Regular paper

Electrical Grid Stability Enhancement using Smart Home Frequency-response Grid -Friendly Appliance System

Load shedding is a powerful scheme used for corrective and preventive measures; corrective to restore system’s stability and preventive to avoid catastrophic failure. However, the affected end users are deprived of power supply absolutely with no choice. This paper presents the design, development, feasibility and merits of Frequency-response Grid-Friendly Appliance System (FRGFAS) in a smart home. FRGFAS is a decentralized Adaptive Load Shaving (ALS) device that supports grid’s system stability by sensing grid’s frequency deterioration level and turns ON/OFF loads accordingly. The FRGFAS permits end users to carry out load shaving at their scale of preference in smart homes via flexible demand responses and automates outdoor lighting to optimum operational hours. FRGFAS obviate load shedding by shaving loads whenever the system is in distress and reset loads supply to the normal state when it stabilizes, this Consequently increases the end user comfort zone and averts a blackout.

Keywords: Adaptive load shaving; FPGA; Frequency response; Grid Friendly Appliance; Load management; Smart home

1. Introduction

The electric power grid system is regarded as one of the robust systems ever build in history. This electrical grid system has been in existence and upholding its architecture for over a century with few upgrades [1]; it has also proven to be among the robust systems ever developed in history over time. Power demand versus generation is ever growing [2] due to development, population increment, and ever-increasing needs of end users in line with technological innovations. Therefore, the direction of the demand tends toward surpassing the available generation; this inequality results in the needs of the requirement to either increment generation or carries out load shedding during peak hours or disturbances. This action will then ensure that the system within desired frequency of operation.

The generation stations usually have several stages of protecting the power systems. These stages include generator governor’s self-adjustment [3], backup power supply, transformer action, capacitor bank compensation, islanding, relay and circuit breaker, and load shedding. Load shedding serve as the last measure to overcome instability issues [4], acting as both corrective and preventive measure.

The conventional load shedding proffers an immediate solution to instability issues of the power system and seems beneficial in utility’s perspective. However, its repercussion on affected customer is not a welcome idea since its action yields regional power outage and one hundred percent dissatisfaction to end users leading to various forms of losses and inconveniences.

The evolution of smart grid tends to provide a brighter future of intelligent power systems. The smart grid realization has been a global aspiration in the quest for a generation, utilization, and consumption of clean energy that will mitigate CO$_2$ emission in the air [5], [6]. This effort will also benefit end users economically via information sharing and energy efficient usage [7]. The smart grid provides backup power supply via
Renewable-Energy Sources (RES) and also intelligent means of utilization via automation, demand response (DR) and smart energy usage [8].

The ALS enables the end user to provide demand response and shave loads with little or no dissatisfaction to their conveniences. ALS schemes utilize intelligent systems such as a microprocessor, microcontroller, DSP, and FPGA embedded systems to provide a real-time solution to the bottleneck of the latter schemes [9], [10]. The controllers measure real-time consumption, uses Real-time Pricing (RTP), Critical Peak Period (CPP) or Time of Use (ToU) and perform DR [11]–[14]. FRGFAS perform real-time ALS with both centralized and decentralized controls, but the majority of the previous efforts based their outcome on simulations rather than hardware realization [15].

This paper focuses on hardware realization of FRGFAS. Similar effort of the design with a different approach is in the literature [15], but FRGFAS is a multi-load controller and differs regarding the algorithm, frequency detection method and also incorporates UDR and lighting control to the design. Literature [15] explores MATLAB and Quartus II while FRGFAS employs Multisim and LabVIEW and explores phase locked loop while FRGFAS utilizes Schmitt trigger. Section 2. defines the acronyms adopted in this paper. Section 3. gives an overview of FRGFAS layout in the smart home environment. Section 4. Analyzes the design of FRGFAS from the input stage to the output stage. Section 5. further elaborates the modus operandi of the FRGFAS, the impact of the outcome of end users and system stability while section 6 concludes on the findings.

2. Acronyms
The abbreviations used in this paper is listed below;
ALS - Adaptive Load Shaving
FRGFAS - Frequency-response Grid -Friendly Appliance System
DIO - Digital Input/Output
DR - Demand Response
DSLM - Demand Side Load Management
FPGA - Field Programmable Gate Array
GFA - Grid Friendly Appliance
L - Load
LDR - Light Dependent Resistor
RES - Renewable Energy Sources
UDR - User Demand Response
UI - User Interface

3. Frequency-response Grid -Friendly Appliance System in smart home perspective

The smart home is an inevitable part of a smart grid that contributes its quota towards effective energy utilization in the consumer domain to perform load management, support electric grid stability, reliability and also for economic benefits to the consumer. This features of the smart grid are lagging in the existing conventional electric grid system where only industries and commercial settings participate towards system stability and energy management via demand response to energy usage [6]. An example of such practice is Tenaga Nasional Berhad (TNB) Malaysia utility with Off-peak Tariff Rider (OPTR) and Sunday Tariff Rider (STR) for medium voltage commercial and industrial end users. This commercial and industrial end users enjoy rebates, low energy prices, and other dividends that the domestic end users are not benefiting [16]. Hence, the needs to convert the existing grid to smart grid and encompass domestic users to enjoy from these is necessary.

FRGFAS is a decentralized frequency responsive load controller that modifies electricity usage based on electrical grid system’s stability conditions. It is a component of
smart home and operates autonomously while considering the UDR priority selection for ALS in two flexible categories. It has a flexible UDR that permits the end user to modify their choices at any point in time, provided the selection be adequate for the embedded system algorithm requirement, else FRGFAS will supplement the UDR autonomously. Fig. 1 showcase FRGFAS in smart home perspective, the FRGFAS averts conventional load shedding in the event of disturbances to an extent of fault magnitude or generation loss, and also controls outdoor security lighting daily.

The ALS by FRGFAS may occur as a result of load-demand imbalance leading to inadequate power supply. The controller performs autonomous control for load management and supports the system stability via load shaving [17] with little or no end user inconvenience. The design aim of the FRGFAS is to provide a frequency response decentralized controller that operates based on myRIO-1900 FPGA embedded system control algorithms [18]. The design algorithm employs NI LabVIEW in connecting and disconnecting loads based on User Demand Response (UDR) and input data to the FRGFAS.

The FRGFAS determined home surrounding lighting status, with autonomous control and based on daylight parameters. All loads other than critical falls within the class of controllable loads, and not limited to the ones shown in Fig. 1. but also other loads with similar ratings.

The FRGFAS is fed with single phase source from the output of distribution board or consumer unit to loads in a smart home, whereas critical and uncontrolled loads connections maintain the normal energy flow from the distribution board to the loads as illustrated in Fig. 1.

![Fig. 1. Layout diagram of FRGFAS in a smart](image)

**4. Design of Frequency-response Grid -Friendly Appliance System**

4.1 Layout of Frequency-response Grid -Friendly Appliance System

Smart appliances have three basic sections; this includes input, processing and output sections. The input section is a set of active/passive data, measured or fed from power electrical components. The fundamental components are current, voltage, and frequency, other data such as resistance, power, temperature, illuminance are derived from these central elements. The processing unit analyzes the input data, processes the data and sends the command to the output for necessary action(s). The processing section of frequency response decentralized load controllers most often employs FPGA, DSP, μC, μP or RISC machine [19]. The FRGFAS has five sections with three data-acquisition sections as input, one intelligent processing section, and one control output section as shown in Fig. 2.
It incorporates hardware and software aspects. The input is a set of hardware while the processing unit is a combination of MyRIO-1900 hardware with embedded software algorithm using NI LabVIEW while the output is a hardware-based control circuit. FRGFAS is powered from an external source to myRIO-1900 via SMPS adapter with an output supplying 12V DC, 1500mA.

4.2. Data Input

The input to myRIO-1900 has three variable data that determines the output based on the appropriate control command sent to the controller from the processing unit; this include frequency, the user selected choice and Illuminance level.

4.2.1. Frequency Sensor

The frequency sensor employs the use of a Schmitt trigger in converting sinusoidal wave of AC mains voltage into a PWM signal [20]. The PWM signal is scaled down to an acceptable input range to MyRIO-1900 having 5.25V as maximum input. It uses a low-pass filter to reduce noise from the AC input signal, and also a capacitor at the output of the Schmitt trigger to suppress voltage spikes at the output of the op-amp UA741CP. Fig. 3 shows the simulation data from the output of the frequency sensor circuit using Multisim 14.0 with inverting single ended input and single rail supply voltage of +5v to the Op-amp.
The output voltage the Schmitt trigger is within to a maximum voltage swing of 2.954v on Channel B and is within a comfortable range for MyRIO-1900 PWM digital output range. Channel A presents the mains AC sinusoidal wave input to the Schmitt trigger while channel B presents the output PWM signal, the PWM output signal deviates from expectation in the first 1.75 cycles.

The input capacitor of the filter network is chosen based on (1) and (2), and the Schmitt trigger is designed to produce a unity gain.

\[ X_L = \frac{R}{10} \]  
(1)

\[ C = \frac{\pi R f X_L}{5} \]  
(2)

Where:
- \( C \) is the capacitance of the filter capacitor
- \( X_L \) is the reactance of \( C \)
- \( R \) is the Input resistance of the Schmitt trigger
- \( f \) is the frequency of the input voltage

### 4.2.2. User Demand Response

The UDR is one of the features of a smart home. In this design, the UDR employs push button switches that are accessible to the user and sends a digital signal to the processing unit. The switches have negative and positive terminals attached to MyRIO-1900 Digital Input Output (DIO) terminals. It also utilizes the built-in pull-down resistor features of the MyRIO-1900 device in determining the digital states. The design employs six user-accessible input switches for the flexible demand response to respective loads. Hence, the FRGFAS performs load management by turning ON appropriate corresponding loads at the output control section based on the signal sent from the processing unit. The UDR can be modified by the end user before the disturbance occurrence at any moment to suit an individual scale of preference that may vary over time.

### 4.2.3. Illuminance Sensor

The Illuminance sensor is a simple circuit that sends a digital signal to myRIO; it relies on the Light dependent resistor (LDR) as the primary component of the sensor. Hence, its resistance value determines the status (ON/OFF) of the outdoor lighting. Fig. 4 shows the circuitry of the illuminance sensor designed in Multisim. The LDR produces an analog output signal that the NPN transistor converts and feeds MyRIO-1900 with a digital signal for further processing.
4.3. Data Processing

The brain of the processing section of FRGFAS is FPGA. FRGFAS utilizes the built-in capabilities of the FPGA in LabVIEW environment; these capabilities include flexible reprogrammability of the logic arrays and accessibility to design needs. The processing section analyzes the data acquired from the input section and processes the inputs based on the algorithms of Fig. 5 and Fig. 6, the two algorithms are embedded in myRIO-1900 and utilize the special feature of FPGA parallelism, which is lagging in DSP, μP, and μC to execute the algorithms simultaneously [19].

In Fig. 5, the frequency sensor obtains a signal from AC mains source, it then converts the sinusoidal signal of the AC voltage to PWM signal and feed myRIO-1900. The algorithm in myRIO-1900 analyzes the signal input for each second and determines the class frequency to be within nominal (in this case 49.6Hz to 52Hz) or underfrequency (in this case ≤ 49.5Hz) zone. If the frequency is within underfrequency category, loads are shaved based on UDR preference, and supplementary are loads shaved where UDR is inadequate. The load is shaved to Stage-I level when the underfrequency occurs for four or more consecutive second, the Stage-II takes place if Stage-I operation fails to bring back the frequency to the nominal range, and the underfrequency contingency continues for another four or more consecutive second, counted after activation of Stage-I. The two stages are reset sequentially starting with stage-II when the frequency improves to the set nominal value for five consecutive seconds or more.

![Fig. 5. FRGFAS embedded algorithm](image-url)
However, the authors realized that underfrequency occurrence is rare due to improved stability of grid systems and availability of reserved power. Illuminance sensor was then added to the main design to improve its utilization of daily activities. The Illuminance sensor saves the end user physical energy for operating the lights, and also reduce bill via optimum operating hours of electricity usage.

Fig. 6. illustrates the algorithm adopted in improving the FRGFAS utilization with the aid of lighting automation control; the illuminance sensor detects the illuminance level and then sends the signal to myRIO-1900. The light will be ON when a digital true signal of a window period of sixty seconds is present, and it will be OFF if a digital-false signal is present for the same period.

In designing the processing section, the criteria [3] listed (i) – (ix) are taking into consideration, this includes:

i. The threshold frequency for turning OFF, \( f_{\text{off}} \) smart loads set to be in conformity with local grid code [21].

ii. The threshold for nominal frequency, \( f_n \) set below the frequency bandwidth of governor adjustment of utility generator tolerance settings.

iii. Duration of delay, \( T_d \) for switching loads between ON and OFF states when conditions for such operation fulfilled.

iv. The frequency to turn load ON from OFF states and vice versa, \( f_R \) categorized into 2-stages \( f_{R1} \) and \( f_{R2} \) based on frequency stability levels.

v. Nominal frequency considered within the range of that set by the utility.

vi. The UDR includes all possible logic combinations of input states for all switches.

vii. The switching capacities of the contactors rated for maximum load's capacity (since it is not a circuit breaker).

viii. The input source designed to be able to accommodate single phase, 240VAC, 50Hz and connected to a single phase from a distribution board/consumer unit.

ix. The underfrequency window time frame set below that of the utility.

The UDR has six input switches corresponding to six loads for demand-side load management (DSLM). Equation (3) express the probability of UDR combinations, \( f(x) \) for Stage-I and Stage-II control. The processor then decides output, \( f(y) \) for any two loads
based on chosen UDR from \( f(x) \) and the designed corresponding. Whereas, in Stage-II, three loads will be controlled with 20 possible choices, \( f(z) \) as expressed in (5) and designated by the embedded system algorithm.

The Illuminance sensor input is automated based on ambient illuminance level, and the LDR feeds continuous input resistance. All the inputs are real-time acquired, and the processing is also real-time and continuous.

\[
f(x) = \sum_{m=0}^{6} P(m) = \sum_{m=0}^{6} K_m
\]

\[
f(y) = 6 K_2 = 15
\]

\[
f(z) = 6 K_3 = 20
\]

Where:
- \( f(x) \) is the total possible logic input combination
- \( f(y) \) is the total possible logic output combination
- \( m \) is the logic input chances
- \( K \) is the combination
- \( P \) is the probability

4.4. Data Execution

The output section is the controller unit that executes the processed data via digital signals to turn ON/OFF loads via relays. The output signal of the controller depends on digital signals sent from the processing unit of MyRIO-1900, the DO of myRIO-1900 is capable of sending out 0/3.3V with a maximum of 150mA per channel. Therefore, myRIO-1900 output rating is not enough to trigger some connected loads directly. A driver circuit with Darlington transistors to further boost the complementary transistors is built while utilizing their \( \beta \) values. Also the protection and maximum ratings of the transistors to drive 80A relay for the grid-friendly loads, and 25A relay for outdoor lighting automation as smart switches are within consideration.

The selection of relay employs normally closed (NC) SPDT relays with DC coil and AC contacts suitable for the circuit operation and overloading. The NC feature enabled the designed system to save power when in sleep mode and allows continuous flow of energy when the controller is faulty. The load controller acts specifically as a smart switch rather the acting like a circuit breaker.

FRGFAS has two control stages. Section 4.3 presents the data processing of stage-I, stage-II control, sheds additional loads to that shed by stage-I and is activated when the stage-I action proves to be incapable of restoring frequency stability. The power-supply continuity is restored in two stages and subject to the improvement of the system’s frequency level.

5. Frequency-response Grid-Friendly Appliance System

5.1. FRGFAS performance in smart home

The FRGFAS is designed to perform autonomous ALS in the event of disturbances in a smart home. Load shedding cannot be neglected since its inactions may cause damages to the system. The effects of load shedding include but not limited to inconveniences and various type losses to both utility and end user. Detailed analysis of this occurrence is given in the literature [9], [22] in a global context.

The uncontrolled loads, \( L_U \) falls in the class of controllable loads which with no
connection to FRGFAS, due to limitations on the number of maximum connectable loads to FRGFAS at a time (six in this design). Critical loads, \( L_C \), falls under the category of uncontrolled and basic essential loads connected to FRGFAS; this loads includes basic lighting, entertainment such as TV, 13A socket outlets for phone charging and similar minor task. Whereas, the Grid Friendly\textsuperscript{TM} Appliance (GFA) Loads (\( L_1 \) to \( L_6 \)) are loads that are controllable by FRGFAS; the FRGFAS modifies loads status between ON/OFF and serve as a spin reserve to the power system stability [23].

Table 1. presents a sample of the loads category, ratings, and available status at the time, \( t \). It also classifies them as controllable, free running, and critical loads.

### TABLE 1: Relationship of electrical appliance with FRGFAS in a smart home

<table>
<thead>
<tr>
<th>Load Category</th>
<th>Appliance</th>
<th>Max Load Rating (w)</th>
<th>Load Available Status</th>
<th>Load Status at Time, ( t ) (w)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Critical Loads, ( L_C )</td>
<td>Home Entertainment, Basic Lighting, Fan, PC</td>
<td>Variable</td>
<td>ON</td>
<td>1650</td>
</tr>
<tr>
<td>Uncontrolled Loads, ( L_u )</td>
<td>Air Conditioner-X, Pump-X, Range.</td>
<td>100-5000</td>
<td>ON/OFF</td>
<td>2500</td>
</tr>
<tr>
<td>Load 1, ( L_1 )</td>
<td>Air Conditioner-I</td>
<td>750</td>
<td>ON/OFF</td>
<td>750</td>
</tr>
<tr>
<td>Load 2, ( L_2 )</td>
<td>Air Conditioner-II</td>
<td>1500</td>
<td>ON/OFF</td>
<td>1500</td>
</tr>
<tr>
<td>Load 3, ( L_3 )</td>
<td>Electric Clothes Dryer</td>
<td>4000</td>
<td>ON/OFF</td>
<td>4000</td>
</tr>
<tr>
<td>Load 4, ( L_4 )</td>
<td>Heater</td>
<td>1500</td>
<td>ON/OFF</td>
<td>1500</td>
</tr>
<tr>
<td>Load 5, ( L_5 )</td>
<td>Electric Cooker with Oven</td>
<td>2000</td>
<td>ON/OFF</td>
<td>2000</td>
</tr>
<tr>
<td>Load 6, ( L_6 )</td>
<td>Dishwasher</td>
<td>1350</td>
<td>ON/OFF</td>
<td>1350</td>
</tr>
</tbody>
</table>

**SOURCE:** [24]

Table 2(A) presents the digital status of the six GFA loads corresponding to the respective loads for seven different instance scenarios. The logic control “0” represent OFF state whereas logic “1” represents ON state of the corresponding loads. The GFA real-time load represents the ON/OFF status of the load at a time, \( t \), the UDR represents the end user choice via UI push buttons, and also the corresponding load shaving algorithm (from design data bank) that the FRGFAS will perform in any given instance.

### TABLE 2(A): Digital status of loads at different instances

<table>
<thead>
<tr>
<th>Instance Scenario</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>GFA Real-time Load</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>UDR</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stage-I Load Shaving</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stage-II Load Shaving</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 2(B) Presents the power consumption of loads corresponding to Table 2(A) Scenario 1, 3 and 7 shows a significant difference between the loads shaved in stage-I, and additional loads shaved in stage-II while no load shaving takes place in scenarios 2 and 4 at all stages. In scenario 5 and 7 stage, stage-II shave no extra load because the load designed to be OFF is in OFF state prior disturbance occurrence.

The design allows muti-scenario to occur in order reduce the impact of shaving more loads at a time; this will invariably reduce the adverse effects of shaving large capacity of loads, which may cause system instability. Table 2(A) and Table 2(B) considered only real power demanded since reactive power consideration is seldom in load shedding [25]. It further elaborates the impact of FRGFAS under disturbance scenarios with UDR for six randomly selected loads (\( L_1 - L_6 \)).
TABLE 2(B): Wattage corresponding to digital status of loads at different instances

<table>
<thead>
<tr>
<th>Instance Scenario</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>GFA Real-time load (w)</td>
<td>15250</td>
<td>4150</td>
<td>13000</td>
<td>10400</td>
<td>13000</td>
<td>7150</td>
<td>11250</td>
</tr>
<tr>
<td>Stage-I Load Shaving (w)</td>
<td>9900</td>
<td>4150</td>
<td>7500</td>
<td>10400</td>
<td>11500</td>
<td>2400</td>
<td>7250</td>
</tr>
<tr>
<td>Stage-II Load Shaving (w)</td>
<td>11650</td>
<td>4150</td>
<td>5500</td>
<td>10400</td>
<td>11500</td>
<td>400</td>
<td>7250</td>
</tr>
<tr>
<td>Percentage of Stage-I Load Shaving (%)</td>
<td>35.08</td>
<td>0.00</td>
<td>42.31</td>
<td>0.00</td>
<td>11.54</td>
<td>66.43</td>
<td>35.56</td>
</tr>
<tr>
<td>Percentage of Stage-II Load Shaving (%)</td>
<td>40.00</td>
<td>0.00</td>
<td>57.69</td>
<td>0.00</td>
<td>11.54</td>
<td>94.41</td>
<td>35.56</td>
</tr>
</tbody>
</table>

When the control section of FRGFAS acts in response to UDR input, some of the loads among L₁-L₆ will be tripped OFF. However, the likely amount is uncertain, this uncertainty is due to variation of critical and uncontrolled loads, these unconnected loads to FRGFAS operates freely. The mean of the loads shaved in stage-I is 27.27% while that of stage-II is 34.17%. The FRGFAS is designed to consider UDR as the “convenience level” of the end user in executing load management control command.

5.2. Aggregated FRGFAS Performance

The load shaving capacity performed by FRGFAS is not constant, hence, it depends on some variables that change with time. Equations (6), (7) and (8) depicts these variables, their relationship, and deviation of loads from nominal loading to Stage-I load shaving, and also from Stage-I to Stage-II. The (6), (7) and (8) presents aggregated total loading of smart homes in the three stages. Equation (6) expresses the loading under normal operation without disturbance on the system while (7) expresses the state transfer of loadings from nominal to Stage-I load shaving, and (8) expresses the state transfer from Stage-I to Stage-II load shaving. Section 4.3 presents the algorithm of the operation between all the states activation functions and reset conditions.

\[
S = \sum_{i=1}^{60} Li(R) \tag{6}
\]

\[
S_1 = \sum_{i=1}^{60} VL\alpha(1-\Delta_1)f_1 , \text{ where } L\alpha = L_i(R) , \; S_1 \in S \tag{7}
\]

\[
S_2 = \sum_{i=1}^{60} VL\alpha(1-\Delta_2)f_1f_2 , \text{ where } S_2 \in S \tag{8}
\]

Where:
- \( S \) is the total load under normal operation,
- \( S_1 \) is the total load under Stage-I operation,
- \( S_2 \) is the total load under Stage-II operation,
- \( i \) is the number of smart homes
- \( L \) is the load controlled by FRGFAS in a Smart Home,
- \( R \) is the assigned random (4kW -12.2kW) values of loads
- \( \Delta_1 \) is the factor of UDR that affects the capacity of \( Li(R) \)
- \( \Delta_2 \) is the factor of UDR that affects the capacity of \( L_i(R) \) in the transition from Stage-I to Stage-II
- \( f_1 \) is the 1\textsuperscript{st} underfrequency window of four consecutive seconds
- \( f_2 \) is the 2\textsuperscript{nd} underfrequency window of four consecutive seconds when " \( f_1 \) " is still active.
Table 2(B) presents the average load shaved for Stage-I and Stage-II as 27.27% and 34.17%. Assuming similar operation applies to sixty aggregated smart homes. Also considering a flexible variation in the probability of users changing consumption level from time to time, as a result of turning ON/OFF loads to be 5%, and chances of the end user to modify their UDR as given in (6), (7) and (8). Then the load management pattern will be as similar or as shown in Fig. 7(b). Fig 7(a). Presents the frequency sample of a grid system under disturbance for one minute, and Fig. 7(b) showcase the corresponding response of FRGFASs to frequency deviations. It considers a smart home subjected to frequency instability for one minute, and also 60 smart homes with deviations over a minute due to nature of changes in users’ behavior, based on the reference smart home considered and with possible deviations as well.

In Fig. 7. The frequency stabilizes within the nominal range in the first ten seconds, and hence, FRGFAS needs not to intervene. The frequency then deteriorates from the eleventh to fourteenth second, this four seconds underfrequency window triggers Stage-I load shaving from the fifteenth second. The Stage-I underfrequency lasted for seven seconds, in which the last four seconds fall within the range of another underfrequency, this four seconds of underfrequency triggers Stage-II load shaving. The Stage-II lasted for six seconds, from the twenty-second to twenty-eighth second. In the twenty-ninth second, deactivation of Stage-II takes place due to frequency level improvement to the nominal range from the twenty-fourth to twenty-eighth second. Also, the continuity of the nominal frequency flow from the twenty-ninth to thirty-third seconds deactivates Stage-II load shaving and restore all loads to normal operation for another eleven seconds. Disturbance leading to underfrequency activates Stage-I load shaving for another eight seconds, and the system is then reset to full capacity supply after the eighth second up to the sixtieth second.

5.3. FRGFAS Contribution to Knowledge

There are several efforts of realizing and improving grid frequency response of decentralized load controllers, even though the majority of the work show fewer efforts on hardware development, depend on the 2-way communication of the signal to and from the utility, and also one controller to one load. However, the design of FRGFAS contributes the under listed quota to existing knowledge.
i. A novel hardware model implementation design over previous which are majority based feasibility studies and simulations.

ii. Flexible UDR improves the end user convenience level via UI.

iii. Integration of autonomous control for home automation improves utilization with daily application.

iv. The Use of Labview and FPGA enables the design to be open-ended and flexible to subsequent design modifications.

v. A single FRGFAS controls multiple loads while the majority of its GFA counterparts, controls only a single load.

6. Conclusion

Load shedding has been performing prominently in protection schemes for the utility; it serves as the last level guard for protective and corrective maintenance in regaining and retaining electrical grid system stability when subjected to stress. However, Load shedding is not welcome by end users due to its inconveniences in the affected region. As such, both the end user and the utility are willing to welcome any feasible solution that can increase end users' convenience and as well support system stability and reliability. The smart grid being the state of the art of in energy research domain seem to open more doors of solutions to these shortcomings.

The FRGFAS design shows that it can avert conventional load shedding and mitigate its adverse effects on end users if adopted, the design proves to be worthwhile doing as depicted in Fig. 7. The design indicates that FRGFAS can avert conventional load shedding and invariably increases end user comfort zone from a blackout to over 50% power supply on the average, it also saves both physical and electrical energy and act as system spin-reserve within its capacity, which depends on the amount of minimum load required to restore stability.

The PWM signal is abnormal in the first two cycles highlighted by blue oval shape color in Fig. 3, however, this will only have affect the frequency count of the 1st second after the FRGFAS is engaged, since it requires at least four seconds of underfrequency to activate stage-I load shaving. The frequency counter will only detect underfrequency due to the behavior of the first two cycles, but will only trigger the circuit wrongly when there is true underfrequency with one second less. it will also self-heal when it discovers that the system is stable. The frequency response speed of the FRGFAS is also affected by its distance from the generation source, and its response is rated to travel at about 500 miles/sec [26].

The selection of FPGA embedded system (in MyRIO) with numerous DIO enabled the design to be open-ended and welcomes development and modifications in the field and future even after installation. It converts existing loads to be smart grid-compatible without altering their internal circuitry, or doing away with the old, hence minimize cost in smart grid realization.

The design can further be improved by incorporating 2-way information sharing system, between utility and FRGFAS since MyRIO-1900 is Wi-Fi enabled. Detect real-time load status before executing UDR via smart plugs and ZigBee applications or other similar devices, improved Home energy management circuits, and other worthwhile upgrades. All these is achievable while maintaining the existing design with the capability of FPGA parallelism and LabVIEW flexibility. The hardware development effort is ongoing currently, and attaining significant success; the authors hope to present the hardware result in due course.
Acknowledgment
The authors appreciate the support given by Universiti Putra Malaysia in carrying out this work through grant number 9412102. The conducive working environment provided Center for Advance Power and Energy Research (CAPER) through the Department of Electrical and Electronic Engineering, Faculty of Engineering, Universiti Putra Malaysia Serdang, Malaysia is also well appreciated.

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