignments which have to be submitted on Monday. By Friday, they quickly return back to school to see if there is going to be take home assignment or probably test. By Saturday, there may be social gathering, attracting most of them to stay back. The prototype is observed to be cutting off some loads whenever the total load is greater than the threshold value.

B. ENERGY SAVED AND RELEVANCE OF THE WORK

From Table 1, the energy saved as a result of the introduction of a consumption benchmark for the average weekly consumptionwas 6.65% of the energy allocated to Engineering Students' Hostel, which is one of the loads centres in the North Core substation. If the concept is further extended to other facilities in North Core, and by extension, to the over 72 load centres in the entire University environment, more energy would be saved, which in monetary terms, translates into millions of Naira, thereby reducing the cost of electricity procurement for the subscriber.

The energy management benchmark is flexible, as the Threshold, which is arbitrarily chosen, can further be adjusted downwards according to the desire of the power grid operator, in order to increase the energy saved.

VI. Conclusion

Energy distribution management, particularly energy limiting is very important for both energy consumers and producers. This is because energy saved by way of careful management can be channeled to other users, thereby increasing the area of coverage and enhancing a prudent and profitable use. The case study was modeled in MATLAB/Simulink. Simulation results showed that load nodes are automatically disconnected when their energy consumption is greater than the allocated energy limit. Energy consumers, therefore, can be prudent in the use of the energy allocated to them if they are aware that they will be disconnected from the supply mains when they exhaust the energy allocated to them.

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Appendix 1: The result obtained from executing the algorithm for the threshold

TIME	ACTIVE POWER (W)	F(t) (THRESHOLD)	REMARK	BREAKER TRIP SIGNAL
13:13:11	4698.78	4905	Close circuit breaker	1
13:43:11	4477.97	5053	Close circuit breaker	1
14:13:11	4266.58	5194	Close circuit breaker	1
14:58:21	4456.6	5330	Close circuit breaker	1
15:28:21	4211.37	5458	Close circuit breaker	1
15:58:20	4378.1	5581	Close circuit breaker	1
16:28:20	4405.56	5697	Close circuit breaker	1
16:58:20	4419.99	5806	Close circuit breaker	1
17:28:20	4381.98	5909	Close circuit breaker	1
17:58:20	4523.74	6006	Close circuit breaker	1
18:28:19	4364.78	6096	Close circuit breaker	1
18:58:20	4827.5	6180	Close circuit breaker	1
19:28:20	4544.82	6257	Close circuit breaker	1
19:58:19	5009.48	6328	Close circuit breaker	1
20:28:20	4774.79	6392	Close circuit breaker	1
20:58:19	5507.44	6450	Close circuit breaker	1
21:28:19	5045.83	6501	Close circuit breaker	1
21:58:19	4837.21	6546	Close circuit breaker	1
22:28:19	5511.6	6585	Close circuit breaker	1
22:58:19	5323.24	6617	Close circuit breaker	1
23:28:19	4424.42	6643	Close circuit breaker	1
23:58:19	5296.33	6662	Close circuit breaker	1
00:28:18	6235.09	6675	Close circuit breaker	1
00:58:18	5834.23	6682	Close circuit breaker	1
01:28:18	7210.18	6682	Open circuit breaker	0
01:58:18	7499.52	6675	Open circuit breaker	0
02:28:18	7405.48	6662	Open circuit breaker	0
02:58:18	7462.07	6643	Open circuit breaker	0
03:28:18	7872.09	6617	Open circuit breaker	0
03:58:18	7415.19	6585	Open circuit breaker	0

04:28:17	7779.43	6546	Open circuit breaker	0
04:58:18	8076.82	6501	Open circuit breaker	1
05:28:18	6541.35	6450	Close circuit breaker	1
05:58:18	5401.74	6392	Close circuit breaker	1
06:28:17	6066.42	6327	Close circuit breaker	1
06:58:18	4716.54	6256	Close circuit breaker	1
07:28:17	4647.46	6179	Close circuit breaker	1
07:58:17	4879.93	6095	Close circuit breaker	1
08:28:17	4568.96	6005	Close circuit breaker	1
08:58:17	4912.67	5909	Close circuit breaker	1
09:28:17	5555.15	5806	Close circuit breaker	1
09:58:17	5486.63	5696	Close circuit breaker	1
10:28:16	4975.36	5580	Close circuit breaker	1
10:58:17	4364.78	5458	Close circuit breaker	1
11:28:16	4359.51	5329	Close circuit breaker	1
11:58:17	3874.32	5194	Close circuit breaker	1
12:28:17	4139.52	5052	Close circuit breaker	1
12:58:17	4215.81	4904	Close circuit breaker	1

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