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NEW DEMAND RESPONSE STRATEGY BASED ON ARM CORTEX M4

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Abstract

The rapid increase in the demand for electric power makes it more difficult to fulfil requirements for consumers. The smart strategy available to decrease power consumption is still necessary due to the same reasons. The lowering of the consumption level initiate after the development of the electrical power generation criteria in the electrical utilities. This paper used a new proposed algorithm to achieve the demand response using the direct load control method. The approach applied on 70 homes and simulated by MATLAB 2018 environment validated the paper results with a smart meter-built base on the ARM Cortex M4 microprocessor. The results reflect that the algorithm can decrease the consumption to a predetermined level specified by the utility operator. The modern-looking now is to generate an amount of power and make the consumers consume that amount no more, which exactly corresponds to the basic principle of the proposed algorithm.

Keywords: ARM cortex, Demand response strategy, Fairly turn off, M4 microprocessor.

1. Introduction

Recent years witnessed the using many new technologies in all the branches of electrical engineering [1]. The new devices with that high smart technology make the control process more accessible and more flexible to apply. It makes the electrical network more complicated and needs more professional operators in many fields like communication and electronics besides those dedicated to power engineering [2]. The complicity in design is one issue besides efficiency, reliability, losses, and pollution. In specific words, the new generation philosophy aims to reduce the high atmospheric pollution resulting from fossil fuel burning to generate more power according to the consumers' increasing demand. The consumption problem should be solved by making the consumption not exceed a specific level depending on the demand response (DR) strategy [3]. One of the suggested solutions for this problem is using a nixed cost for electricity all day, leading to an excellent peak to average ratio (PAR). The increase in electricity rate regarded as a suitable alternative to installing more power plants to produce more power because that will continue forever and may affect all the configurations and the infrastructures of the transmission and distribution networks [4]. The presence of the smart grids changed all that philosophy, and the utility can be used now the nonconvention sources in homes like photovoltaic (PV) or wind energy as a distribution generation (DG) sources to provide the energy to all the consumers. The main difference is the consumers' limitation to consume a specific amount of energy equal to that amount generated in the available plants no more by using the incentives or motivates.

The motivations can make the consumption curve flat and similar to the generation curve [5]. The alter of the consumption pattern from one style to another can be achieved by the DR programs by lowering the consumption [6]. DR idiom means "changes in electric usage by end-use customers from their normal consumption patterns in response to changes in the price of electricity over time, or to incentive payments designed to induce lower electricity use at times of high wholesale market prices or when system reliability is jeopardized" [7-9]. In this paper, loads of the consumers can be controlled directly by using the direct load control (DLC) program that allowed the utility to switched OFF specific loads in the consumer's homes according to motivations that grant to the participators when there is a specific issue threaten the system stability or when there is a necessity to shed some loads in the network [10-12]. Specifically, the utility contract with the DLC program's participators has the full right to reach their loads and change its state from ON to OFF at any time or in the time of the incidents. For that, it pays incentives or grants some motivations for those participators [13].

The barriers of the demand response strategy can be classified into two forms which are fundamental and secondary [14]. The first type based on human nature while the second barriers depend on anthropogenic institutions such as markets. Nolan and O'Malley [15] define some of the most important barriers. O'Connell et al. [16] describes some obstacles that face the demand response to be as contributor to system services. Cappers et al. [17] Presents assessment of different types of barriers in multiple type of consumers. This paper presents a proposed algorithm for selecting the loads to be extinguished to achieve the desired goal. The implementation of this algorithm will help both the generation and the user side to achieve near-maximum benefit at the lowest cost with acceptable fairness.

Two basic factors were adopted in the proposed algorithm to achieve acceptable fairness in the process of selecting the loads to be extinguished. These two factors are the average uptime of previous periods and the amount of energy consumed in this load. The motive of writing this algorithm is to find a way to distribute the limited electrical energy in the most equitable way possible among consumers, in addition to reducing the overall rate of energy consumed. The difficulty with this goal is choosing which load to turn off first and on what basis.

2. Methodology

This paper's idea should be applied in the secondary distribution networks (SDN), where various loads can solve the increased demand problem because it takes a large amount of energy when it works. The honest algorithm (HA) is the proposed algorithm used in the residential distribution area to apply the DLC DR program to reduce consumption to a new level. The domestic area under consideration has 90 homes, and each one has a three-phase smart meter installed to read the current consumed by each phase. The assumption here is the utility succeeds in making 70 homeowners participate in the DR program. A load of each consumer represents by the current consumed and recorded by the smart meter, and it is generated randomly in MATLAB to test the HA performance, and they deserve motivation each time the utility used their loads to overcome a specific problem. In this case, the utility has full control over 210 phases and is denoted as the participated phases (PP) in the DR program. The HA gives the consumers the ability to dedicate priority to each phase. The participator can prioritize each phase in his home, depending on the circumstances, and it changed from time to time. There are three priorities suggested to each phase in the program: low, middle, or high. The HA has not switched OFF any phase with super-priority just if there is no other solution to handle the problem in the network. The consumer can be giving super-priority to the phase with an essential load like the air-conditioning during the summer periods. The algorithm goes away from all the super-priority phases and searches about the phases with the low or middle priorities, but when the problem still available, the algorithm uses the super-priority phases to solve the issue and return the system to its natural case. There are three main parts used to achieve the DLC program according to this algorithm:

- The chief control unit (CCU): This is the main computer that is installed in the utility, and it can monitor the generation and consumption level. When there is inequality between them it activates the DR program to solve the problem.
- The secondary control unit (SCU): This part represents the processing unit of a specific distribution area, and it is installed in the distribution transformer in that area. It can communicate with the CCU by a system with duplex communication. The HA has been installed in the Arm Cortex M4 microcontroller that represents the heart of this unit.
- The smart meter: It is installed in all the consumer's homes, and it has the ability to sending all the requested quantities to the SCU by wire or wireless technique. The smart meter also has an Arm Cortex M4 programmed to measure each phase's current consumption and its priority. It has a mechanism that enables it to switch the requested phases to be OFF and return it to be ON when the emergency case has been gone depending on some actuators like the contactors or the solid-state relays.

The overall procedure of the demand response program (refer to Fig. 1.) in this paper can be described in the following steps: The CCU in the utility computes all the power generated and communicates with all the SCU installed in the distribution networks to know the total consumption and the consumption of the PP in the DR program; The SCU communicates with all the smart meters under its control to measure the consumption of the PP and return that to the SCU; Each SCU sends the consumption of its area to the CCU; The CCU computes the total consumption and what the PP consumed and compared total consumption with the total generation. When there is a difference between them, the CCU solves the problem by decrease the consumption to be equal to the generated power depending on the PP; The CCU computes how much the consumption should be decreased that denoted by the new consumption level (NCL) and send an order to all the SCU to reduce the consumption to a specific level declared by the CCU (refer to Fig. 2.).

The second novelty to the HA besides it can give the consumers the right to determine a priority for each phase is the justice in choosing the phases that should be switched OFF each time. The algorithm does not elect the same phases when some event has been done to solve the problem, but instead of that, it chooses other phases in each event to achieve fairness to all the participators in the DR program. This paper supposed there are three priorities, and the consumers can use specific one of them for each phase in the home:

- Super Priority (SP): The consumer needs that phase to be ON and may discomfort if it is switched OFF.
- Middle Priority (MP): The consumer needs that phase but no problem if the utility switched it OFF.
- Low Priority (LP): The consumer does not need this phase, and the utility can switch it OFF without any problem.

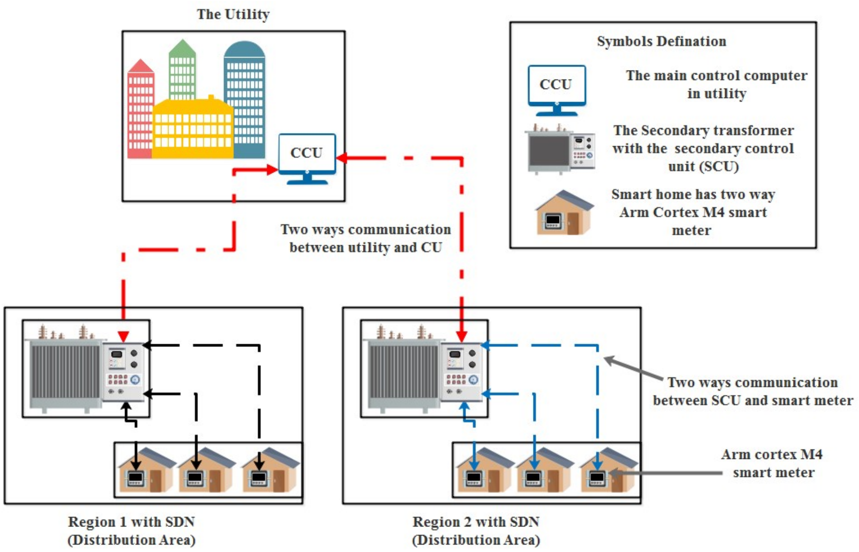

Fig. 1. The communication between the main three parts to achieving the DR program.

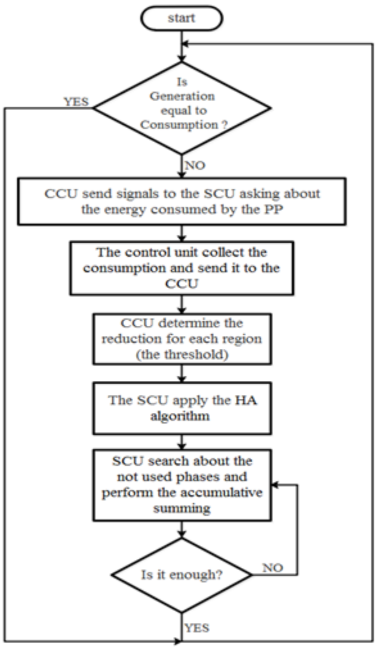

Fig. 2. The flowchart of DR program in the distribution networks.

The HA that installed in the SCU follow the following steps to reduce the consumption fairly: It receives the amount of reduction that it must achieve, depending on the PP; It sent a signal to all the smart meters to measure the current consumption of all the phases that participated in the DR program. All the phases current recorded and saved in a matrix called by consumption matrix (CM); The HA also collected all the consumer's priorities and saved them in the priority matrix (PM); The justice is achieved depending on the step matrix (SM), and it represents a counter that computes how many times each phase is used in past events; Based on the NCL, HA that is programmed in a specific SCU decides if there is a need to decrease the consumption in the area or not (refer to Fig. 3.).

If the NCL is larger than the total consumption of the area, the algorithm does not do anything. If NCL less than the consumption so depending on the CM and the SM, the HA can de decide which is the suitable phases that should be switched OFF according to three cases:

- When the NCL larger than the current of SP and MP: Switch ON all the phases with SP and MP; Switch some of the LP phases to reach the NCL.
- When the NCL larger than the current of SP: Switch ON all the phases with SP; Switch some of the MP phases to reach the NCL.
- When the NCL less than the current of SP: Switch some of the SP phases to reach the NCL; Switch OFF all the other phases.

The proposed algorithm for selecting the appropriate loads to switch them off fairly is demonstrated in Fig. 4.

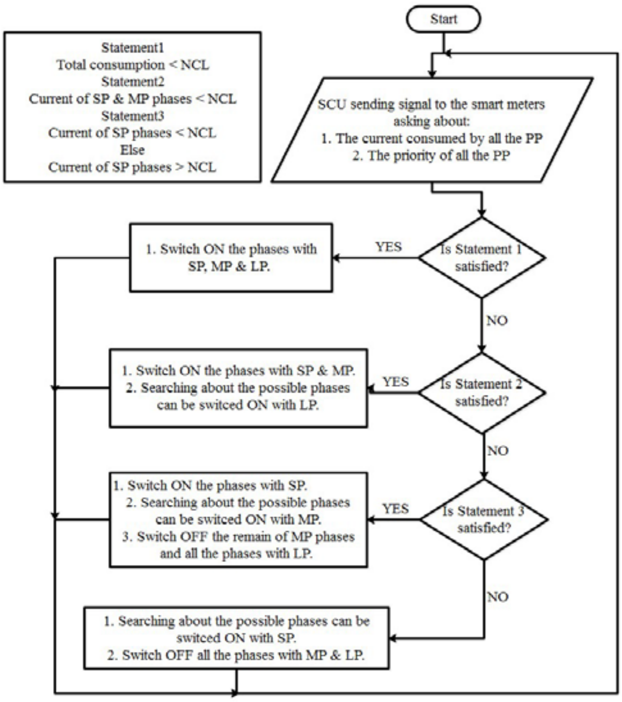

Fig. 3. The overall states of the DR that programmed in the SCU.

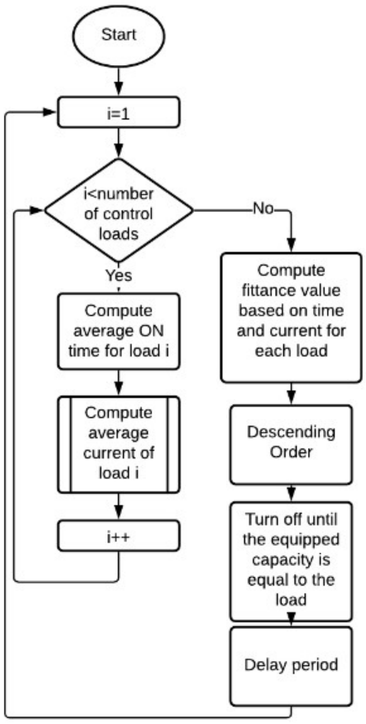

Fig. 4. The proposed algorithm for selecting for fairly switch off loads.

3. Results

The MATLAB 2018b environment achieves this paper's results based on simulated data for 90 homes that were under consideration. The homes in the studied distribution network were 90 homes, and the assumption here is the utility succeeds in making 70 homes in the DLC program according to specific motivation offers. The utility installed in each home three-phase smart meter has the ability, according to a specific signal from the SCU, to switch any phase ON or OFF if there is an urgent event, and it can achieve that without any prior alarm to the participators. The paper results represent applying any consumption data in the HA, and it can give the demanded reduction in consumption according to one case of the four cases mentioned in Fig. 3. As an example, for testing the first case in the proposed algorithm, a random residential network has been elected that consists of 70 homes with an assumption that the current in each phase does not exceed 40 amperes in all the PP. In a specific event, the SCU measure the current consumption, and it was as depicted in Fig. 5 where the red bar represents the total consumption and it more than 1200 amperes, whereas the current consumed by the first feeder (the blue bar) was more than 600 amperes and the second (black bar) more than 400 amperes and eventually the third feeder carries more than 200 amperes (the green bar).

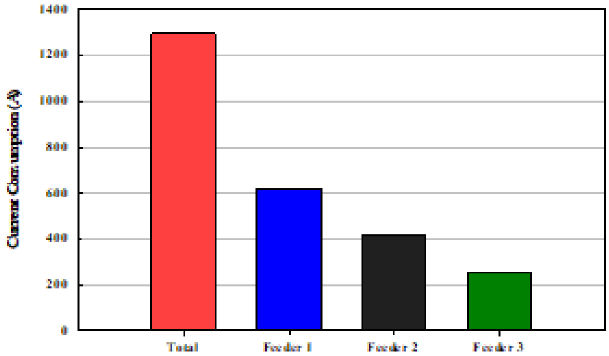

Fig. 5. The current of the distribution transformer during a specific event.

The current of each phase has been showing in Fig. 6, and the priority of those phases is illustrated in Fig. 7.

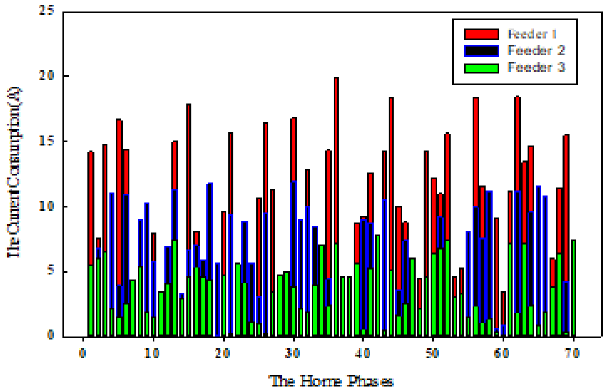

Fig. 6. The current consumed by each phase in all the residential homes.

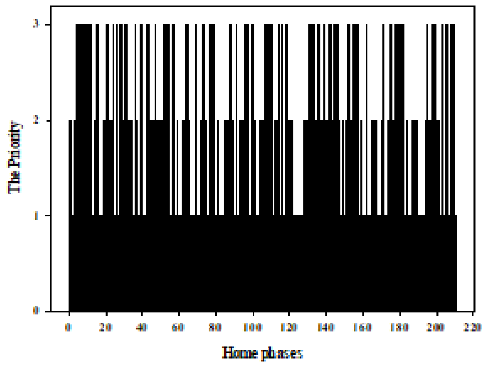

Fig. 7. The priorities of all the home phases in the DR program.

The associates give the most phases LP because of the motivation (the LP represents number 1, MP as number 2, and SP as number 3), as shown in Fig. 7. The MP is greater than SP but less than the LP because SP is used in the participators' necessary cases. The significant parameters of the area under consideration during the event are shown in Table 1.

Table 1. The parameter is measured by the SCU.

The Parameter	The value in Ampere
The overall consumption	1.2953e+03
The consumption of LP phases	510.9854
The consumption of MP phases	423.3867
The consumption of SP phases	360.9736

The HA has been tested in four different methods to validate it can achieve the power consumption to a specific level with keeping the fairness for all the PP in the program as the following:

3.1. When there is no need to apply the algorithm

In this case and according to the data in Table 1, we will assume that the NCL equal to 1310 amperes, and here the algorithm should not care for that event and remain the network without any modification. The result of this case is shown in Fig. 8 and as that clear, the algorithm does not take any action, so there is no change in consumption level before and after the event because the case 1 has been activated.

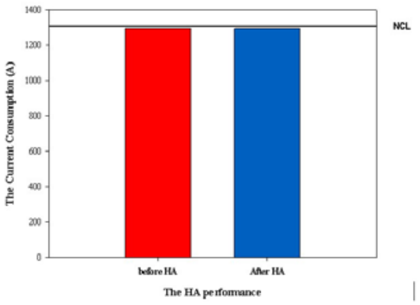

Fig. 8. The consumption before and after applying HA when case 1 activated.

3.2. Random one test

In this case, we will suppose the NCL lowered to be 1000 amperes, and the algorithm has to reduce the consumption to be equal to or less than this value. The consumption condition has been shown in Fig. 9.

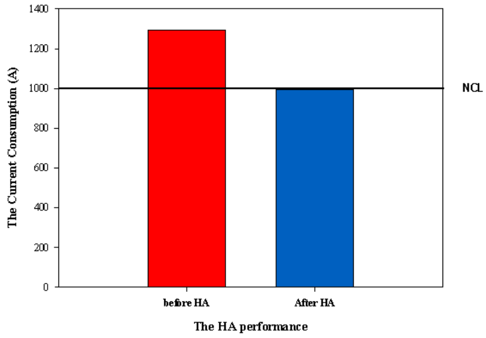

Fig. 9. Performance of HA when there is an event activates case 2.

3.3. Random 50 test

In this section, we will test the fairness principle of the proposed algorithm under the following conditions:

- There 50 events that happened in one month.
- The current consumed by each phase and the overall consumed current differs in each event.
- There is a different priority for each phase in each event.

The experiment results have been showing in Fig. 10, and it clear that the HA succeed in making the consumption level in all the 50 events under the predetermined threshold (750 Amperes). The fairness has been achieved as clearly in Fig. 11, where all the PP has been switched ON around twenty to thirty times, and the algorithm does not focus on specific phases to switching ON and leaving the other OFF, and that gives a clear impression that all the participated phases in the DR program will be treated equally without any difference.

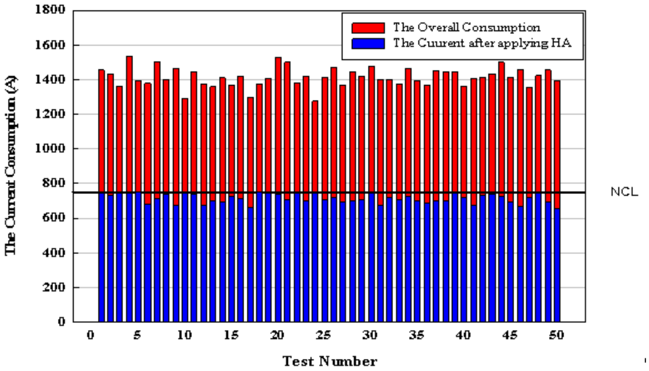

Fig. 10. The result of applying the HA on 50 different events.

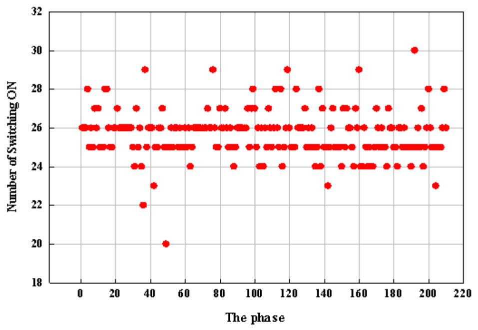

Fig.11. The fairness principle for all the PP during 50 events.

3.4. Random 500 test

For more verification, the number of events that the proposed algorithm should handle increased to be 500 and NCL decreased to be 500 Amperes. HA succeeds in reducing the consumption to be under the specified level (refer to Fig. 12) and achieve the PP's fairness principle, as illustrated in Fig. 13.

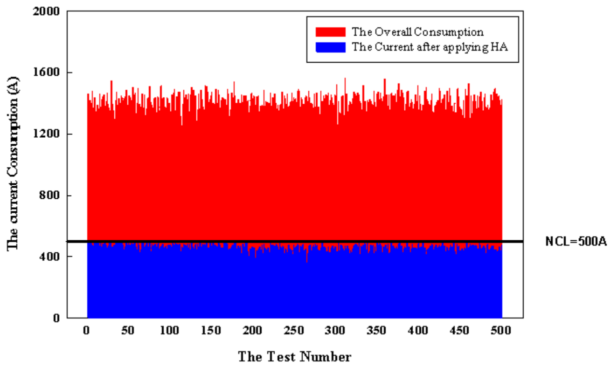

Fig. 12. The result of applying the HA on 500 different events.

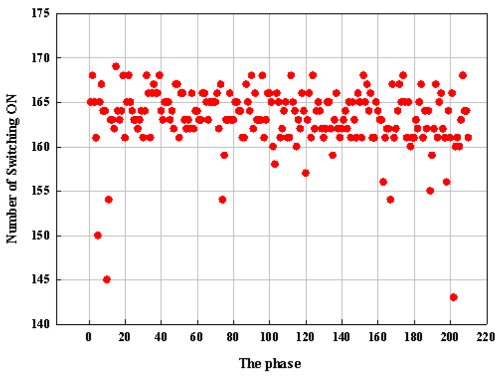

Fig. 13. The fairness principle for all the PP during 500 events.

4. Conclusion

The demand response regarded as one of the essential matters because it can change all the aspects of power generation and solve many problems like decreasing pollution and the greenhouse effect. The proposed algorithm has been succeeded in achieving the DR program to decrease the level of consumption in the distribution networks. Fairness is a new feature added to the algorithm to achieve justice for all the participated consumers in the DR program. The algorithm has been tested on 50 and 500 events, and it handled all that and reached the predetermined level without any troubles.

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