Prototype of Demand Response Controller for Demand Side Management on Home Electricity using Particle Swarm Optimization Algorithm

Djoni Haryadi Setiabudi[1], Michael Santoso[1], Iwan Njoto Sandjaja[1], Yusak Tanoto[2]
[1]*Informatics Department, Petra Christian University.*
[2]*Electrical Engineering Department, Petra Christian University.*
djonihs@petra.ac.id

***Abstract*—Demand Side Management (DSM) program can be implemented using electric load shedding approach. In practice, this can be realized using equipment called the Demand Response Controller (DRC). The discharge of electricity with DRC is one of the efforts to respond to the increasing electricity tariff. In further, such technology allows users to shift duration of electricity usage, for example from the peak load period to the off-peak period. This research develops a website-based prototype with devices that have been integrated with Raspberry Pi as a controller. Devices arrangement is connected to home electrical devices in order to allow users change the condition of electronic devices everywhere, in terms of its utilization period. To support DRC, there is a feature where users can enter the limits of electricity usage and then the PSO algorithm will set electronic devices so that it can be switched on and off in accordance with the restrictions of the users. The prototype has been able to perform the optimization by turning off the device in accordance with user requirements. The PSO algorithm has been tested and an accuracy of 96% can be achieved at most possible, finding a combination of kilowatt limits according to user requirements.**

***Index Terms*—Demand-Side Management; Demand Response Controller; Home Electricity; Particle Swarm Optimization**

I. INTRODUCTION

Demand Side Management (DSM) has become the prominent alternative to efficiently manage the use of electric energy on the customer side through investment in efficient energy infrastructure and load management so that additional power generation capacity can be avoided or delayed [1]. The suggestion of DSM implementation as the main program of energy policy came from Forum of Economic and Social Commission for Asia Pacific (ESCAP) cooperation at Asia Pacific Business Forum event in Bangkok, April 2008 [2], where Indonesia became one of its members.

Implementation of Demand Side Management (DSM) can be done through two kinds of approaches that aim to plan the existing loading profile to suit the desired, that is through energy efficiency approach and load cutting approach. The energy efficiency approach is generally done by installing energy-efficient electrical appliances without reducing the time of use. Meanwhile, the load-cutting approach is done by disconnecting one or more electrical appliances. Electrical equipment termination approach to obtain the desired form of loading profile is called Demand Response (DR).

The termination of the electrical load on the DR mechanism is one of the efforts to respond to the increase in electricity tariffs (by maintaining the amount of energy consumed), or to shift the hours of electricity from the peak load period to the peak-out time period so that the tariff can be cheaper. Several developed countries have implemented this DR technology in line with the implementation of DSM in their power sector, including in the home electricity sector, by providing incentives for consumers willing to implement this mechanism. Meanwhile, the implementation of DSM in developing countries, including in Indonesia, is still limited to the use of energy efficiency approach and has not touched the approach of disconnecting burden or DR technology, so that there is no control mechanism of the state electricity company, in this case, PLN to its customers, particularly to monitor energy used.

There are several studies that have been done related to DSM and DR. In Indonesia, there have been studies that provide access to users to be able to control the condition of home electrical devices through smartphones. The application supports the purpose of DSM, improving usage efficiency by providing users with ease for controlling the condition of electronic devices through applications (website/device) from anywhere. [3]. But there is no automation to perform household electrical management according to the needs of users.

Artificial Intelligence Algorithms have also been used to support DR on household electricity. The algorithm acts as a DR control tool, determining the combination of the condition of the electronic device. Combination results adjust to the conditions of electricity tariffs, or the maximum usage of kilowatts that are incorporated as per the needs of the users, in order to make savings in electricity usage and home electrical optimization. Research using DSM using Artificial Intelligence has been done in India. The Particle Swarm Optimization (PSO) algorithm is used as a DR Controller and achieves satisfactory results. Electricity consumption can be saved as much as 39.1% which is the result of PSO algorithm implementation [4].

This research applies the DRC using PSO algorithm, where this algorithm determines the combination of the condition of the household appliance, adjust to user input to make efficient use of electricity applied to home electrical management. By implementing DRC, users can monitor, and set the condition of electrical devices, which are integrated with websites and mobile devices.

II. Demand Side Management (DSM)

DSM is categorized as the systematic activities undertaken by electricity and government companies designed to change the amount and/or timing of electricity usage on the customer side including the use of energy-saving equipment [5]. DSM has two interrelated main goals. First, to reduce the peak load requirement so that the addition of generating capacity can be avoided. The second goal is to reduce the use of electricity to overcome energy problems by changing the amount and pattern of electrical energy consumption [6].

The household sectors as one of the electricity subscribers have a "faster than average" growth compared to the average electricity demand in other sectors. This sector is identified as particularly problematic for power companies because it contributes directly to high peak loads. In most Asian countries, peak loads occur at night as a result of lamp usage and the use of other electrical equipment [7]. DSM's effective activities have been implemented in Guadeloupe Island, a French region served by Electricite de France (EDF). With a program cost of US $ 460,000, EDF saves the US $ 3.5 million annually for fuel and estimates a peak load reduction of 15 MW [8].

Thailand became the first Asian country to formally adopt DSM activities as a national master plan. DSM activities took place from September 1993 for a period of five years to 1997. During this period, the US $ 189 million budget resulted in a peak load savings of 295 MW and an energy savings of 1.564 GWh per year until May 1997. This is equivalent to more than 1 Million tons of CO2 reduction and an investment savings of US $ 295 million [9].

Previous DSM studies with the aim of peak load clipping in the household sector were conducted for Madura Island study area through energy conservation with energy saving lamps [10]. In that study, discussed the possibility of the implementation of energy conversion in the form of the use of energy-saving lamps with technical analysis approach to marketing. The background of the problem is the peak load in Madura reached 76.8 MW, while in the afternoon only 20 MW. This condition indicates that electricity has not been optimally utilized by most customers who are residential consumers. The characteristic of this burden is predicted to be 5 years to 10 years. Another study with the purpose of valley filling is the planning of DSM activity in PT. PLN (Persero) Branch Situbondo [11]. The strategy used is to increase demand in the LWBP period as well as energy conservation strategies by raising public awareness to use the energy-efficient electrical equipment. Influence of DSM Program for PLN is improving load factor, increasing efficiency, and decreasing of investment and operation cost due to decreasing of peak load. While the benefits for PLN customers is assured reliability of supply and availability of electrical energy as well as power savings and electricity costs for PLN customers.

III. Demand Response (DR)

According to the Federal Energy Regulatory Commission, Demand Response (DR) is defined as: changes in the use of electricity by customers from normal usage patterns in response to changes in electricity costs, or in response to the incentives provided by power companies to reduce subscriber electricity consumption to improve system reliability and preventing shortages of power supplies [12].

DR activity is an attempt to modify the pattern of electricity consumption to limit the usage time, peak load level, or overall electrical energy consumption. The DR program is expected to reduce electricity consumption or shift the usage time from peak load period to peak-out time, depending on consumer preferences and lifestyle [13]. DR Activity is a voluntary action from electric customers to adjust the time and use of electricity. This action is generally a response to economic signals, for example, because of price increases, as well as incentives or limitations [14].

Thus, DR is one of the cost-effective alternatives compared to the addition of generating the capacity to meet peak load or instantaneous peak load increase. For the long term, the DR mechanism can reflect the expected supply amount through changes in consumer energy patterns [15].

IV. Particle Swarm Optimization (PSO)

Particle Swarm Optimization is an algorithm based on the Stochastic Optimization technique developed by Dr. Eberthart and Dr. Kennedy in 1995, inspired by the social behavior of a group of birds or a group of fish.

PSO has many similarities with Genetic Algorithm (GA). The system is initialized with a random population and finds the maximum value by renewing each of its generations. But unlike GA, PSOs do not have evolutionary operators like crosses and mutations. In PSO, a potential solution is called a particle, flying through the problem space by following the best value available [16].

Each particle records its coordinates in the problem space, which in turn corresponds to the best solution (fitness) achieved so far. (The fitness value will be saved). The fitness value that each particle gets is called the personal best (*pbest*). Another value which is the best value of all particle *pbest* will be stored and called global best (*gbest*) [4].

V. Proposed of The Prototype

The proposed system is using the hardware that was introduced in the previous study [17]. In Figure 1, we can see the diagram of the prototype. The Raspberry Pi reads the power used by home electrical appliances and store the data in the database on the server. Data stored on the server and also parameters entered by the user will then be in the process of the algorithm, which is run on the server. Once the algorithm generates the desired decision, the results will be stored in the database on the server to be displayed to the user using the website or mobile device application.

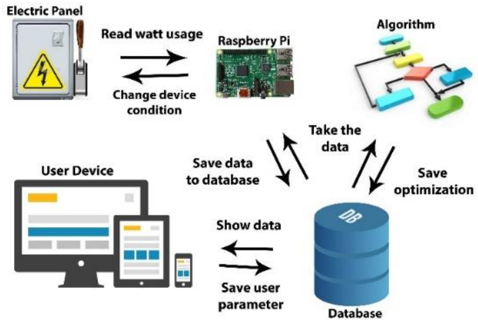

Figure 1: DR Prototype

Raspberry Pi will turn on or off electrical equipment based on the wishes of the user and meet the criteria of saving electricity desired by the user.

The algorithm of the software prototype can be seen in Figure 2. Parameters that have been entered by the user will be used to perform optimization. This optimization is done inside the server. Next, the final result will be saved into the database server. Optimization is divided into 5 stages.

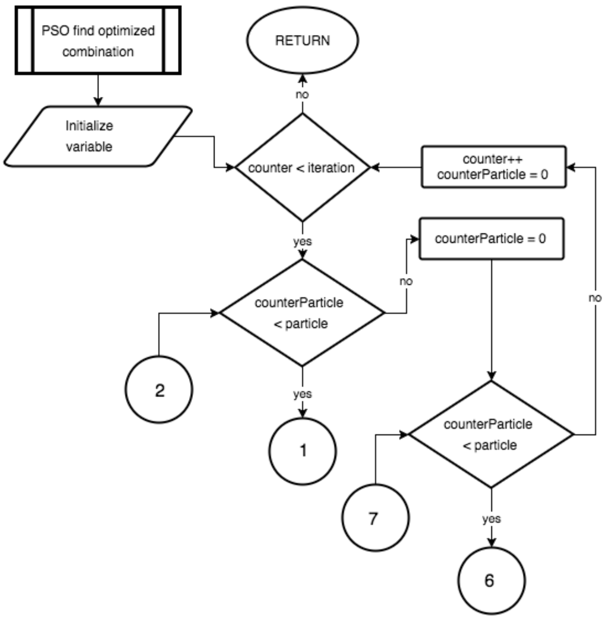

Figure 2: PSO Algorithm

The first stage of the algorithm is the initial initialization of the number of iterations and the number of particles to be used to obtain the appropriate combination, the target kilowatt limit to be sought which is the result of a reduction of the kilowatt of priority devices and the existing working hours, like in Figure 2.

In the second stage, initialization of the position of the existing particle to spread its position according to the area of data in the database is done. The position of the particle will be spread by randomly positioning X. X has a value between 0 until a maximum of the total combination of devices.

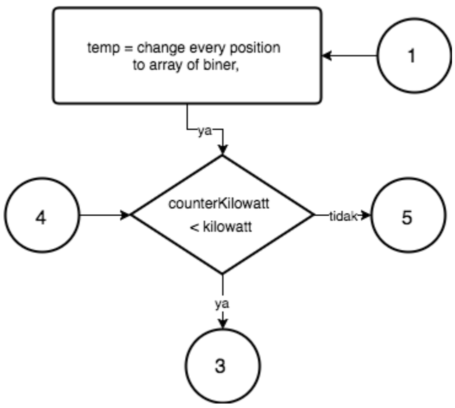

Figure 3: PSO Algorithm (cont)

In Figure 3, the third stage there will be a loop for each iteration that has been initialized and the initialized particle. Based on the position of the particle position array according to the counter looping particle will be taken a combination value that can occur by changing the position value on the particle position array into binary, then converted to the array to be processed in a kilowatt loop.

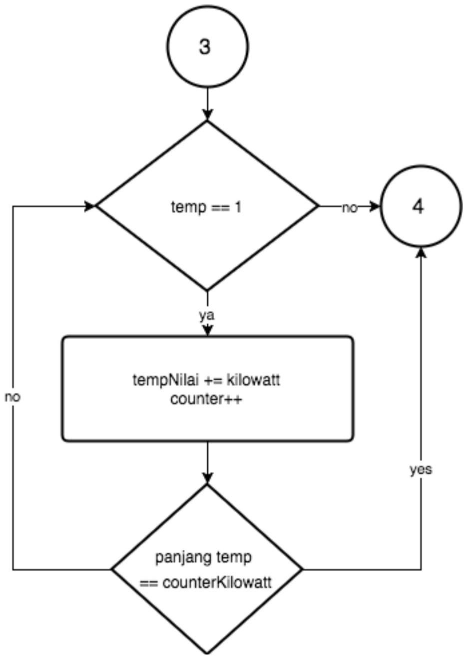

Figure 4: PSO Algorithm (cont)

Further on the loop as in Figure 4, each kilowatt array content will be added to the *tempNilai* variable, if the binary index of the kilowatt array has a value of 1. The loop is performed along the binary array.

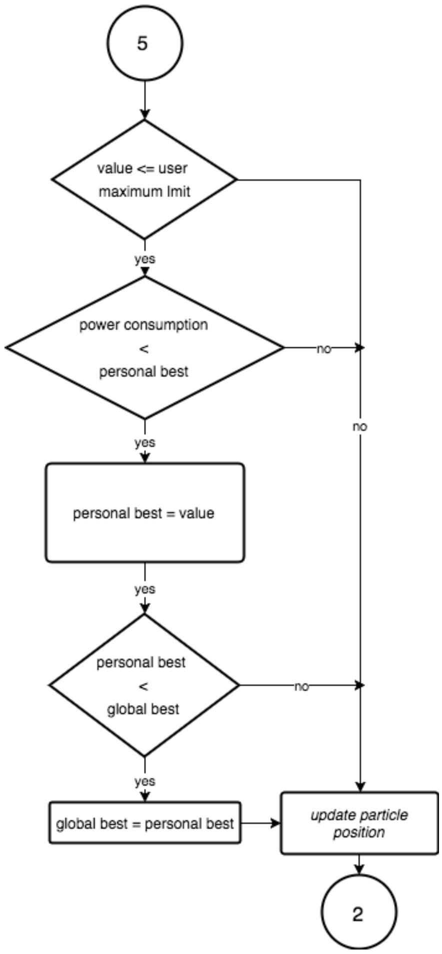

Figure 5: PSO Algorithm (cont)

After binary array looping is done, the *pbest* and *gbest* updates are done by checking the *tempNilai* with the *pbest* array value as it is in Figure 5. If the *tempNilai* is higher than *pbest* then the *pbest* and *pbest* position will be updated. Last checked the *gbest* and *pbest* values. If *gbest* is higher than *pbest,* then *gbest* value and *gbest* position will be updated with *pbest* at that time.

In the fourth stage like in Figure 6, the particle position is updated. The particle position in the update approaches the total usage value corresponding to the user usage parameter. Then the third and fourth stages will be repeated in accordance with the number of iterations that have been initialized at the beginning until completed. After the iteration is completed, in the fifth stage the combination is obtained according to user parameters, the combination will be displayed in the user interface to be allocated to the user.

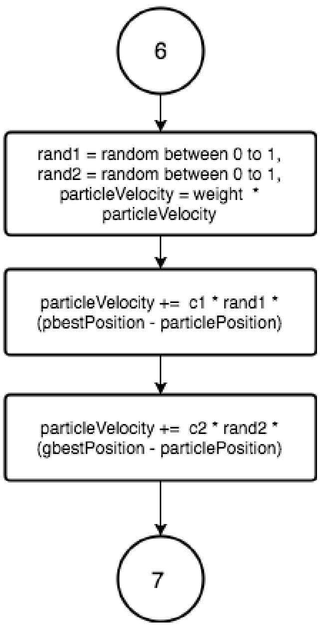

Figure 6: PSO Algorithm (cont)

VI. EXPERIMENTAL RESULTS

A. Testing of the Algorithm

The first test is to find the best particle and iteration among the PSO algorithm. Testing is done by combining samples of 10, 20, 30, 40, 50, 60, and particle of 5, 500, 5000, 5000. The combination of testable limits is 62 combinations, due to the limitations of variables that cannot accommodate more than 62 combinations. The first experiment uses 5 particles. The accuracy obtained by using 10 devices is 99% and will continue to decrease to 83% when the combination reaches 60 in 0.002 seconds. The second experiment uses 50 particles. The accuracy obtained by using 10 devices is 100% and will continue to decline by up to 90% when the combination reaches 60 in 0.02 seconds. The third experiment uses 500 particles. The accuracy obtained using 10 devices is 100% and will continue to drop by 95% when the combination reaches 60 in 0.2 seconds. The fourth experiment uses 5000 particles. The accuracy obtained by using 10 devices is 100% and will continue to drop by 96% by the time the combination reaches 60 within 2 seconds.

In Figure 7 the numbers 0 to 100 on the left of the image are the magnitude of the accuracy. It can be seen from the graph that the comparison of variations between PSO parameters shows significant decrease accuracy in the combination of 60. The algorithm with a particle of 5000 has the accuracy of 96% and an average time of 2 seconds.

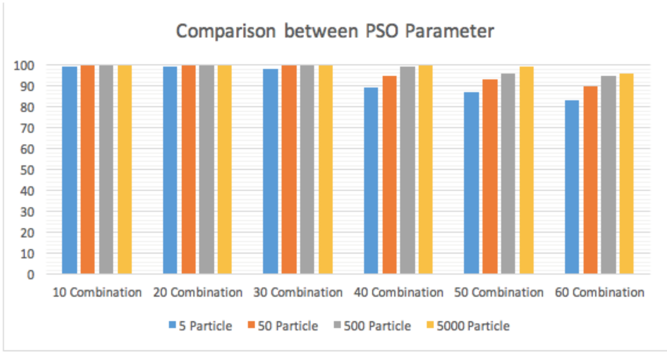

Figure 7: Comparison of PSO Parameters

In comparison, testing with the Brute Force algorithm is also carried out in this study. Brute Force algorithm has an initial speed of 0.0017 seconds for 10 devices while the PSO algorithm has an average time of 2 seconds to search for any combination there. Every addition of new devices, the time required by Brute Force to look for optimization will continue to increase by an average of 2 times over the previous time. Which can be seen in Figure 8.

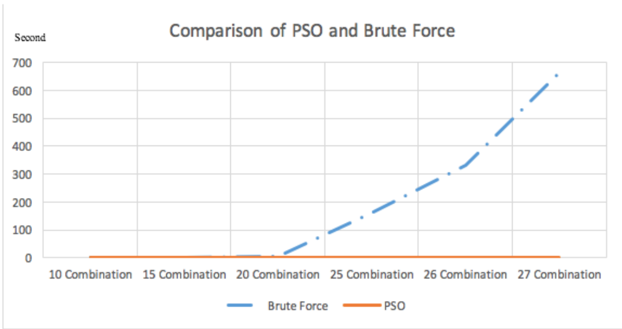

Figure 8: Comparison of PSO and Brute Force

Each experiment using the Brute Force algorithm obtains the maximum end value, because Brute Force tries on every possibility, thus achieving 100% accuracy. The PSO algorithm gets only 96% accuracy, but with a much faster time to get the desired result. For example, assuming an increase in time required by 2 times than before. To find a combination for 1 week, with a total of 30 possible combinations, if using Brute Force takes as much as 4724464025.6 seconds or 18227.1 months with 100% accuracy.

B. Application Testing

Then the application will be tested. Simulated electrical appliances are rice cooker, air conditioner, refrigerator, washing machine, oven, water pump. The test is performed by the user by entering the amount of kilowatt or the desired amount of charge for electricity consumption for a month.

Firstly the user to set maximum power settings within the limits of his home electricity, and the consumption of each existing device, as in Figure 9.

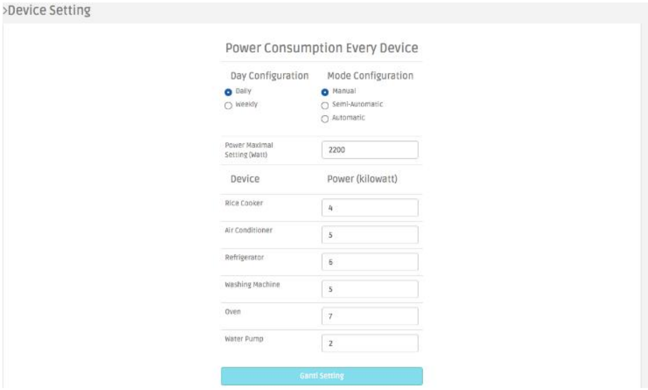

Figure 9: The Devices Setting

The default initial condition of all devices on the display of the website can be seen in Figure 10.

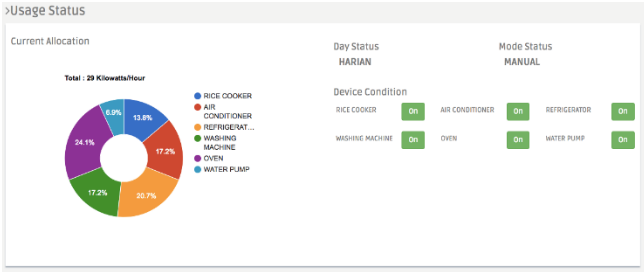

Figure 10: Initial Condition of the Home Appliances

Furthermore, the user will make settings for working hours of each existing device. Users make settings for working hours between the hours of 04:00 to 10:00 with all the device conditions lit. It can be seen in Figure 11, the green button means the user to set the working hours for the device.

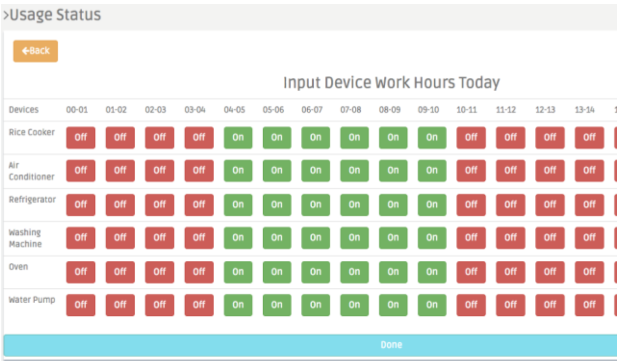

Figure 11: Working Hour Setting

After setting the working hours, the user sets the clock priority for each device. Priority is a condition where the device must be on, and will not be turned off by the algorithm. It can be seen in Figure 12 that the green button indicate the user gives priority to the device.

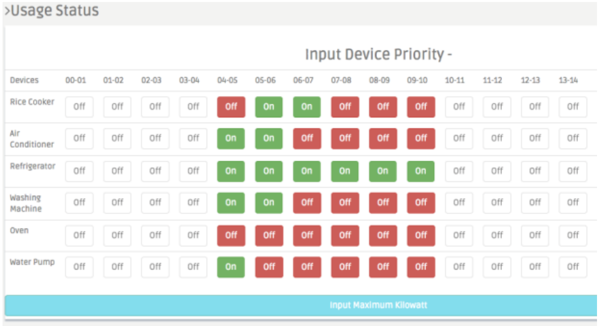

Figure 12: Priority Setting

The last stage before the optimization is done, the user inputs the parameter limit, where the user can enter the kilowatt limit, or the price that wants to be the limit as in Figure 13. After the optimization is done, the program will display the result of the final combination as in Figure 14. Users can change the on / off of a device as desired. Users can see their daily usage results on graphs as in Figure 15. The lower numbers indicate the time that will be updated every minute. The left digit denotes the use of kilowatts in the minute.

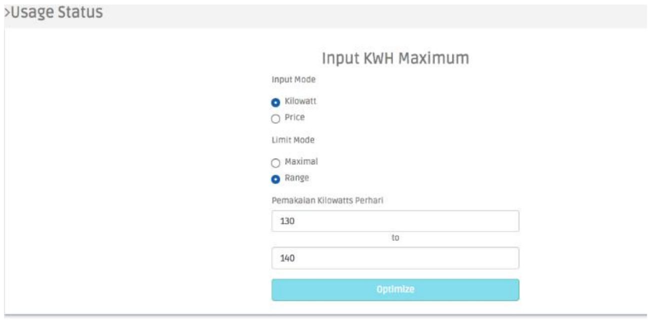

Figure 13: Price and Kilowatt Setting

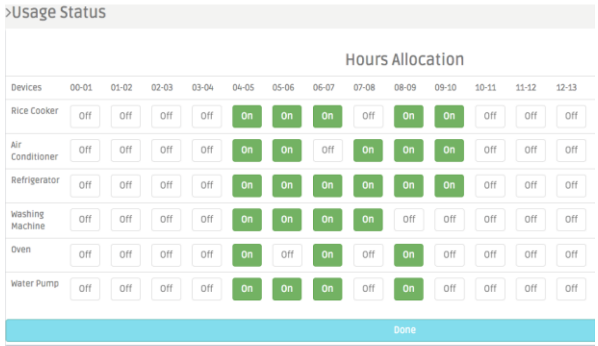

Figure 14: Allocation Setting

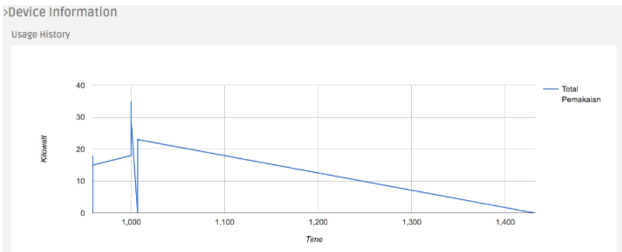

Figure 15: Graph of Usage

CONCLUSION

The application is able to search for combinations and change the condition of electrical equipment according to user requirements. The PSO algorithm is able to adjust the parameters entered by the user and produce time-efficient, daily, weekly, monthly combinations of times according to the target of the user. The application is capable of displaying daily reports on electricity usage under active conditions. Brute Force algorithm can be achieved 100% results. But the time required is very long, if the combination is a lot. While the PSO takes the same time for each combination.

REFERENCES

[1] Bonneville,E. & Rialhe, A., "Good Practice for Energy Efficiency in Industry",www.leonardo-energy,org, 2006.

[2] Ministry of Energy and Mineral Resources of the Republic of Indonesia. Siaran Pers No. 33/HUMAS/DESDM/2008. "ESCAP serukan DSM jadi program kebijakan energi", 2008. Accessed from: www.esdm.go.id

[3] Putra, et al., Design and Implementation of Web Based Home Electrical Appliance Monitoring, Diagnosing, and Controlling System. Jurnal, 2015.

[4] Anil Kumar Pathak, Anil Kumar,et,.al., "Artificial Intelligence Based Optimization Algorithm for Demand Response Management of Residential Load in Smart Grid", International Journal of Engineering and Innovative Technology (IJEIT) Volume 2, Issue 4, October 2012

[5] Gellings, C.W. and Chamberlin, J.G. Demand-Side Management Plannings. Fairmont Press Inc., 1993.

[6] Surapong, C. "Lecture Notes of Demand Side Management", Asian Institute of Technology, Bangkok, Thailand, 2000.

[7] Schipper, L. and Meyers, S. Improving Appliance Efficiency in Indonesia, Energy Policy, July/August 1991, pp. 578-587.

[8] Boyle, S. DSM Progress and Lessons in the Global Context, Energy Policy. Vol 24, No.4, pp 345-359,1996.

[9] EGAT. Compact Fluorescent Lamp Program — Program Plan Evaluation Plan, Demand-Side Management Office, Planning and Evaluation Department. Bangkok, Thailand, 1997.

[10] Narjanto, Implementasi Demand Side Management di Pulau Madura Dengan Peak Load Clipping Lewat Konservasi Energi Berupa Lampu Hemat Energi Pada Sektor Rumah Tangga. Thesis S2 Institut Teknologi Sepuluh Nopember Surabaya, 2001.

[11] Suharto. Implementasi Program Demand Side Management (DSM) di PT. PLN, (Persero) Cabang Situbondo. Thesis S2 Institut Teknologi Sepuluh Nopember Surabaya, 2001.

[12] Balijepalli, Murthy, et.al., "Review of Demand Response under Smart Grid Paradigm". IEEE PES Innovative Smart Grid Technologies, 2011.

[13] Albadi, M. H. And E. F. El-Saadany, "Demand Response in Electricity Markets: An Overview". Power Engineering Society General Meeting, 2007. IEEE, 1-5, 2007.

[14] Sianaki, O.A.; Masoum, M.A.S., "A fuzzy TOPSIS approach for home energy management in smart grid with considering householders' preferences," Innovative Smart Grid Technologies (ISGT), 2013 IEEE PES,vol.,no., pp.1,6, 24-27 Feb. 2013, doi: 10.1109/ISGT.2013.6497819

[15] Sianaki, O.A.; Hussain, O.; Dillon, T.; Tabesh, A.R., "Intelligent Decision Support System for Including Consumers' Preferences in Residential Energy Consumption in Smart Grid," Computational Intelligence, Modelling and Simulation (CIMSiM), 2010 Second International Conference on , vol., no., pp.154,159, 28-30 Sept. 2010 doi: 10.1109/CIMSiM.2010.84

[16] Hu, Xiaohui., (2006). Particle Swarm Optimization. Retrieved August 4, 2017, from http://www.swarmintelligence.org/

[17] Tanoto, Y.; Setiabudi, D.H., "Development of autonomous demand response system for electric load management," 2016 Asian Conference on Energy, Power and Transportation Electrification, 25-27 October 2016, Singapore. DOI: 10.1109/ACEPT.2016.7811532.