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**Pricing Policy Applied to Power Quality
in Smart Metering System**

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Abstract

Meeting energy demands of the power system has been one of the main objectives of power engineers, but due to power quality issues, these demands are never satisfied. Power quality problems have existed in every power system, the more advanced the system, the higher probability for issues to occur, and the smart grid is no exception.

In this project, a study of a residential area is implemented using the LabVIEW simulation software, in which the power of each house is monitored in real time, each house with its own appliances, meaning the power of the whole system is also monitored, both instantaneous and accumulative power, current, power factor, all elements for system assessment, also a billing policy of each individual house to see the total price to be paid for the power supplied. All these factors would help to analyze and overview the effect of power quality problems on the area both electrically and economically.

The results of the simulation indicate that the pricing policy proposed is indeed effective for both sides of the grid, the supplier and the consumer.

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Abbreviation and Acronyms

RMS	Root Mean Square
SMETS	Smart Metering Equipment Technical Specifications
PQ	Power Quality
SLG	Single Line to Ground
THD	Total Harmonic Distortion
WT	Wavelet Transform
DWT	Discrete Wavelet Transform
MRA	Multi-Resolution Analysis
HT	Hilbert Transform
P	Real Power
Q	Reactive Power
S	Apparent Power
TFR	Time-Frequency Representation
DF	Displacement Factor
PF	Power Factor
DPF	Displacement Power Factor
VI	Virtual Instruments

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Dedication

This study is wholeheartedly dedicated to our beloved parents, who have been our source of inspiration and gave us strength when we thought of giving up, who continually provide their moral, spiritual, emotional, and financial support. To our brothers, sisters, mentor, friends, and classmates who shared their words of advice and encouragement to finish this study.

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*We thank ALLAH for all His blessing & strength that He gifted us to complete this
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General Introduction

One of the major challenging issues that power engineers and scientists encounter nowadays are power quality problems in electric power, that is being transmitted and distributed to enterprises, business establishments, and residences that could have an unpleasant impact on the electrical grid, making both suppliers and consumers concerned. This is owing to the steady increase in renewable energy penetration in addition to the vast use of harmonic-creating nonlinear loads such as adjustable-speed drives and switched-mode power supplies, arc furnaces, electronic fluorescent light ballasts.

Power Quality can be described as any electrical parameter or connection that impacts the operation of the equipment from the standpoint of the power user. This covered all electrical parameters, connections, and grounds, regardless of whether the supply was from utility, local equipment, or other users [1].

Electric power must transit such great distances from power plants via transmission and distribution lines, which include multiple transformations and changes that impair its quality even before it reaches customers, and in return this deteriorating in the quality of electrical power will shorten the life expectancy of the power equipment and devices that used in this process.

The traditional electrical grid has always suffered from quality issues, especially these past few decades due to electronic evolution, it is no longer viewed as “practical”, so the smart grid is meant to be the replacement, yet it has its own share of these quality problems.

The terminology "smart grid" describes a method of controlling the power system that employs telecommunications, power electronic technologies, and storage technologies to manage the supply and demand at all stages, in other words from within client end to the top voltage levels [2].

Here are some of the common problems that the grid suffers from:

- ❖ Harmonics
- ❖ Poor power factor
- ❖ Voltage variations (sag and swell)

Power quality problems are a significant threat because of the damage that can be done and they are simply getting worse, a reason for it is the increasing sensitivity of appliances, escalating their power demand. So they must be identified and corrected; for this purpose, detection methods are implemented, particularly time related, in conjunction with the smart meter, one of the most essential tools in a smart grid, all for the goal of minimizing grid damage as much as possible.

General Introduction

This study is constructed as chapters that cover an introduction to the electrical grid in the first chapter, followed by a more extensive discussion of the smart grid and smart meter, as well as power quality problems and their descriptions, origins, and repercussions.

Chapter 2 focuses on the detection methods and their main utilization, energy and power parameters, power factor and its effect on the electrical network, and different pricing policies.

The third chapter is the simulation part, which is composed of certain number of simulations, each one done to remark the effect on the residential area's electrical grid, a network of sixty houses with different status of problems grouped into six sectors, where each house contains eight different appliances, each appliance possess its own parameters for making the simulation more realistic. These houses offer current, instantaneous and accumulative power, and the billing price data, for a more precise monitoring.

The simulation is exercised for the same period on a two levels starting on the house level by implementing the simulation on five different houses each house with its specific PQ problems

the first house without problems, the second suffers from harmonics, the third with voltage swell and sag , the forth with poor power factor and the last with the 3 problems combined, finally on the entire network level where a 2 parts simulation of system is done, one with faulty system and the other after fixing the issues.

CHAPTER ONE: Generalities

1.1 Introduction

For the past 100 years, the power grid has barely changed. The multi-level grid's elements are approaching the end of their lifespan while the electricity consumption has kept increasing as the electrical grid aged. Today's power transmission and distribution network is extremely complex and unfit for the needs of our time. Other difficulties include the expanding population and consumption of energy, as well as the numerous power quality issues that are disrupting the system and triggering equipment failures for both suppliers and consumers.

As a result of the urgent need for a new grid infrastructure to meet these difficulties, a new approach of next generation electric power system, the smart grid, has emerged, with a sophisticated electric power grid infrastructure for enhanced efficiency, reliability, and safety, with seamless integration of renewable and alternative energy sources, as well as a modern smart meter on the consumer end to help monitor both power usage and the consequences of power quality problems on the system[3].

1.2 Electrical grid

"The grid," more specifically the electric grid which is composed of a network of transmission lines, substations, transformers and devices that transport electricity from the power plant to the consumer's home or business factory in the goal of fulfilling their electrical energy needs.

The first appearance of the current electric grid was in the early 1890s, it made such a great impact not only in the power industry but also in all life scopes, it was a revolutionary invention that competed with the dominance of the traditional ways that were known back then such as steam, coal and hydraulic turbines that were located in the premises of each consumer, as result the electric grid facilitate the connection and availability of electricity to all consumers in an effective and economical manners[4].

1.2.2 Components of Electrical grid

Contains many stages which are listed as follows:

- a.** Generation: starting with power plants that provides electrical energy by converting mechanical energy using turbines (nuclear, hydro, wind, natural gas) or from sunlight using photo voltaic panels[4].
- b.** Transmission: this process is achieved by the use of high voltage lines between two transformers where the first transformer is responsible of stepping up the voltage of

electricity from generator side to allow long distance transmission with minimum power loss due to the resistivity of the conducting wire until it reaches the substation where the second transformer steps down the voltage to retain the required level of electricity directed to distribution[4].

c. Distribution: it corresponds the final stage of the electrical grid where the electrical power is reduced to safer levels for the consumers to handle (from 1k V to 100V - 400 V) or it may be integrated to a smaller and lower grid in order to distribute electricity to homes [5], industry, and other users that is connected to the consumers in manly 3 possible constructions which are:

- ❖ Radial distribution system: it consists of only one connection between the substation and the consumer.
- ❖ Loop distribution system: it consists of two or more connections between the substation and the consumer.
- ❖ Interconnected distribution systems: it consists of number of feeders that supply electricity.

There are two types of distribution system according to the voltage:

1-Primary distribution system (11kV – 3,3kV)

2-secondary distribution system (415V – 230V)

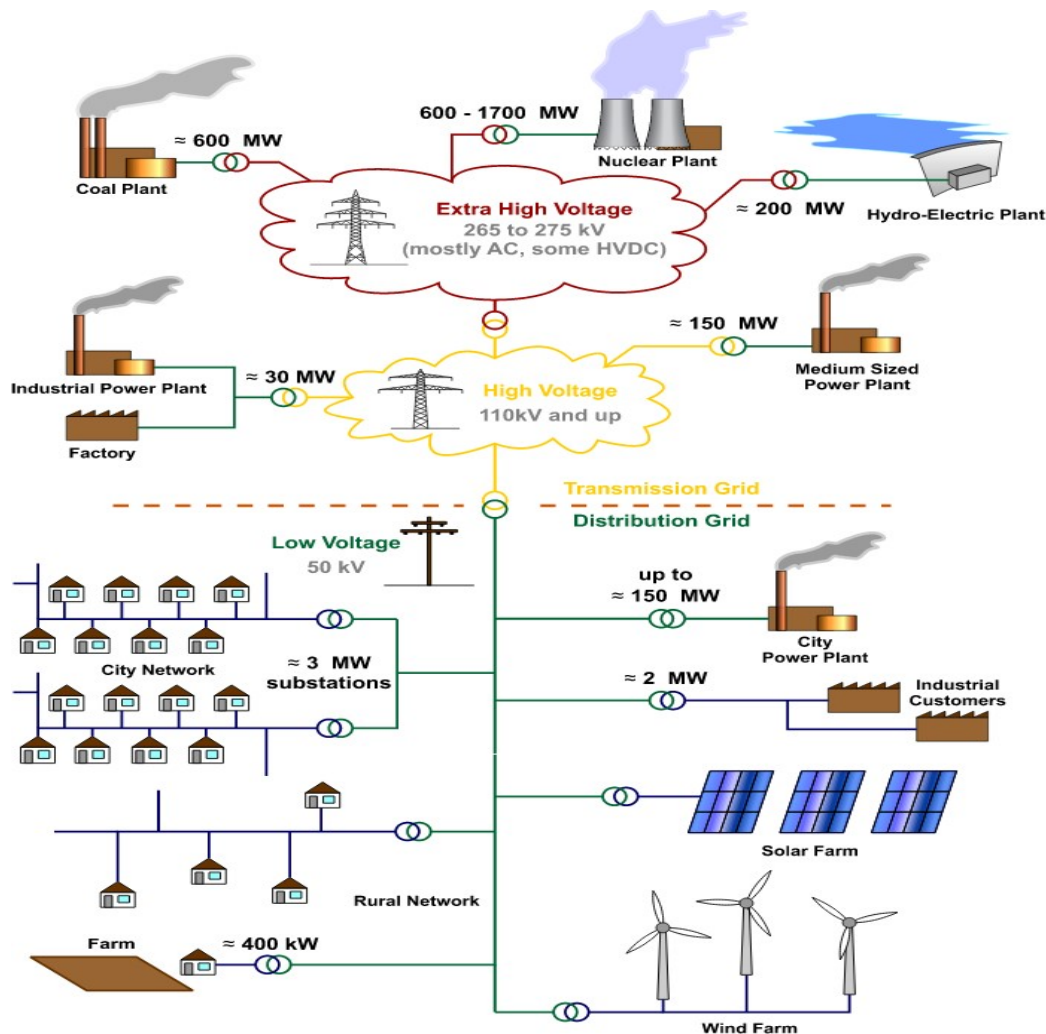


Figure 1- 1 Electric grid scheme [4]

1.3 Smart grid

Is combination of control and communication devices that allows for two-way communication between a unit that is called the control center and its customers, another characteristic of the smart grid is sensing the change in variables along the transmission lines, Like the Internet, the Smart Grid will consist of controls, computers, automation, and new technologies and equipment sending and receiving data from each other in the aim of achieving the best flow of electricity according to the demand, one of the new features of the smart grid is to enable new technologies to be integrated such as wind and solar energy production and plug-in electric vehicle charging, the smart grid will replace the ancient infrastructure of today's grid, and the control centers can better communicate with consumers. Also, these technologies will work with the electrical grid to respond rapidly to our fast changing electric needs[6].

The positives that the smart grid provides are [6]:

- ❖ More efficient transmission of electricity.
- ❖ Faster restoration of electricity after power disturbances.
- ❖ Decreasing in operations and management costs for control centers, and ultimately lower power costs for consumers.
- ❖ Less of a peak demand, which will also help decrease electricity rates.
- ❖ Facilitate the integration of renewable energy systems in the electrical grid.
- ❖ Better managing the grid.
- ❖ More secure system

One of the important features of a smart grid is so-called self-healing. A self-healing smart grid can provide a number of benefits that lend themselves to a more stable and efficient system. Three of its primary functions include:

- ❖ Real-time monitoring and reaction, which allows the system to constantly tune itself to an optimal state.
- ❖ Anticipation, which enables the system to automatically look for problems that could trigger larger disturbances.
- ❖ Rapid isolation, which allows the system to isolate parts of the network that experience failure from the rest of the system to avoid the spread of disruption, enabling a more rapid restoration.

1.3.2 The main components of the smart grid

It can be decomposed into levels:

- a. Generation level: the smart grid provides a quick response to every change in power demand especially when intermittent renewable become an important part of our nowadays power system. As more and more generation sources are distributed, a smart grid will help to integrate them to the grid and provide valuable data to the consumers.
- b. Transmission level: which is the liaison of the power source to the distribution phase it consists of cables and transformers that help to transport electricity between stations, in the smart grid the transmission line towers hold communication lines that transmit information from and into the data centers to the other parts of the grid[7].

- c. Distribution level: it gives a smooth remotely monitoring and managing the electric distribution system with the purpose of balancing the needs. Without bypassing that smart grids are also capable to detect outages that is caused by any break in the system due to storms, bad weather or sudden changes in electricity demand. The smart grid distribution intelligence counter these energy's fluctuations by automatically identifying the problems, redirecting and restoring power delivery, control centers can further use distribution intelligence to predict and manage electricity usage with the customers' co-operation leading to lower production cost and also have a response capabilities which allow them to occasionally 'self-heal'[7].
- d. Consumption level: this is probably the pillar of the smart grids. The smart meters that are located at the consumer properties are designed to measure and calculate specific values and send it back to data centers as a feedback and according to these sent measurements a controlling processor will process and develop a quick response in form of orders directed to the components of the grid. For example, it can reduce the energy consumption at your home when the grid is under stress from high demand, when the cost of electricity is high especially at the peak hours. It's so intelligent that it can predict consumption patterns and respond to the situation accordingly to reduce the electricity use and costs[7].
- e. Operating center: it is a data center that collect the received information in real time from all the parts of the grid in order to process for monitoring and controlling all the functions taking into account electricity supply and real time demand during the transmission and distribution process thus making the while process of generation, transmission and distribution much more efficient and reliable[7].

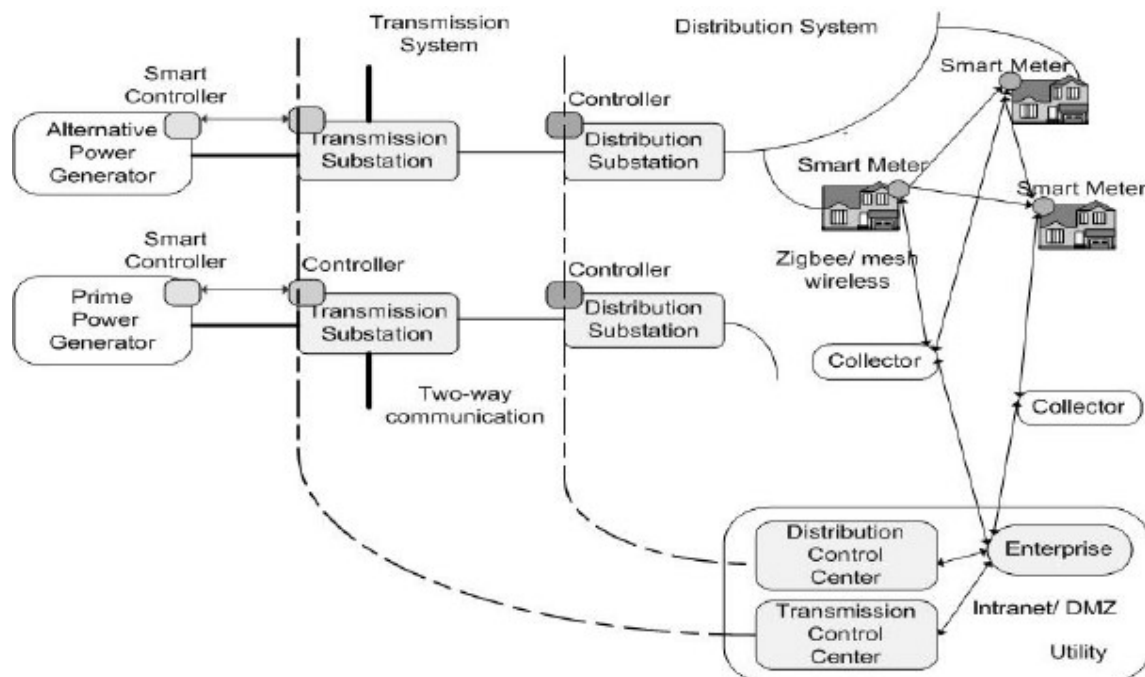


Figure 1- 2 the smart grid scheme [8]

1.4 Smart meter

The smart meter is one of the most important devices used in the smart grid, the smart meter is an advanced energy meter that obtains information from the end users' load devices and measures the energy consumption of the consumers and then provides added information to the utility company and/or system operator for better monitoring and billing. With smart meter, electrical data such as voltage and frequency are measured and real-time energy consumption information is recorded. Smart meter supports bidirectional communications between the meter and the central system. Also, smart meter has the built-in ability to disconnect-reconnect certain loads remotely and can be used to monitor and control the users' devices and appliances to manage demands and loads within the "smart-buildings" in the future[9].

1.4.2 The work of smart meters

Some of the main applications of the Smart Meter:

- Save automatically the information of the electrical power absorbed and its usage chronologically ordered in their integrated memory.
- Due to its telecommunication with the data center the information is continuously transmitted to the network operator to be analyzed and processed.
- Can be observed and checked by the network operator remotely ;

- Send an alarm to the network operator in case of unusual electrical activities in the goal of preventing fraud or electrical theft attempts[9].



Figure 1- 3 Smart Meter [10]

1.4.3 The advantages of the smart meter

Naming a few features that the smart meter provides to the grid:

- ✓ Provide daily monitoring of power consumption which is an important role in adapting the consumption of electricity in a more economical way.
- ✓ Gives the ability to interface the energy consumption and cost in customer display for a better electrical and bills control.
- ✓ A more stable and secure grid due to its power management that helps reducing quality problems especially during peak hours.
- ✓ Thanks to its shared information it is possible to forecast the power flow at any time of the day due to the developed patterns by the operator center.
- ✓ Raise the awareness of energy usage by changing behavioral habits to lessen the pressure on electricity grid.
- ✓ Shows the amount of power is used every time allowing to notice any sudden changes due to the existence of faults[9].

1.4.4 Example of a Smart Meter

To this day, there exists two types of smart meter that are used, SMETS1 and SMETS2. SMETS1 being the first generation of smart meters and the widely common used, it is known for using the 3G sim card to communicate with the supplier and the supplier only which created a problem when switching supplier in case of power issues accruing, leading it to stop sending automatic readings[10].



Figure 1- 4 SMETS1 Smart Meter [11]

The previous problem is treated using the second generation meter SMETS2 ,it kept all the good aspects of the previous smart meter with enhanced features ,the software used in this type of smart meter have the capability of exchanging and exploiting the information from other SMETS2 so in case of changing the supplier it would not be necessary to change the smart meter ,another feature of this device is that it is connected to a control center that is used for collecting all data from all suppliers that have direct access, so they keep functioning “smart” in any situation[10].



Figure 1- 5 SMETS2 Smart Meter [12]

1.5 Power Quality Problems

There exist many power quality problems in the distribution system of electricity which can be considered as faults if it is not permanent and it last for a long time, it can cause a harmful impact not only to the grid system but also to the consumer’s appliances where the losses are estimated to be a great deal from an economical point of view which can be

manifested as : equipment damage ,work cost, labor costs hence in the industry power, losses are not welcomed so a set of procedures are developed to improve power quality.

The power quality problems are defined as any disturbance that may cause voltage, current or frequency deviations in the power supply or any type of sourcing, it may also result in failure or mal-operation of a network. The most emerging and famous power quality issues are: overvoltage, surges, spikes, transients, voltage sags, voltage swells, voltage unbalanced, flicker, interruptions, and harmonics, “interharmonics”.

a. Overvoltage:

It refers to a power supplying above the normal voltage range, it may last from a few minutes to several days, 3 types are distinguished of overvoltage problems which are: surges, spikes and transients.

1- Surges:

Are high energy pulses arising from power system switching disturbances, may occur when the voltage gets higher than the normal and nominal range over a short term, it is considered to be caused by lightning or due to switching off heavy loads, it rarely makes any damage or interrupt devices because it is not strong enough most times[14].

2- Spikes:

It is very rapid rise of voltage amplitude over a small time period; these variations may reach thousands of volts, even in low voltage. It may be caused by lightning strikes or power outages it can be harmful when it gets to higher values compare to the normal range of voltage but mostly it is not very harmful[13].

3- Transients:

It is very fast increase of voltage amplitude in very small period of time. It can be in nanoseconds, caused by sudden changes in the power system. This impulse may not be dangerous because it passes after a very short time without harming devices[14].

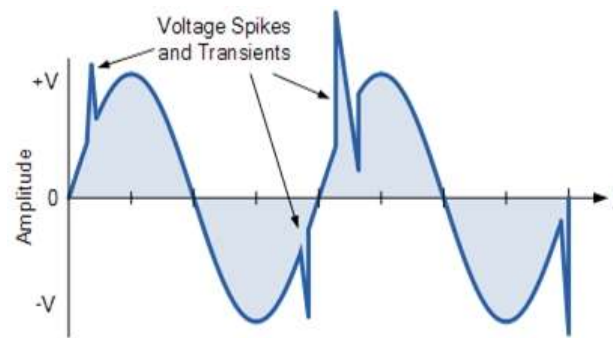


Figure 1- 6 Voltage Spikes and Transients [15]

4- Brief Voltage increases (swells):

It is short duration increment in the RMS voltage (between 110%-180%) occasionally associate voltage sags ,it emerges on the unfaulted phases of three phase circuit that has developed a single phase short circuit, it also occur after load rejection in addition the starting of large motor, light system loading and incorrect tap setting of the transformer[14], the voltage swell is divided into 3 categories[16]:

Instantaneous: with magnitude of 110 % --- 180% and duration of 0.5 ---- 30 cycles

Momentary: with magnitude of 110% --- 140% and duration of 30 cycles --- 3 seconds

Temporary: with magnitude of 110% --- 120% and duration of 3 seconds --- 1 min

The undesirable outcomes that result by swell are over heating of DC regulators and higher iron loss in most machine application it is preferable to use fast acting tap changer and voltage isolation in the aim of preventing the damage.

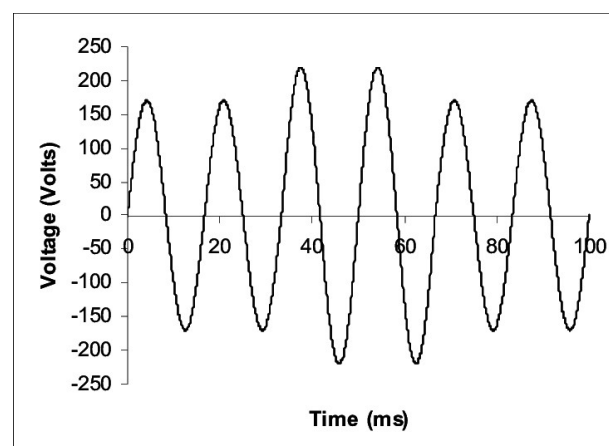


Figure 1- 7Voltage Swells [17]

b. Frequency variation:

Frequency variations take place in power networks as a result of active power generation and demand imbalances. The amplitude of the frequency variation is determined by the scale of the generation-demand imbalance in relation to the system size, to be specified it is a change in the number of wavelengths of the voltage where the longer the wavelength, the lower the frequency, the shorter the wavelength, the higher the frequency. Every country has a specific electrical frequency that must be operated at any change of that limitation would create PQ problems that may harm the equipment[18].

c. under voltage:

It happens when the applied voltage that is supplied get down and drops 90% from its rated values, it may last for period of days it is usually caused by overloaded utility and facility transformers especially if the demand for power exceeds the capability of the transformer, and as a result the voltage drops hence it produces high current that may damage equipment particularly 3 phase motors and heat up the cables.

d. Voltage sags:

To clarify, it is a disturbance where the RMS value of the line voltage is reduced for a period ranging from one half-cycle of the voltage to 500 MS it can be considered as short term under voltage problem, it appears because of Faults on the transmission or distribution network. Faults in consumer's installation, by switching on heavy loads or start on huge induction motors that normally draw 5 to 7 times their rated current during startup or due to single line to ground (SLG) fault, when the voltage sag take a duration of 1 minute then it becomes an under voltage , we can divide voltage sag into three main classes based on the duration of the occurrence, the classes are instantaneous sag, momentary sag, temporary sag it rarely be harmful to the devices ,it is possible to prevent the occurrence of the sags by using uninterrupted power supplies or power conditioners [13][14].

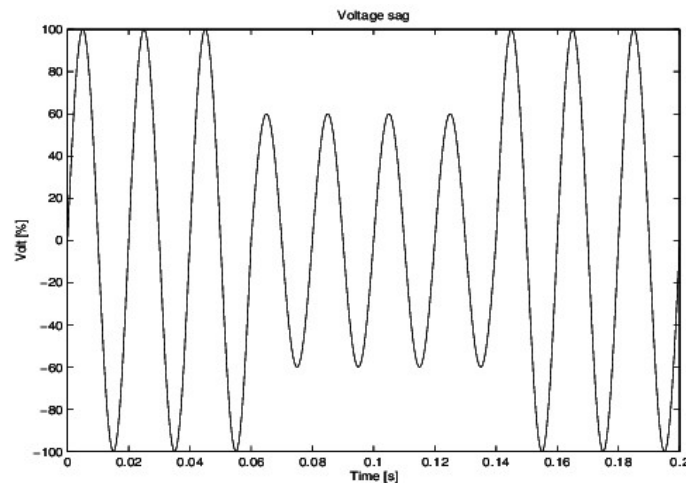


Figure 1- 8 Voltage Sags [19]

e. Voltage Unbalance:

It is a three-phase voltage variation where the three voltage magnitudes or phase angle measurements between them are not identical. The cause of such an issue could be large single-phase loads (induction furnaces, traction loads), or inappropriate distribution of all single-phase loads by the system's three phases (this may be also due to a fault).

Imposing several effects such as unbalanced systems indicate the presence of a negative sequence that is problematic to all three-phase loads. Three-phase induction machines are the most impacted loads[13].

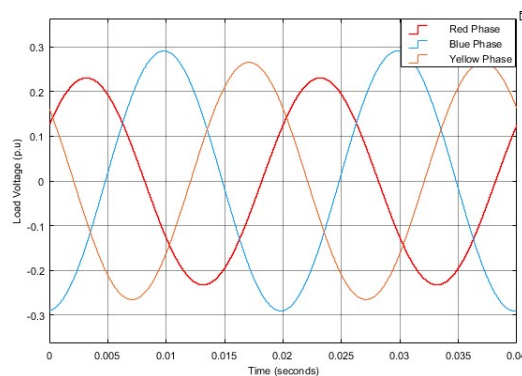


Figure 1- 9 Voltage Unbalance [20]

f. Voltage Fluctuations (Flickers):

It is a sequence of changes in the voltage (RMS) value by 10% (90%-110%), its occurrence is possible according to the type of loads being used, drawing large and highly variable currents. Due to the impedance of the power system these changes produce amplitude modulation of the voltage at the load bus and even at remote buses. Another common source is the starting of electric motors where to produce sufficient starting torque they may draw current many times their full load running current. The flicker wave shapes are mainly

triangular and may be periodic or non-periodic. The most noticeable effect is flickering lighting and screens, which creates the impression of instabilities in human vision[13][14].

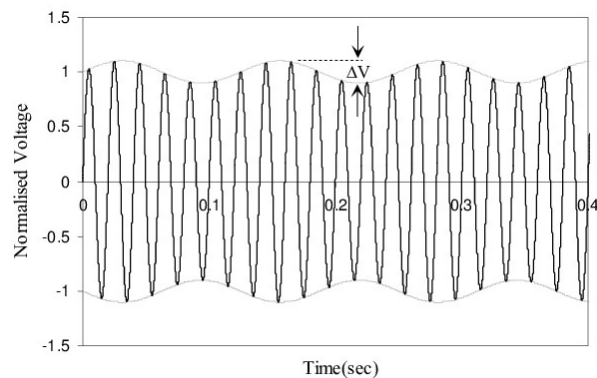


Figure 1- 10Voltage Flickers [21]

g. Brief Interruptions:

Is a voltage shutdown in the entire system; it can be expressed as a 90%-100% of a voltage sag, considered momentarily if it is restored to normal states in less than 3 seconds and a short duration or temporary if it takes a duration of 3 seconds up to a minute, could happen due to a blown fuse or a breaker opening giving the outcome of a great and expensive costs[14].

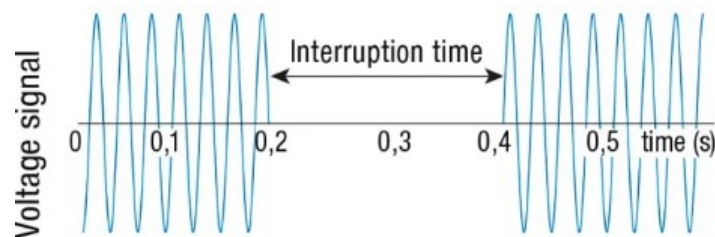


Figure 1- 11 Voltage Interruption [22]

h. Blackouts:

Which means the total interruption of power energy for more than 1 to 2 seconds, interrupting daily functions due to equipment failure in the electric grid, storms and objects (trees, cars, etc) striking lines or poles, fire, human factors, poor coordination, or failure of fuses, which may lead to the malfunction of all network elements, and is perceived the most serious concern of PQ problems[13].

i. Noise:

Can be seen as superimposing of high frequency signals on the wave form of the power-system frequency. Accurse due to electromagnetic interferences provoked by Hertzian waves such as microwaves, television diffusion, and radiation due to welding machines, arc furnaces, and electronic equipment. Improper grounding may also be a cause.

It would be shown as disturbances on sensitive electronic equipment, usually not destructive. May cause data loss and data processing errors[13].

j. Harmonics:

It is Voltage or current waveforms assume non-sinusoidal shape. The waveform is the sum of several sine waves of varying size and phase, with frequencies that are modified versions of the power-system frequency. Can happen to the reason of electric equipment operating above the knee of the magnetization curve (magnetic saturation), arc furnaces, welding machines, rectifiers, and DC brush motors are all common sources. All non-linear loads, including power electronics equipment such as ASDs, switched mode power supply, data processing equipment, and high efficiency lights, are modern sources. It may lead to increased likelihood of resonance occurrence, neutral overload in 3-phase systems, overheating of all cables and equipment, loss of efficiency in electric machines, electromagnetic interference with communication systems, measurement errors when using average reading meters, and nuisance tripping of thermal protections[13].

1.6 Conclusion

In this chapter, electrical grid has been reviewed along with its problems especially the ones associated with power quality, and the upgraded version of it which is the smart grid that would provide the solution to many previous issues and one of its most important tools, the smart meter.

CHAPTER TWO: Detection of Power Quality Disturbances

2.1 Introduction

The monitoring of the grid is progressed in real time, and the possibility of many quality problems occurring is always existing, therefore many detection methods are required to make sure that the grid is as operational as possible, so for different problems, different methods must be applied, for issues such as voltage fluctuation (sag and swell), voltage drop, harmonics and transients... are a signal processing dependent techniques for obtaining most real time data as possible. These methods require a certain parameters to identify the characteristics of the signal such as RMS,THD...etc.

This will reflect on the system in the form of poor power factor and higher frequency harmonics.

Electricity companies charge for lost power using particular pricing to make customers more knowledgeable on wasted energy, as well as for health and environmental benefits.

2.2 PQ Detection

Some common detection techniques are as follows:

2.2.1 Detection based on the value of Root Mean Square (RMS)

Starting with the most common and used technique, RMS for the advantage it has due to it being simple to implement and fast in performance and for its ability to narrow frequencies to its most approximated fundamental version in amplitude and form ,Where a step-by-step comparison is made between our reference frequency and the actual waveform throughout many samples[23].

The RMS error is defined by the following expression:

$$RMSE = \sqrt{\frac{\sum_{i=1}^N (Predicted_i - Actual_i)^2}{N}} \quad (2.1)$$

Where the difference is between the reference frequency and the actual voltage sample, and N being the number of sample points.

2.2.2 Kalman Filter

It is an iterative numerical handle that employs a set of conditions and continues information inputs to assess the genuine value rapidly, the calculation the fundamental

frequency and harmonic components amplitudes of the voltage or current signals are done and estimated using the Kalman filter. At that point the instantaneous total harmonic distortion (iTHD) and the energy are calculated. For each half cycle of the handled signal, five choice quantities are estimated based on iTHD and energy and these quantities are the three successive maximum values of iTHD, standard deviation and energy difference between misshaped signal and its fundamental frequency component. Based on these choice quantities, choice rules are connected to distinguish and classify the PQ events in this captured signal[24].

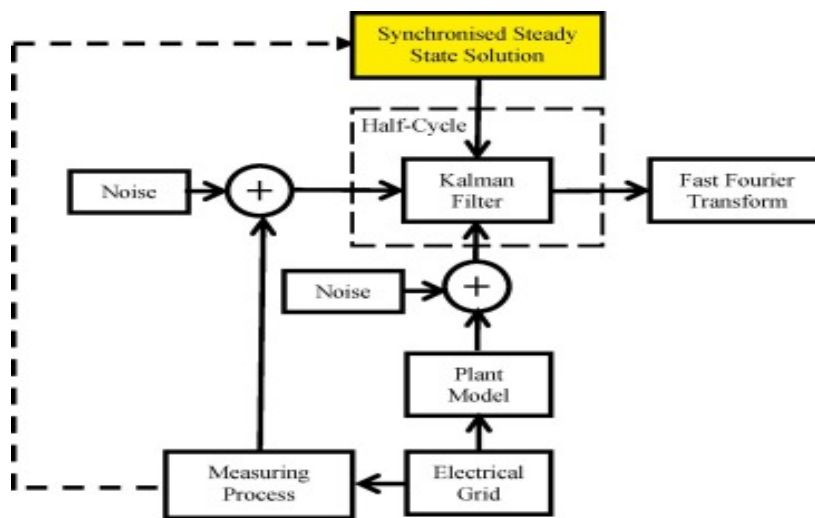


Figure 2- 1 Enhanced harmonic state estimation in unbalanced three-phase electrical grids based on the Kalman filter [25]

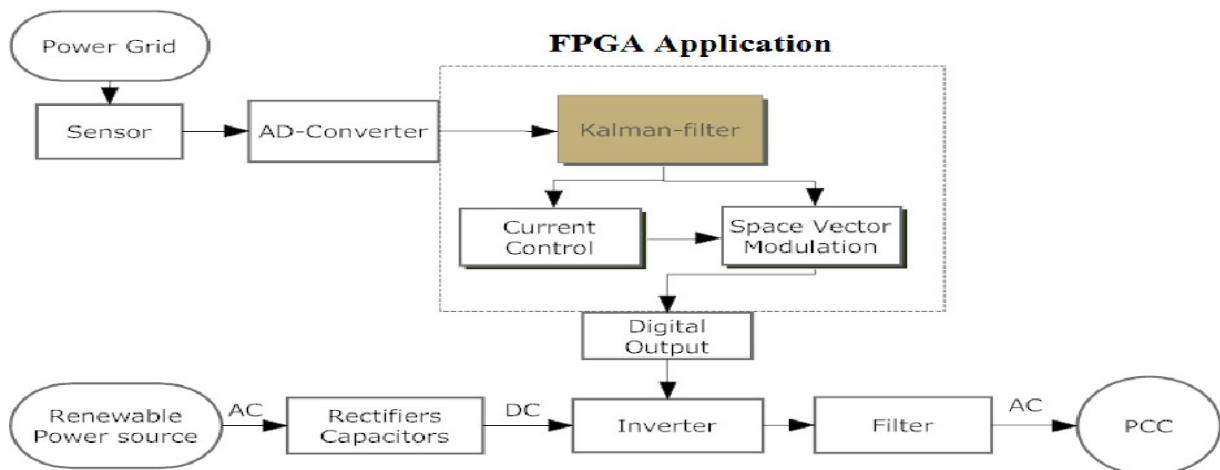


Figure 2- 2 Power Grid Integration using Kalman Filtering [26]

2.2.3 Wavelet Transform Technique

One of the most effective signal processing algorithms The wavelet transform (WT) was inferred initially for seismic signals processing, and to supply with a quick and effective method to analyze transient, non-stationary voltage and current waveforms in both time and frequency domains(an improved tool of Fourier Transform) . The WT works as the following: it decomposes a signal into its frequency components, and unlike the Fourier transform, the wavelet can tailor the frequency’s resolution, a valuable property within the characterization of the source of a transient. The main advantage of wavelets is the capacity of focusing on brief time intervals for high frequency components and long intervals for low-frequency components which improves the analysis of signals with localized impulses and oscillations, especially in the presence of a fundamental and low-order harmonic[23].

A wavelet is the outcome of product an oscillatory function and a decay function, a MOTHER wavelet is expressed as:

$$g(t) = e^{-\alpha t^2} e^{-j\omega t} \tag{2.2}$$

To estimate any given function, a number of wavelets generated from a MOTHER wavelet can be utilized. These wavelets are inferred via scaling and shifting (in time) MOTHER wavelets and can be stated as[23]:

$$g'(a, b, t) = \frac{1}{\sqrt{a}} g\left(\frac{t - b}{a}\right) \tag{2.3}$$

As a result, the number of oscillations in the resulting wavelets is the same as in the MOTHER wavelet. The one-dimensional signal was converted to a two-dimensional function of A (scale) and B (translation)

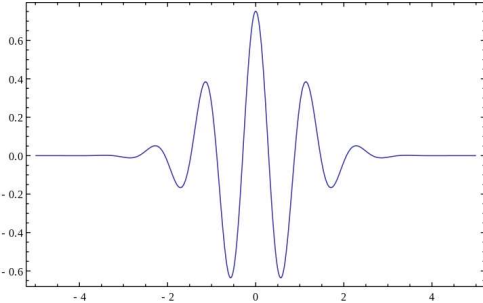


Figure 2- 3A sample mother wavelet [23]

The wavelet transform of a continuous signal $X(T)$:

$$WT(a, b) = \frac{1}{\sqrt{a}} \int_{-\infty}^{\infty} f(t)g\left(\frac{t-b}{a}\right) dt \quad (2.4)$$

Depending on whether $a > 1$ or $a < 1$, the time extent of the wavelet $g((t-b)/a)$ is stretched or reduced in time. A value of $a > 1$ expands $g(t)$ in time while decreasing the frequency of oscillations in $g((t-b)/a)$. whereas $a < 1$ compresses $g(t)$ in time while increasing the frequency of oscillations in $g((t-b)/a)$. As a result, as a varies across some interval, often beginning with unity and increasing, the input is processed by an increasingly dilated function that becomes less and less focused in time. The discrete wavelet transform is a digitally applied alternative to The WT[23].

b) Discrete Wavelet Transform

The scale and translation variables of the original signal are discretized in DWT, but not the independent variable. It should be observed that the two variables a and b in the continuous transform are continuous. Nonetheless, in order to facilitate computer implementations, the independent variable will be broken down to short segments during the reconstruction process. DWT provides a number of wavelet coefficients that are proportional to the integer number of the discretization steps in scale and translation, expressed by m and n , respectively. As a result, any wavelet coefficient may be represented by two integers, m and n . If a_0 and b_0 are the scale and translation segmentation step sizes, respectively, the scale and translation in terms of these parameters will be[23]:

$$g'(m, n, t) = \frac{1}{\sqrt{a_0^m}} g\left(\frac{t - nb_0 a_0^m}{a_0^m}\right) \quad (2.5)$$

The wavelet transform for a continuous signal using DWT:

$$DWT(m, n) = \int_{-\infty}^{\infty} \frac{1}{\sqrt{a_0^m}} f(t)g(a_0^{-m}t - nb_0)dt \quad (2.6)$$

The idea behind adopting DWT is to use numerous cut-off filters for evaluating the signal throughout different scales, using a combination of high pass and low pass filters, and then breakdown the examined signal into smooth and detailed versions[23].

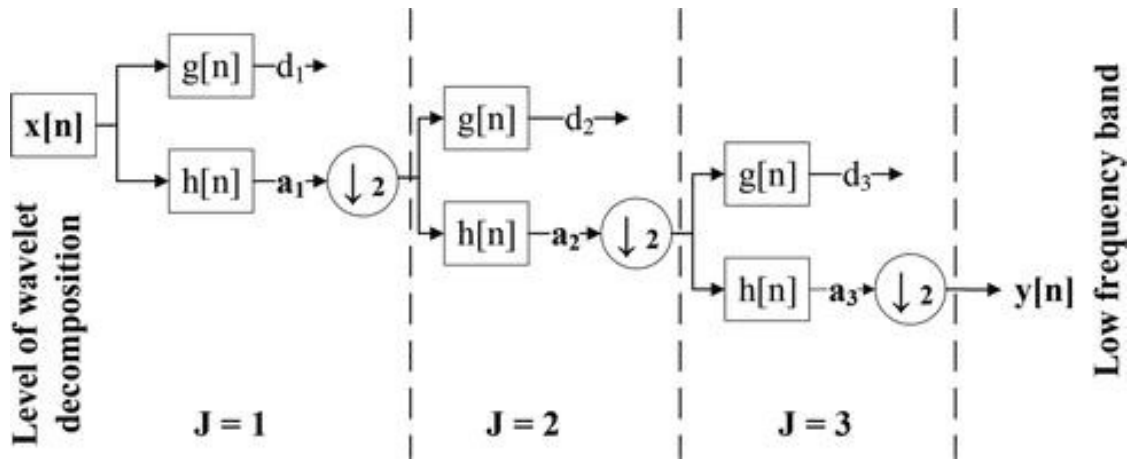


Figure 2- 4Multi Resolution Signal Decomposition Implementation of Wavelet Analysis [27]

2.2.4 Stockwell Transform

The Stockwell Transform is mainly a hybrid of short-time Fourier analysis and wavelet analysis containing elements of both, creating a new category. It performs a multi-resolution analysis (MRA) of a time varying signal while retaining the absolute phase of each frequency, in a purpose to create signal representations with varying levels of resolution by decomposing the time domain signal using a width varying windows inversely with frequency where it construct basic components for signal decomposition and reconstruction at various resolutions[28].

High pass and low pass filters are respectively related to the process [29].DWT evaluation involves two steps. In first step the “wavelet coefficients” are determined. These obtained coefficients represent the signal in the wavelet domain. In the next step, the obtained wavelet coefficients are used for calculating ‘approximation’ as well as the ‘detailed’ version of original signal, in different levels of resolutions, in the time domain are done. Output of first level decomposition of signal is first level wavelet coefficient of approximation and of detailed version, which are $y_h(k)$ and $y_g(k)$ respectively[29].

These coefficients are known as $cA_1(n)$ and $cD_1(n)$ respectively and can be stated as:

$$cA_1(n) = \sum_k f(n).h_d(-k + 2n) \tag{2.7}$$

$$cD_1(n) = \sum_k f(n).g_d(-k + 2n) \tag{2.8}$$

When these signals pass through another low pass digital filter then second level wavelet coefficient of approximation and of detailed version can be obtained they can be

written as $cA_2(n)$ and $cD_2(n)$ respectively [29]. The component obtained after level MRA analysis level 1 will be initial signal for MRA level 2. This signal is then passed through low pass filter and high pass filter. The filter's output are the high frequency component in level 2.

$$c_2(n) = \sum_k h(k - 2n) c_1(k) \tag{2.9}$$

$$d_2(n) = \sum_k g(k - 2n) c_1(k) \tag{2.10}$$

This process will continued up to “n-1” in order to calculate to calculate the “n” level approximated and detailed wavelet coefficients. Wavelet transform in time domain can be determined only after calculation of all wavelet coefficients. This is obtained by the process known as “rebuilding” the corresponding wavelet coefficients, along the different resolution levels. At each step of decomposition, filtering and down sampling will produce half the number of samples (half the time resolution) and half the frequency spectrum (double the frequency resolution) [29].

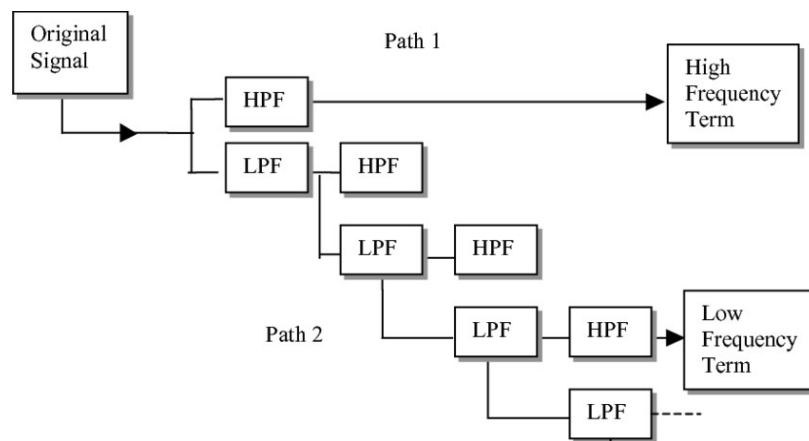


Figure 2- 5 Signal decomposition using MRA [30]

2.2.5 Hilbert Transform

The Hilbert transform (HT), as a type of integral transformation, is important in vibration signal processing. There are two common applications for it. First, the HT examines the instantaneous properties of a vibration: frequency, phase, and amplitude. Second, the HT can determine the real component of a system's transfer function from the system's imaginary part and vice versa. This enables frequency domain analysis of systems[31].

When the HT is applied to the initial signal, it provides some extra information regarding the amplitude, instantaneous phase, and frequency of vibrations.

The HT of the function can be defined by an integral transform:

$$H[x(t)] = \tilde{x}(t) = \pi^{-1} \int_{-\infty}^{\infty} \frac{x(\tau)}{t - \tau} d\tau \quad (2.11)$$

A real valued function $x(t)$ HT's would also be a real valued function defined by eq. As a result, $\tilde{x}(t)$ is the convolution integral of $x(t)$, written as $\tilde{x}(t) = x(t).1/\pi t$. The HT of a constant is a zero. The HT of HT gives back the original function but with the opposite sign. Hence, it shifts the original signal by -90° [31].

The analytical signal provides the information about the amplitude as well as the phase of the signal. When dealing with general modulated signals, it is often convenient to define the analytic signal $X(t) = x(t) + i\tilde{x}(t)$, where $\tilde{x}(t)$ is related to $x(t)$ by the HT.

A real vibration process $x(t)$ is merely one of several possible projections (the real component) of an analytic signal $X(t)$. Then, according to the HT, the second projection of the same signal (the imaginary component) $\tilde{x}(t)$ will be conjugated [31].

$$X(t) = |X(t)|[\cos \psi(t) + i \sin \psi(t)] = A(t)e^{i\psi(t)} \quad (2.12)$$

Instantaneous amplitude:

$$A(t) = |X(t)| = \sqrt{x^2(t) + \tilde{x}^2(t)} = e^{Re[\ln X(t)]} \quad (2.13)$$

Instantaneous phase:

$$\psi(t) = \arctan \frac{\tilde{x}(t)}{x(t)} = Im[\ln X(t)] \quad (2.14)$$

2.3 Power measurement

Active power, also called real power (P), is measured in Watts or KW and performs useful work. Electrical equipment like motors and transformers require reactive power (Q) to create a magnetizing current for the operation of induction devices and allow work to be performed, it is measured in VAR. As for the apparent power (S), also referred to as the total power delivered is the combination of the two previous powers [32].

Power measurements consist of active power, reactive power, apparent power and power factor. These can be calculated as follows [33]:

$$S = |V_{rms}||I_{rms}| \quad (2.15)$$

The RMS value of the fundamental voltage and current components, as well as the PF, can be used to calculate the active (P) and reactive (Q) powers[34]:

$$P = V_{rms}.I_{rms}.PF \quad , \quad Q = V_{rms}.I_{rms}.\sin(\cos^{-1}(PF)) \quad (2.16)$$

As for the energy, by multiplying the active and reactive power quantities by time, the active and reactive energies would be calculated [34]. Active and reactive energy are equivalent to active and reactive power when the time is set to one second.

2.4 PQ parameters

From the time-frequency representation (TFR), the signal parameters are estimated to identify characteristics of the signal. Instantaneous root mean square voltage, instantaneous RMS fundamental voltage, and the instantaneous total harmonic distortion (THD) are the list of signal parameters used for detection of power quality disturbances [33].

2.4.1 Instantaneous RMS Voltage

$$V_{rms}(t) = \sqrt{\int_0^{f_{max}} P_x(t, f) df} \quad (2.17)$$

Where $P_x(t, f)$ is the time frequency distribution, and f_{max} is the maximum frequency of interest[33].

2.4.2 Instantaneous RMS Fundamental Voltage

Defined as the RMS voltage at power system frequency and may be found by[33]:

$$V_{1rms}(t) = \sqrt{2 \int_{f_{lo}}^{f_{hi}} P_x(t, f) df} \quad (2.18)$$

$$f_{hi} = f_1 + \frac{\Delta f}{2}, \quad f_{lo} = f_1 - \frac{\Delta f}{2} \quad (2.19)$$

Where f_1 is the fundamental frequency that corresponds to the power system frequency, Δf is the bandwidth, Δf is set to 50Hz.

2.5 Sags and Swells

Sags were first defined as any drop in voltage below a user-specified threshold of one cycle and 2.55 seconds. Swells, formerly known as surges, were similar to sags in that the

voltage surpassed a user-defined high limit. Sag effects are considerably more obvious than swell effects, although swell impacts seem to be more harmful than sag effects.

The sources of sags have been classified into three categories: transmission (usually above 65kV), distribution (65kV to 12kV), and point-of-use (120-480V).

A swell could appear on the system as a result of a single line-to-ground fault, which can also cause a transient voltage surge on the unfaulted phases. Swells can also be caused by unexpected load decreases [16].

2.6 Harmonics

Harmonics are unwanted multiples of the line frequency that are added to the original or "fundamental" sine wave [35]. The addition of harmonics to a pure sine wave alters the original pure sine content. The distortion can be measured and defined as Total Harmonic Distortion (THD %) which is essentially a ratio of all the harmonic energy added as a ratio to the fundamental energy.

2.6.1 Instantaneous Total Harmonic Distortion

To identify harmonic content in a signal, given as[33]:

$$THD(t) = \frac{\sqrt{\sum_{h=2}^H V_{h,rms}(t)^2}}{V_{1rms}(t)} \quad (2.20)$$

Where $V_{h,rms}(t)$ is the RMS harmonic voltage, H is the highest measured harmonic component.

2.7 Power factor

To adequately define the power factor, the term Displacement Factor will be used for a deeper comprehension. DF and PF are exchangeable in some loads, but not in the majority of real-world loads[35]. Displacement factor is set to be the phase angle displacement from the voltage to the current. DF and PF are dimensionless numbers with values ranging from 0 to 1. The outcome of the perfect DF/PF is DF/PF = 1. A DF =0 happens when the voltage and current are shifted by 90 degrees. The load is now completely reactive and cannot perform any work in Watts. The notion of power factor is typically presented using pure sine waves with 0% harmonic distortion, which simply does not correspond to real-world waveforms, where waveform distortion is included in PF calculation. Harmonics can only make PF worse. For example, if the load current has no displacement (DF=1) but there is considerable harmonic distortion, the PF will be weak.

$$PF = \left(\frac{1}{\sqrt{1 + THD_i^2}} * DF(\cos \theta) \right) \quad (2.21)$$

When looking at equation (2.21), there is a distortion term at the start and a DF term on the right. We can conclude that even if the $DF = 1$, but there was significant distortion, the PF would suffer. However, even if the DF is low and there is no THD, the PF will also decrease [35].

Power factor of the load may also be represented as the ratio between the real power and the apparent power of an electrical system showing how effectively the S delivered is being used.

$$pf = \frac{P}{S} \quad (2.22)$$

A relationship of all powers may be derived as:

$$S^2 = P^2 + Q^2 \quad (2.23)$$

Any industrial process that employs electric motors (to power pumps, fans, and conveyors, for example) contributes inefficiencies into the power grid by drawing additional currents known as "inductive reactive currents[36]."

Even though these currents generate no functional power, they increase the demand on the switchgear and distribution network of the supply, as well as the switchgear and cabling of the consumer [36]. The power factor is used to describe efficiency; a typical uncorrected industrial power factor is 0.8, which means that a 1MVA transformer, for example, can only supply 800kW. The supply must generate far more current than is supposedly required due to low power factor equipment. This access current, like the effective current, goes through generators, wires, and transformers. If no actions are done to enhance the load's power factor, all equipment from the power station to the installation sub-circuit wiring must be larger than necessary. As a result, transmission and distribution losses increase across the whole network [36]. To prevent inefficiency, Electricity companies charge for wasted power using specific pricing.

2.8 Pricing policy

Tariff is the rate at which electrical energy is provided to a consumer[37].

- The cost of producing electricity is determined by the amount of electricity delivered to the load.
- Tariff fixing must be applied to various sorts of consumers (e.g., industrial, domestic and commercial).
- Tariff assessment for different customers is more challenging.

There exist numerous objectives to be accomplished in the pricing policy such as:

- Electrical energy is sold at a price that not only covers its costs but also produces a respectable profit. Tariffs should encompass the following objectives:
 - The cost of producing electrical energy at the generating station is compensated.
 - Recovery of cost on the capital investment in transmission and distribution systems.
 - Recovery of cost of operation and maintenance of supply of electrical energy.
 - A suitable profit on the capital investment.

Some of the policies characteristics that Tariffs are restricted to are listed as follows:

- i. Proper Return
 - Total consumer receipts must match the cost of producing and supplying electrical energy plus a suitable profit.
 - This will allow the electric utility to provide consumers with consistent and dependable service.
- ii. Fairness:
 - The tariff must be ethical in order for different sorts of consumers to be pleased with the rate of charge for electrical energy.
 - A big consumer should be billed at a lower rate than a small consumer with fixed rates, lowering the overall cost of electrical energy production.
 - A consumer whose load conditions do not deviate much from the non-variable load should be charged at a lower rate than big consumers with variable load [37].
- iii. Simplicity:
 - The tariff ought to be straightforward enough for the average consumer to comprehend.
 - A convoluted tariff may raise hostility from a public that is often skeptical of supplier companies.

iv. Reasonable Profit :

- The profit element in the tariff should be reasonable.
- An electric supply company is a public utility company and generally enjoys the benefits of monopoly.
- Because there is little competitive pressure, the investment is reasonably safe, and the profit is expected to be around 8% each year.

v. Attractive :

- The tariff ought to be appealing enough to entice a significant number of customers to utilize electrical power.
- Efforts should be made to fix the tariff in such a way so that consumers can pay easily

2.8.1 Types of Tariff

There are several types of tariff [37]:

1. Simple tariff :

When there is a fixed rate per unit of energy consumed, it is called a simple tariff or uniform rate tariff.

a) Advantages of Simple Tariff :

- In a simple tariff, the cost does not fluctuate with the number of units utilized.
- An energy meter is used to record the consumption of electrical energy at the consumer terminals.
- This is the most basic tariff and is comprehensible by customers.

b) Disadvantages of Simple Tariff :

- Regardless of load variance, every consumer must pay the same fixed prices.
- The cost per unit delivered is high
- It does not promote the use of electricity.

2. Flat rate tariff :

When different types of consumers are charged at different uniform per unit rates, it is called a flat rate tariff.

- In this type of tariff, the consumers are grouped into different classes and each class of consumers is charged at a different uniform rate.
- The different classes of consumers are made taking into account their diversity and load factors

a) Advantages of Flat Rate Tariff:

- This tariff is more benefit to different types of consumers
- Flat rate tariff is quite simple in calculations

b) Disadvantages of Flat Rate Tariff :

- Separate meters are required for lighting load, power load etc
- The application of such a tariff is expensive and complicated
- A particular class of consumers is charged at the same rate irrespective of the magnitude of energy consumed

3. Block rate tariff :

When a given block of energy is charged at a specified rate and the succeeding blocks of energy are charged at progressively reduced rates, it is called a block rate tariff[37].

- The energy consumption is divided into blocks and the price per unit is fixed in each block.
- The price per unit in the first block is the highest and it is progressively reduced for the succeeding blocks of energy.
- For example, the first 30 units may be charged at the rate of 60 paise per unit; the next 25 units at the rate of 55 paise per unit and the remaining additional units may be charged at the rate of 30 paise per unit.

a) Advantages of Block rate tariff:

- The consumer gets an incentive to consume more electrical energy.
- This increases the load factor of the system and hence the cost of generation is reduced.

b) Disadvantages of Block rate tariff:

- It lacks a measure of the consumer demand.
- This type of tariff is being used for majority of residential and small commercial consumers.

4. Two-Part Tariff :

A two-part tariff is used when the rate of electrical energy is charged based on the consumer's maximum demand and the units consumed [37].

- In two-part tariff, the total charge to be made from the consumer is split into two components viz., fixed charges and running charges.
- The fixed charges depend upon the maximum demand of the consumer while the running charges depend upon the number of units consumed by the consumer.
- Thus, the consumer is charged at a certain amount per kW of maximum demand plus a certain amount per kWh of energy consumed i.e.

Total charges = Rs ($b \times \text{kW} + c \times \text{kWh}$) where,

b = charge per kW of maximum demand

c = charge per kWh of energy consumed

- This type of tariff is mostly applicable to industrial consumers who have appreciable maximum demand.

a) Advantages of Two-Part Tariff

- It is easily understood by the consumers.
- It recovers the fixed charges which depend upon the maximum demand of the consumer.
- It is independent of the units consumed.

b) Disadvantages of Two-Part Tariff:

- The consumer has to pay the fixed charges irrespective of energy consumed.
- There is always error in assessing the maximum demand of the consumer.

5. Maximum Demand Tariff :

It is comparable to a two-part tariff with the exception that the maximum demand is really measured by putting a maximum demand meter in the consumer's premises.

a) Advantages of Maximum Demand Tariff:

- The maximum demand is assessed merely on the basis of the ratable value.
- This type of tariff is mostly applied to big consumers.

b) Disadvantages of Maximum Demand Tariff:

- It is not suitable for a small consumer.
- Separate maximum demand meter is required.

6. Power Factor Tariff :

Power factor tariff is the tariff that takes the power factor of the consumer load into account.

- A low power factor increases the rating of station equipment and line losses.
- A consumer having low power factor must be penalized.

The following are the important types of power factor tariff[37]:

i. KVA Maximum Demand Tariff :

- It is a modified form of two-part tariff.
- In this case, the fixed charges are made on the basis of maximum demand in kVA and not in kW.
- A low power factor consumer has to contribute more towards the fixed charges.

ii. Sliding Scale Tariff :

- This is also known as average power factor tariff.
- In this case, an average power factor, say 0.8 lagging, is taken as the reference.
- If the power factor of the consumer falls below this factor, suitable additional charges are made.
- If the power factor is above the reference, a discount is allowed to the consumer.

iii. KW and KVAR Tariff :

- In this type, both active power (kW) and reactive power (kVAR) supplied are charged separately.
- A consumer having low power factor will draw more reactive power and hence shall have to pay more charges.

7. Three-Part Tariff :

When the total charge to be made from the consumer is split into three parts viz., fixed charge, semi-fixed charge and running charge, it is known as a three-part tariff

$$\text{Total charge} = \text{Rs}(a + b \times \text{kW} + c \times \text{kWh})$$

Where [37]: a = fixed charge made during each billing period

 b = charge per kW of maximum demand

 c = charge per kWh of energy consumed

- It may be seen that by adding fixed charge to two-part tariff, it becomes three-part tariff.
- The principal objection of this type of tariff is that the charges are split into three components.
- This type of tariff is generally applied to big consumers.

2.9 Conclusion

In this chapter, some detection techniques have been discussed, with their basic and primary task, followed by the well-known issues to be encountered on the consumer's end, and lastly with varieties of pricing policies so that consumers well manage their consumption to get a better and healthier power grid that would benefit both suppliers and customers.

CHAPTER THREE: Results and Discussion

3.1 Introduction

Detection of power quality problems possess a major importance in the procedure of enhancing the electrical network and making it healthier, especially on the consumers level where significant damage may occur not only to the resident's equipment, but also may harm the electrical network devices such as transformers and cables for that PQ problems effect the normal flow of electrical energy and disturb the balance of supply and demand ratio.

In order to demonstrate the effect of PQ problems on the smart grid, focusing on the consumer sector, a simulation is composed using LabVIEW simulator. Adopting two parts scenario, one with current and voltage problems, a second of a healthy grid with no issues.

3.2 LabVIEW Software

LabVIEW (Laboratory Virtual Instrument Engineering Workbench) is a software that uses graphical programming language G which ease for engineers to develop and simulate automated research, validation, and production test systems; also called as virtual instruments, or VIs. LabVIEW provides a complete set of tools for data acquisition, analysis, display, manipulation, and storage, along with instruments for diagnosing code. In addition it offers the ability to implement arithmetic and logic operations. VI contains the three components-the front panel, the block diagram, and the icon and connector pane. The user interface is located on the front panel.

The block diagram contains the graphical source code for the VI's functionality. The icon and connection pane identify the VI, allowing it to be utilized in another VI. The various leveled architecture of the VI is what gives LabVIEW its effectiveness. A VI can be utilized on the block diagram of another VI after it has been generated. A subVI is a VI that exists within another VI. A subVI corresponds to a subroutine in text-based programming languages. Using subVIs allow users to manage adjustments and easily debug the block diagram [38][39].

3.3 Simulation

Using LabVIEW software, a modulation of a residential area is applied in order to see and try to get a better comprehension of some major power quality problems where the area is divided into six sectors, each sector with a number of houses as it shown in the table below,

Table 1 Houses division into sectors

Houses	Sectors
1 – 12	01
13 – 20	02
21 – 33	03
34 – 40	04
41 – 51	05
52 – 60	06

Each house is equipped with different appliances (TV, Washer, Dryer, Iron, Fridge, Microwave, Computer, Heater)

3-3-1 At the appliance level

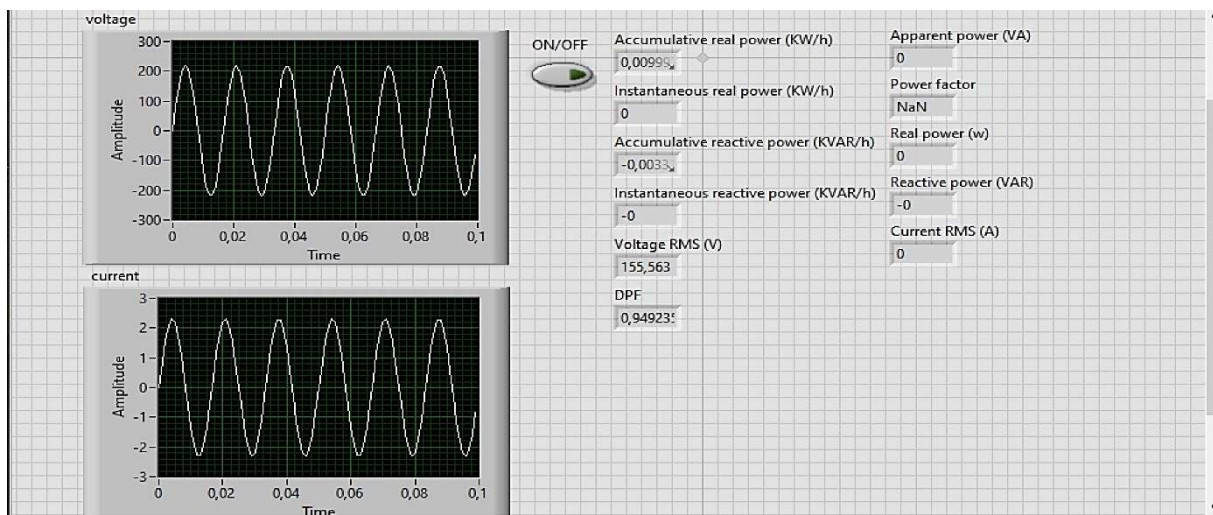


Figure 3- 1front panel of TV appliance

(Figure 3-1) shows the appliance's ON/OFF switch and both voltage and current waveforms, numeric indicators of its RMS values, power factor, accumulative and

instantaneous real and reactive power, apparent power, and displacement power factor. With taking accumulative and instantaneous real power, current RMS, apparent power, real power as outputs to be treated on the house level.

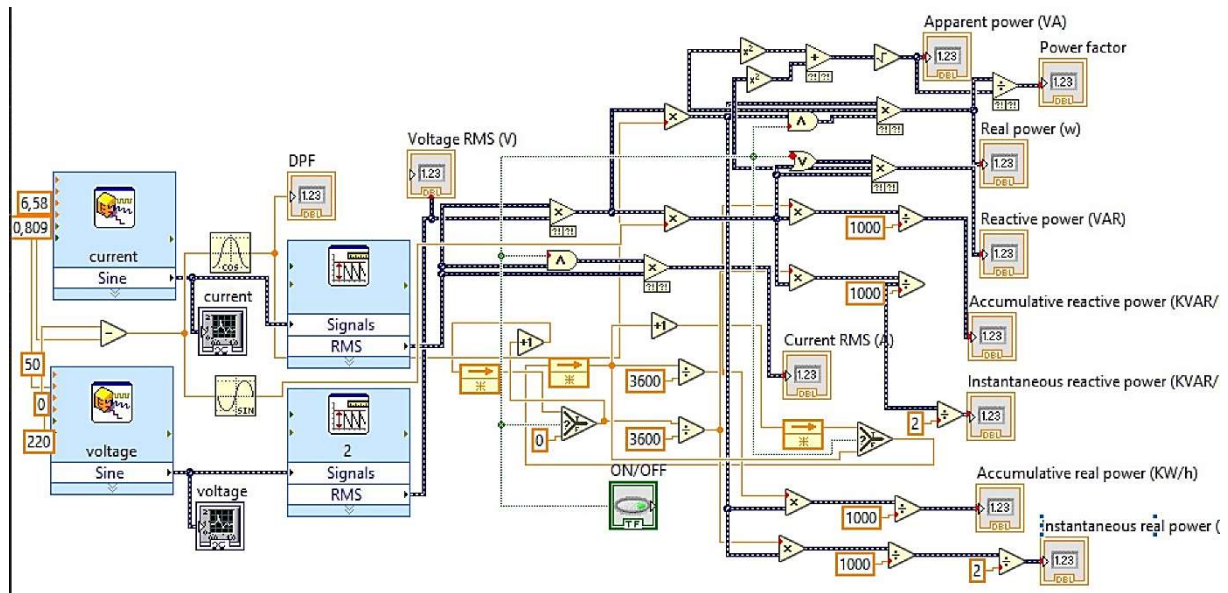


Figure 3- 2 Block Diagram of TV Appliance

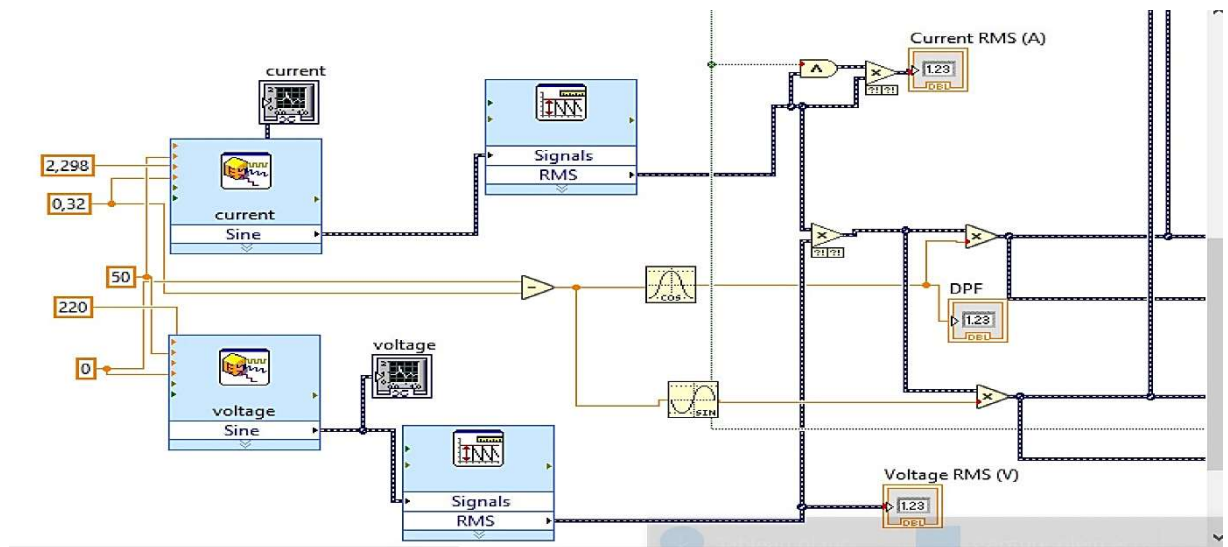


Figure 3- 3 Voltage and Current Generation

Voltage and current waveforms generated with amplitude and phase calculated from power factor consumption, having the voltage as a fixed value of 220 V, a phase of 0 rad, and a frequency of 50 Hz to mimic the Algerian criteria. As for the current, it is deduced from the power consumption factor and the power factor listed in table 2.

Table 2 List of appliances estimated Watts [42]

Common Appliances	Estimated Watts
TV 42" Plasma	240
Washing Machine	500-1000
HairDryer	1000-1875
ClothesIron	1000-1500
Refrigerator	500-750
Microwave	1000-2000
Laptop Computer	20-75
Space Heater	750 / 1500

Table 3: Power Consumption Factor calculation with Power Factor [40][41]

Appliance	Current Amplitude (A)	Power Factor	Phase (rad)	Power Consumption Factor (W)
TV	2.298	0.949	0.320	240
Washer	6.58	0.69	0.809	500
Dryer	10.909	1	0	1200
Iron	9.091	1	0	1000
Fridge	10.487	0.65	0.8629	750
Microwave	12.75	0.998	0.0632	1400
Computer	0.41	0.997	0.0787	45
Heater	6.818	1	0	750

Finding the current absorbed by each appliance using the estimated watts:

$$P = V_{rms} \cdot I_{rms} \cdot PF \quad (3.1)$$

By taking the voltage as 220v we get: $V_{rms} = 155v$

Example for TV: $I = \frac{P}{V_{rms} \cdot PF} \times \sqrt{2} = \frac{240}{155 \times 0.949} \times \sqrt{2} = 2,298 A$

After getting the RMS of current and voltage values from the generated signals, with the Displacement Power Factor (DPF) that is being the difference between voltage and current phases, then $\cos(\text{DPF})$ is multiplied with V_{rms} and I_{rms} in order to produce the real power consumption factor. Same operation is done for reactive power consumption factor except taking the DPF's sine instead of cosine.

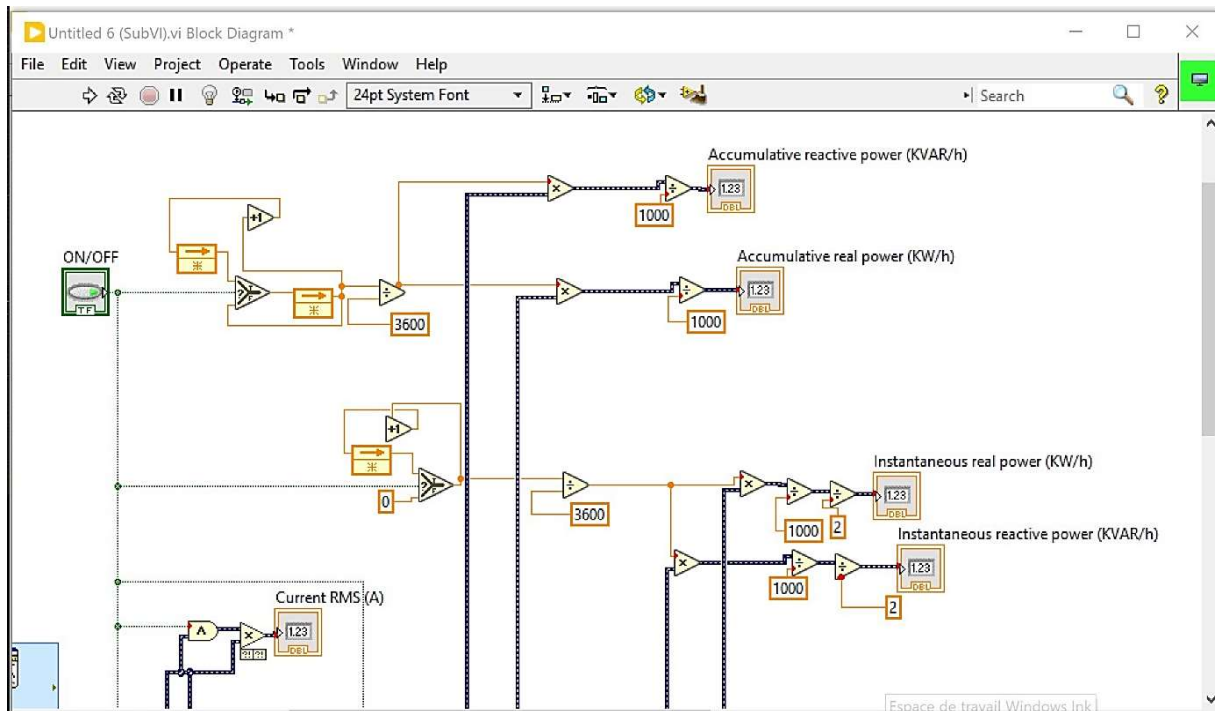


Figure 3- 4 Instantaneous and Accumulative Consumption Power Generation

Showing the code that calculates the consumed kWh and kVARh accumulatively and instantaneously through time, after converging into hours is done by multiplying the progressive outcome of the counters by the reactive and real power consumption factor then dividing the outcome by 1000 to get the energy in kW and kVAR.

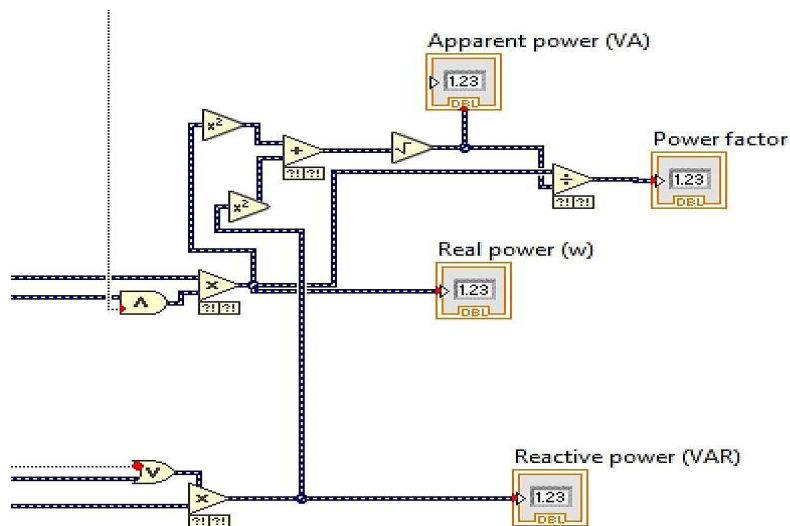


Figure 3- 5 Calculation of Power Factor

(Figure 3-5) shows how the power factor is achieved simply by dividing the real power by the apparent power that is found by taking the square root of the sum of real power squared and reactive squared.

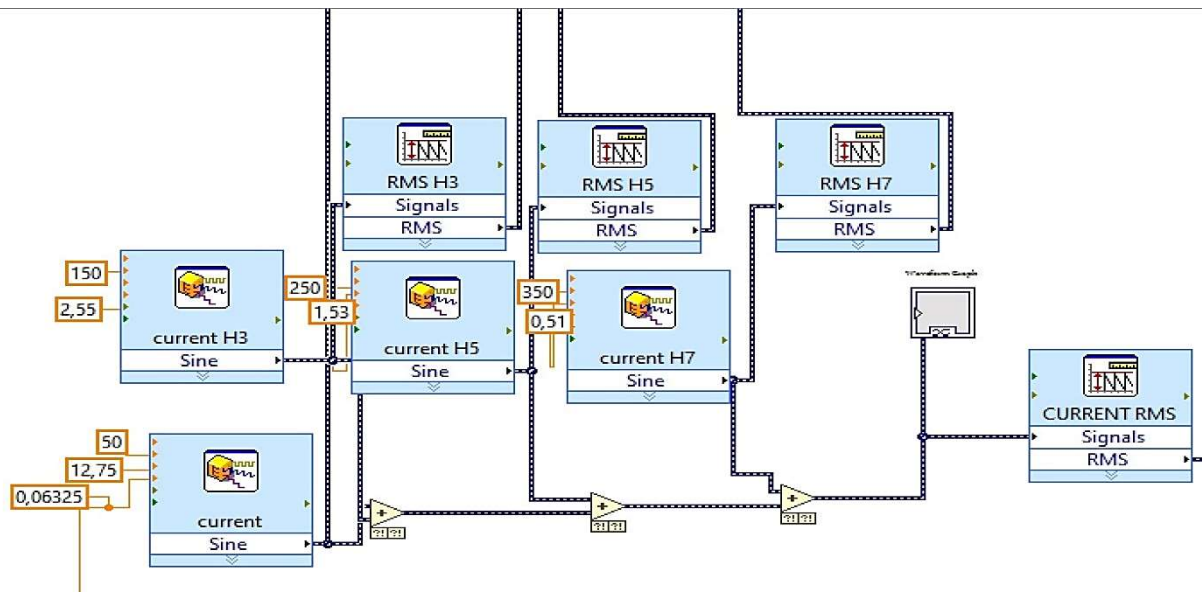


Figure 3- 6 Added Harmonics

In the aim of programming the added harmonics, three block diagrams of signals have been added with frequency multiple of the fundamental frequency as shown in (Figure 3-6) to mimic the effect of the third, fifth, and seventh harmonics with eliminating the second, fourth and sixth because the even harmonics do not occur in electrical grid due to symmetry between positive half cycle and negative half cycle.

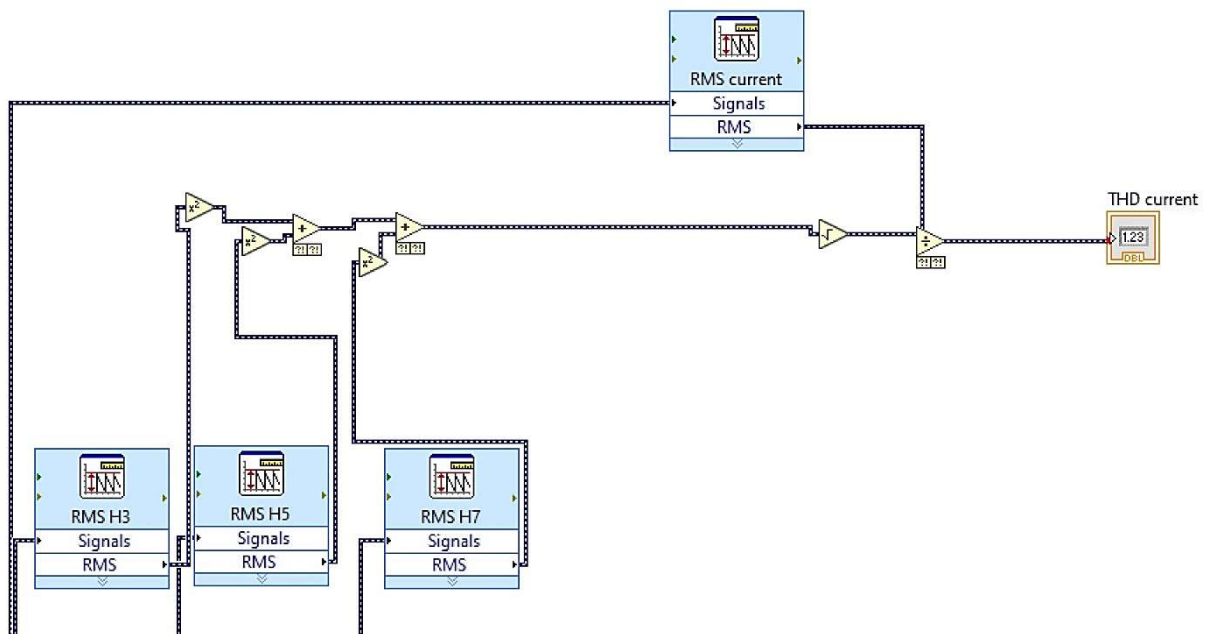


Figure 3- 7 Calculation of Total Harmonic Distortion

This block diagram manifests the calculation of the total harmonic distortion (THD) by the ratio of the square root of the sum of the square RMS values of the current harmonic signals, to the RMS value of the fundamental current signal.

3.3.2 At the house level

Figure 3-8 shows the appliance's ON/OFF switches grouped in one cluster.

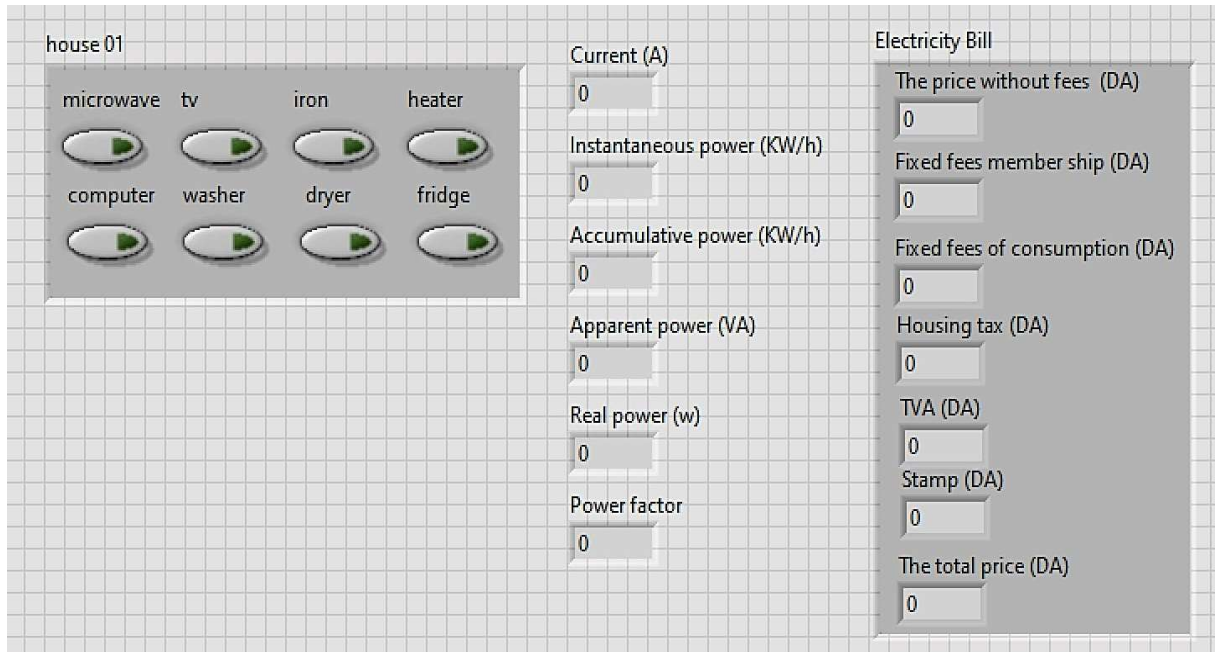


Figure 3- 8 Front Panel of House 01

Electricity bill that demonstrate the different fees, the price without fees and the total price, also the house parameters outcomes such as: current, instantaneous power, accumulative power, apparent power, real power ending with the power factor.

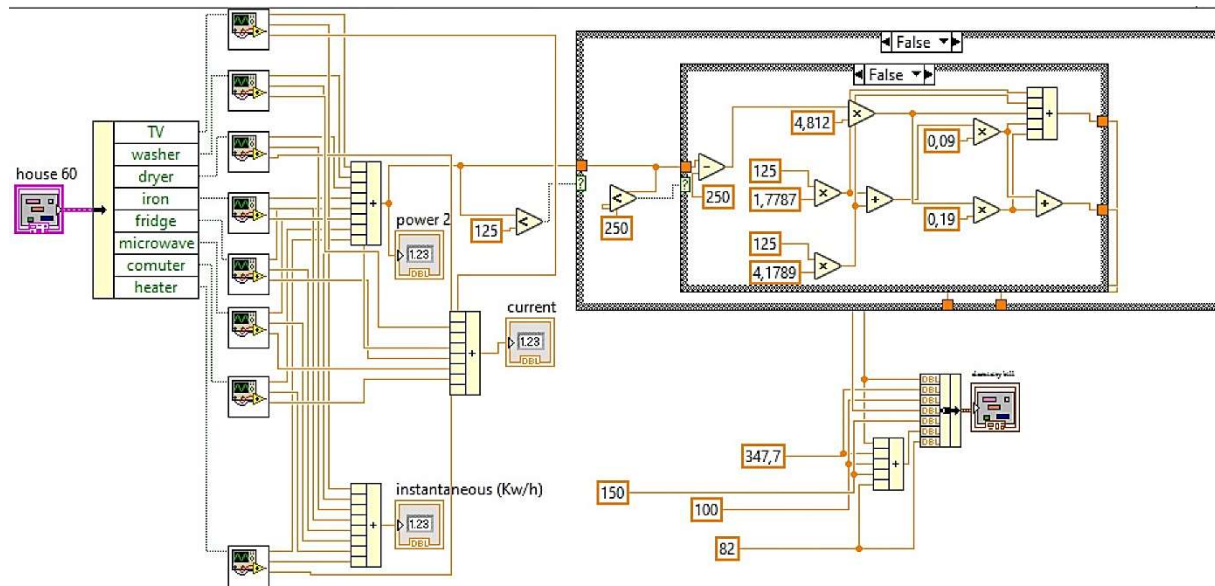


Figure 3- 9 House Block Diagram

The previous block diagram represents 8 sub VIs that simulates the 8 house appliances, each with its own ON/OFF switch button where all the buttons are grouped in one cluster to facilitate the control of the simulation, the kWh consumed instantaneously and accumulatively, the current, apparent power and real power of the all 8 appliances outputs are added to result the total instantaneous power ,the total accumulative power ,the total current, the total real power and the total apparent power, then the resultant total real power is divided over the total apparent power in order to get the power factor.

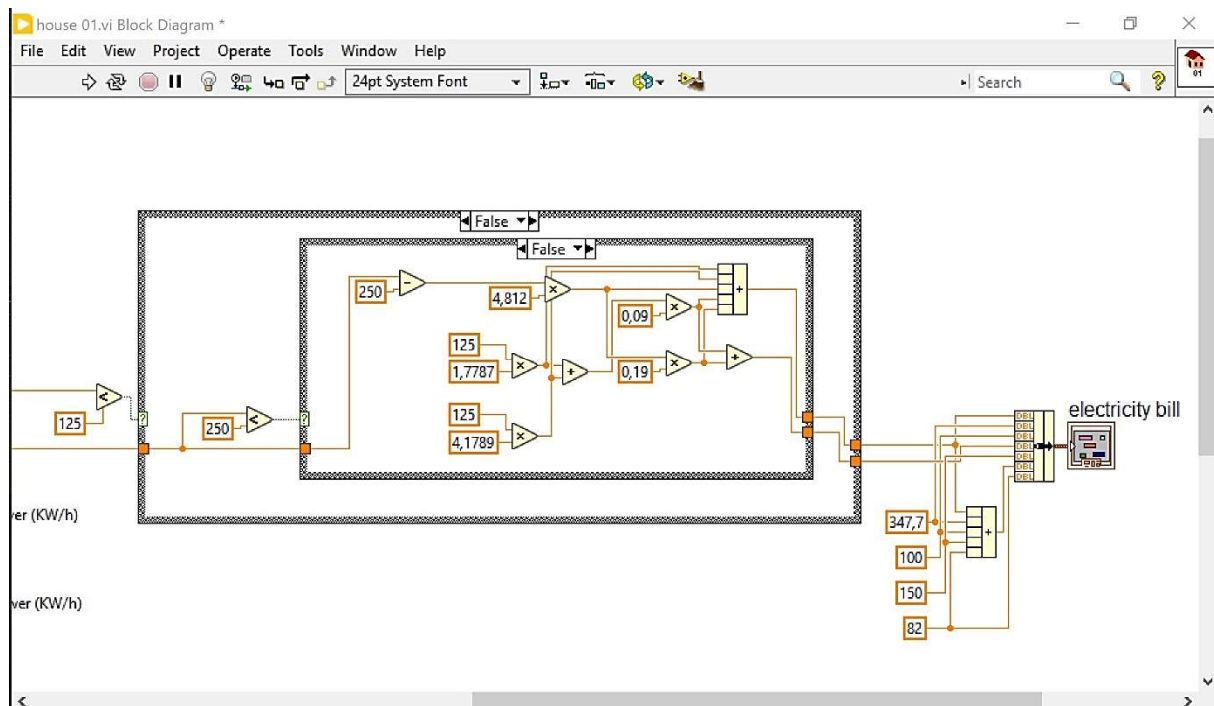


Figure 3- 10Code of Electricity Bill

This figure demonstrate a code that provides Sonelgaz pricing policy and billing tariffs with all the fees and tranches system.

3-3-2-a) Sonelgaz Pricing

First, starting with consumed energy in a trimester, where it is the difference between the new and old energy index, then multiplied by a coefficient to find the consumption in kWh.

Next, is calculating the price of the used energy through dividing it into 4 tranches, tranches are used for enticing the consumers to use less energy and not waste it.

Each tranche with its own pricing, the first tranche is for the first 125 kWh with a price of 1.7787 DA/kWh excluding tax, then for the next 125 kWh the price increases to 4.1789 DA/kWh excluding tax also, third tranche is 4.8120 DA/kWh up to 1000 kWh, and the fourth is 5,4796DA for every kWh beyond 1000kWh.

The first two tranches are summed then adding a 9% tax, where a 19% tax is added to the sum of third and fourth tranche, there is also a fixed value to be paid of 78.66 DA plus a 9% tax added to it, the total electricity price is the sum of all previous values, now we add a fixed right payment of 100DA and 150DA for habilitation to get the total price to be paid[44].

The kWh price is characterized by different tariffs. Where a tariff for consumption per quarter was used.

There are three tariff periods, designated for commercial, agriculture, and industrial establishments.

Table 4:Tariff Periods in Algeria

Period	Schedule
Off-peak hours	10:30 pm -6 am
Full Hours	6 am – 5pm and 9 pm-10:30pm
Peak Hours	5pm-9pm

In this tariff the pricing is time-dependent where the peak hours are with the highest price of 8.1147 DA/kWh followed by full hours pricing with 2.1645 DA/kWh and ending with off-peak hours enticing price of 1.2050DA/kWh[43].

In order to generate voltage swell and sag problems, a numeric control is connected to all the voltage signals of the 8 appliances and changed according to the voltage issue that meant to be mimicked as shown in the figure below.

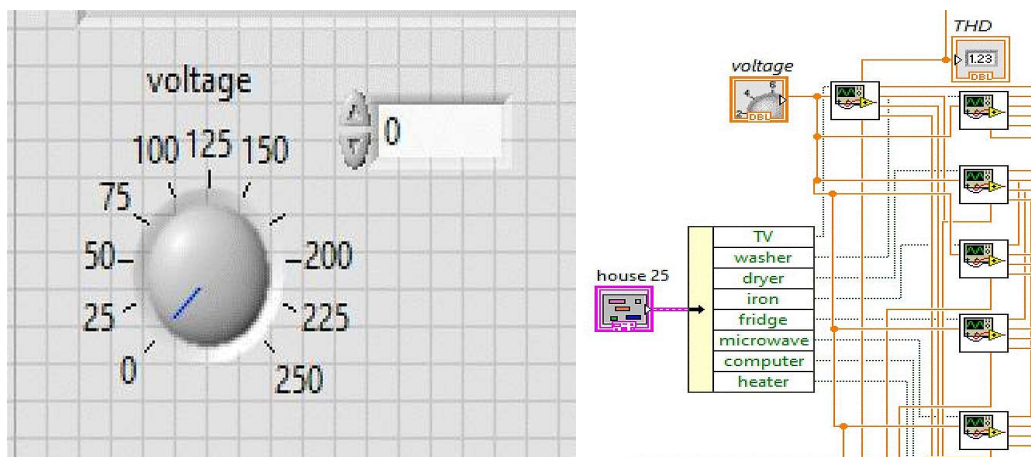


Figure 3- 11 Voltage Control Front Panel and Block Diagram

3.3.3 At the Residential Area level



Figure 3- 12 Front Panel of Residential Area

The figure above represents the front panel of the Residential Area that is composed of six sectors with each sector provided by:

Two clusters: one that contains current and accumulative power numeric indicators of each house that is a part of the sector. The second that contain all the ON/OFF buttons of appliances of each house in the sector.

Three graphs for each sector with digital visual indicator: the total accumulative power consumption, the total instantaneous power consumption, and the total current of the sector.

A numeric indicator to provide the amount of money that the consumer is paying for the electrical company supplier for each sector and for the entire residential area.

In addition a graph with digital indicator of the sum of currents and instantaneous consumption power of all the six sectors.

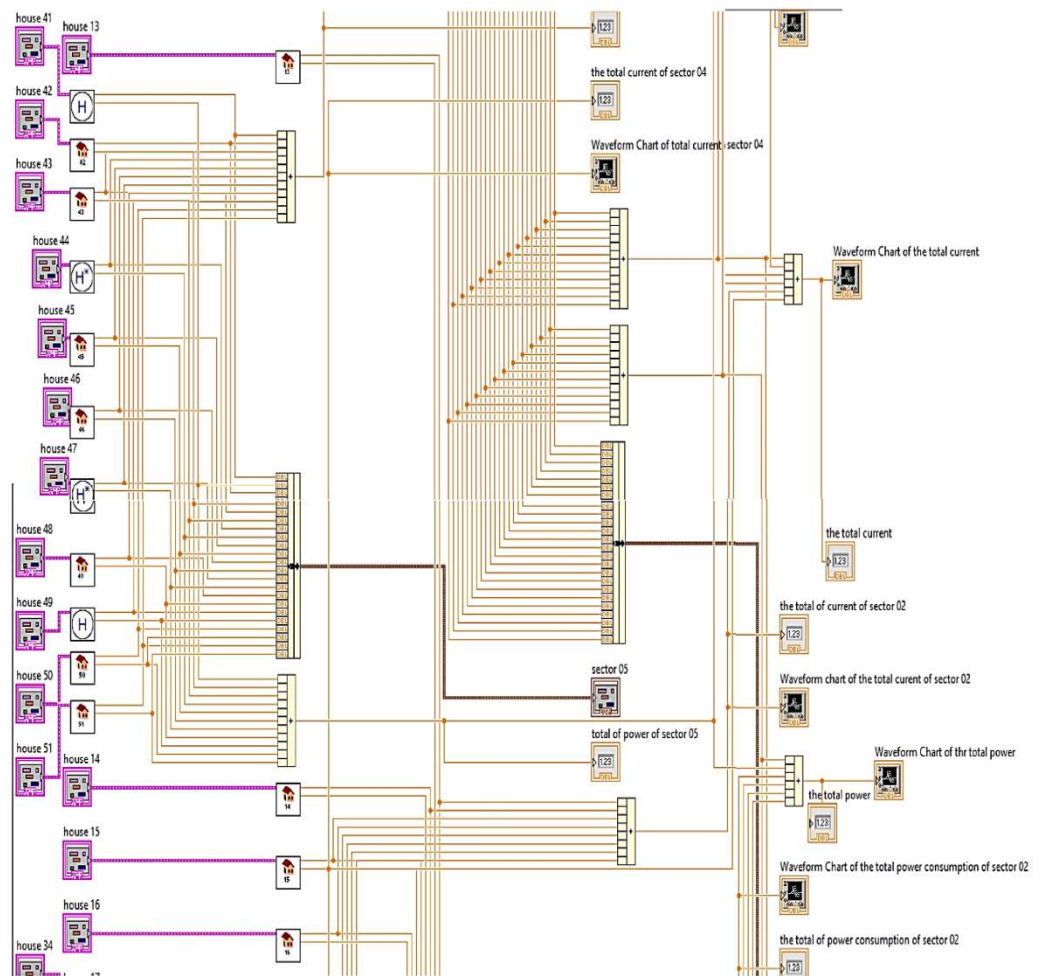


Figure 3- 13 Block Diagram of Residential Area

This block diagram represents sub VIs that correspond to the houses, and each sub VI is connected to a cluster as an input in the goal of switching on or off appliances of the houses, and to numeric indicators attached with graphs icons of instantaneous consumption power, accumulative consumption power, RMS current and the total price as an output that are connected to four adders to produce the total RMS current, accumulative and instantaneous power consumption and the total price for each sector . In addition to the result of the adders are summed as well with the other results of the rest sectors in order to get the total RMS current, instantaneous power consumption and the total price of all the smart city, with the total results being graphed.

In order to spot the effect of power quality problems on the electrical grid and the consumers house, and by emphasizing on the consumers level, two parts are achieved in this

simulation, one with current and voltage problems, a second with a healthy grid with no issues effecting the system. With taking the same duration of simulation (one hour).

a) House without PQ problems



Figure 3- 14 Healthy House

The Figure shows a front panel of a healthy house consumption with a good power factor (above the permitted value of 0.9), no harmonics are detected and with stable voltage.

b) House with harmonics

The figure demonstrates front panel of house 02 with harmonics of total harmonic distortion (THD) reaches the value of 23,66% effecting both the current wave form that is showed below and the power factor that decreased from 0,9053 to 0,881. In addition the real power viewed in the house with harmonics is much greater than the one in the healthy house which leads to higher power consumption due to the slight increment in the RMS current.

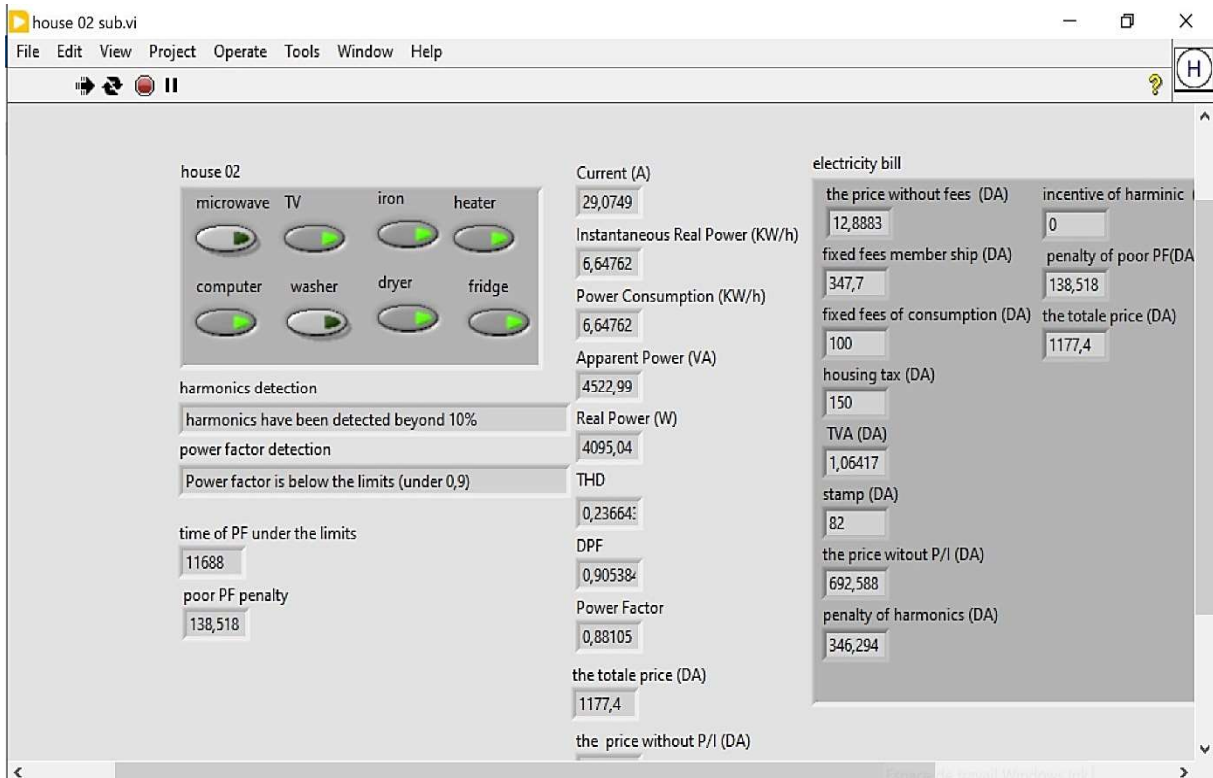


Figure 3- 15 Front Panel of House 02

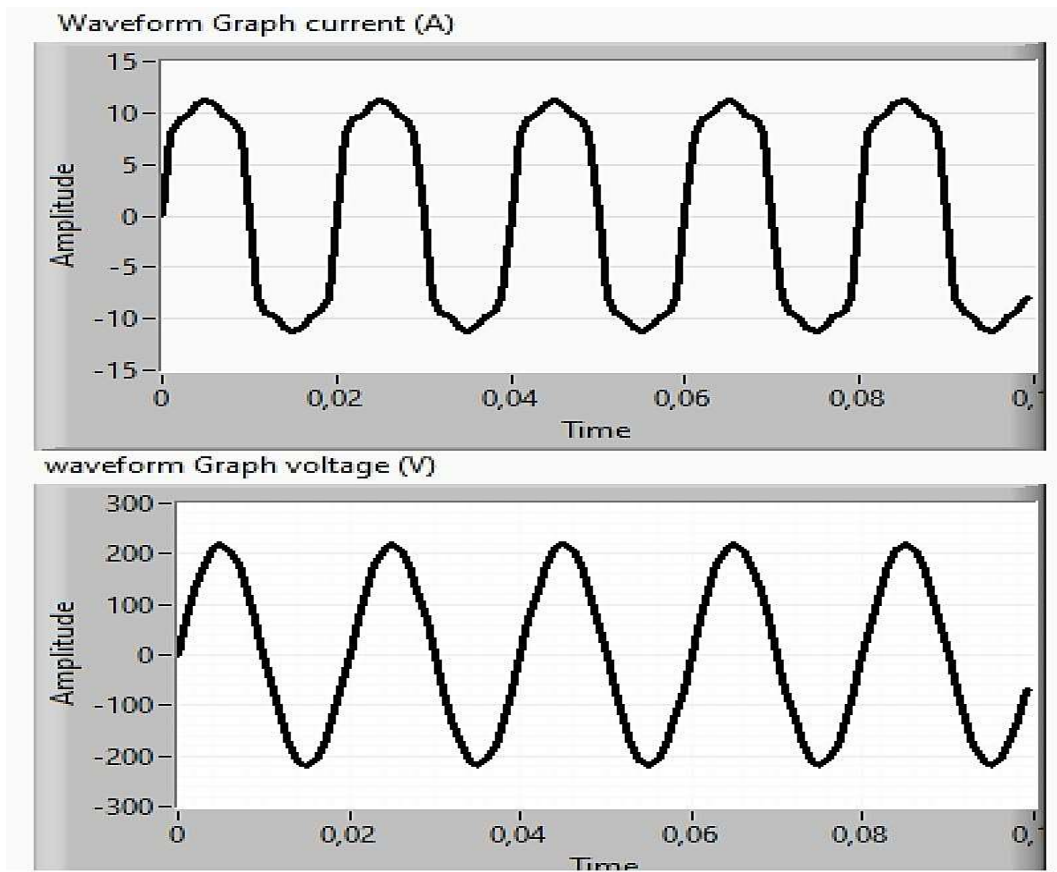


Figure 3- 16 Current and Voltage Graphs of House 02

c) House with poor power factor

Figures 3-17, 3-18, and 3-19 represent the changing in the power factor according to the combination of appliances that are switched ON.

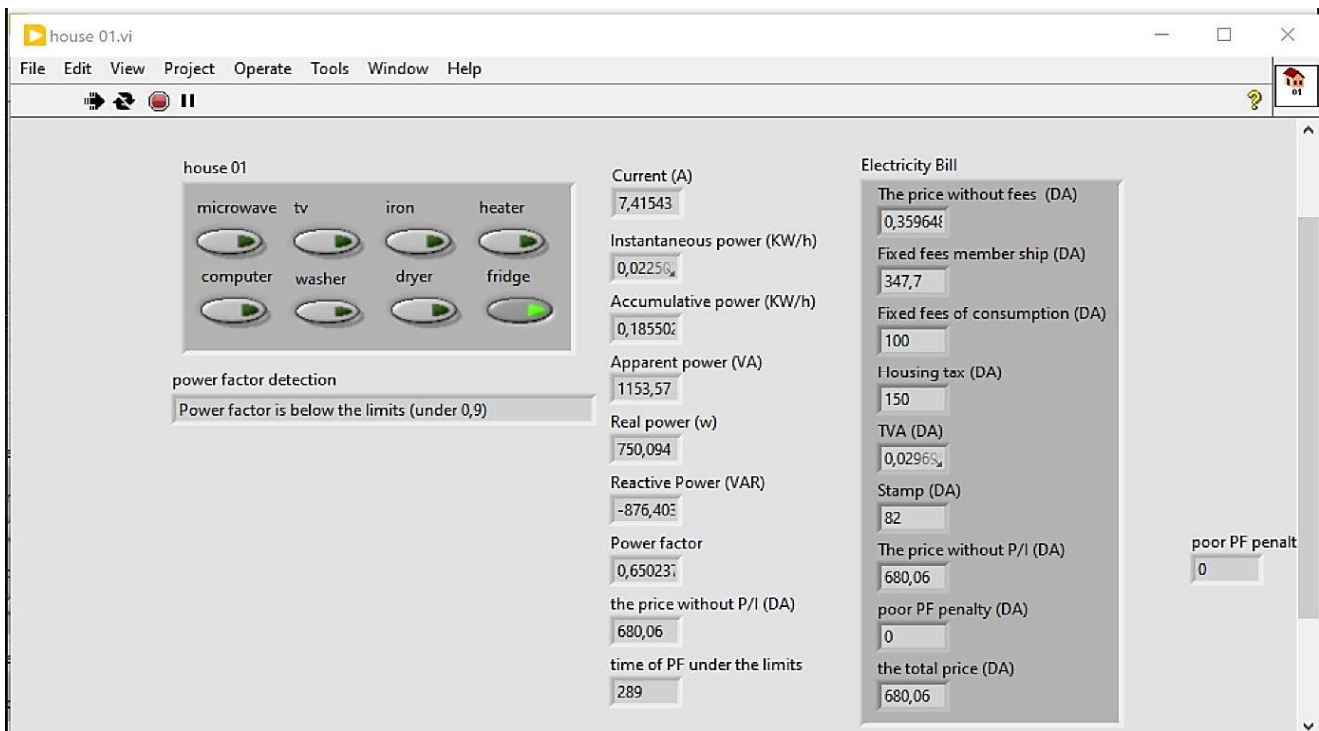


Figure 3- 17 Front Panel of House 01 with Power Factor 0,65

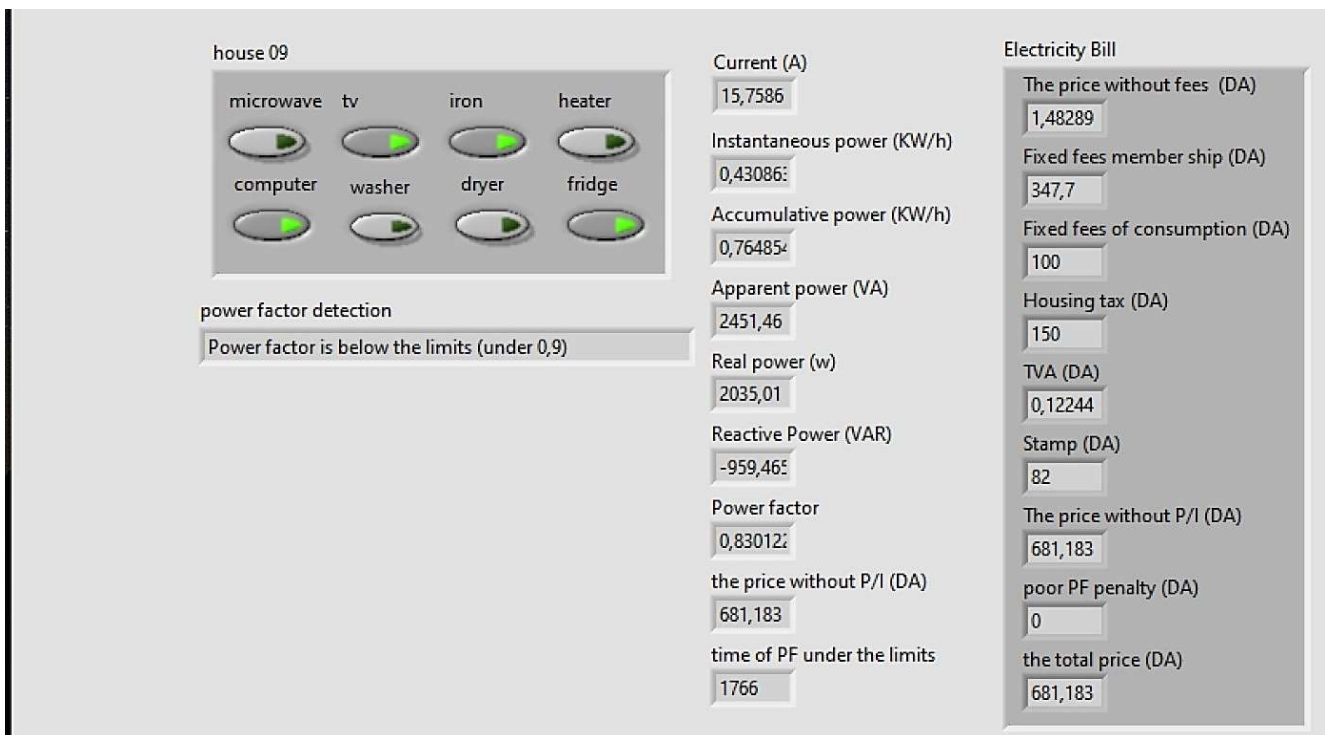


Figure 3- 18 Front Panel of House 01 with Power Factor of 0,83



Figure 3- 19 Front Panel of House 01 with Power Factor of 0,901 at the End of Simulation

It is noticed that when the power factor is far from 0,9 the greater is the value of reactive power, which indicates that the appliances are exploit considerable amount of reactive power.

d) House with voltage swell

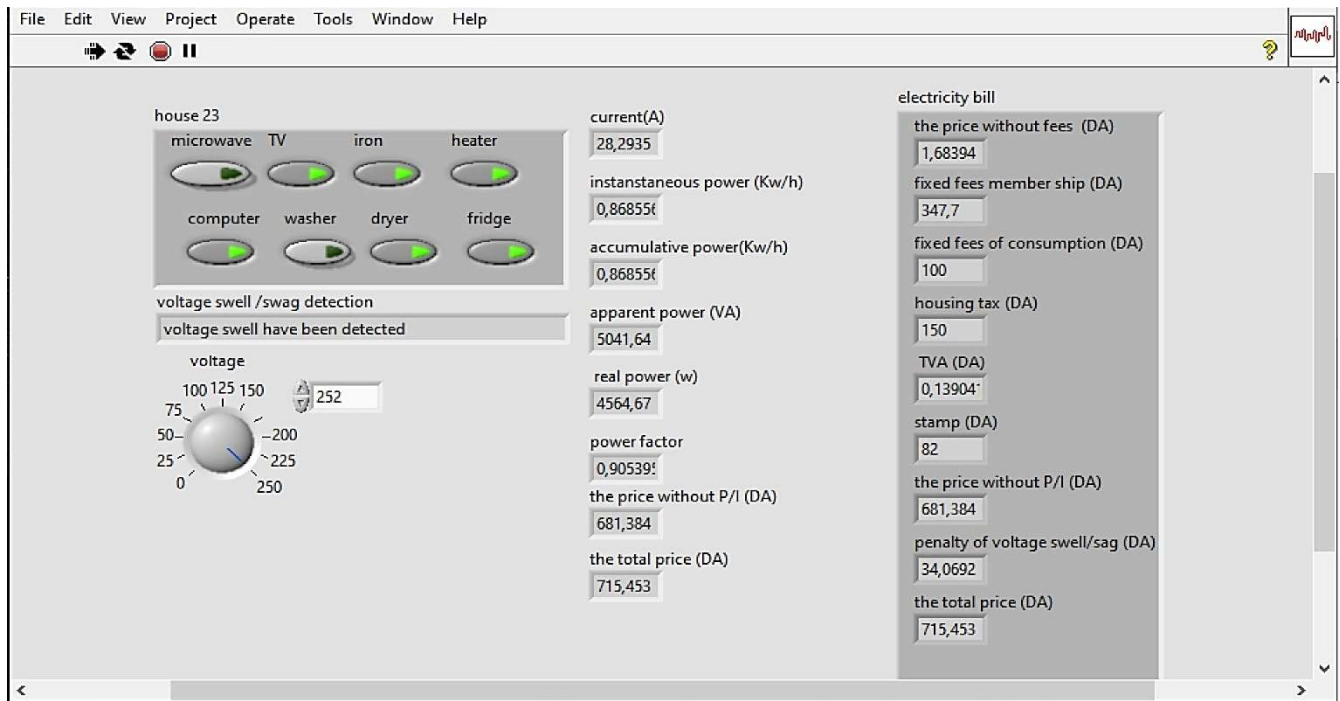


Figure 3- 20 Front Panel of House 23 with Voltage 252

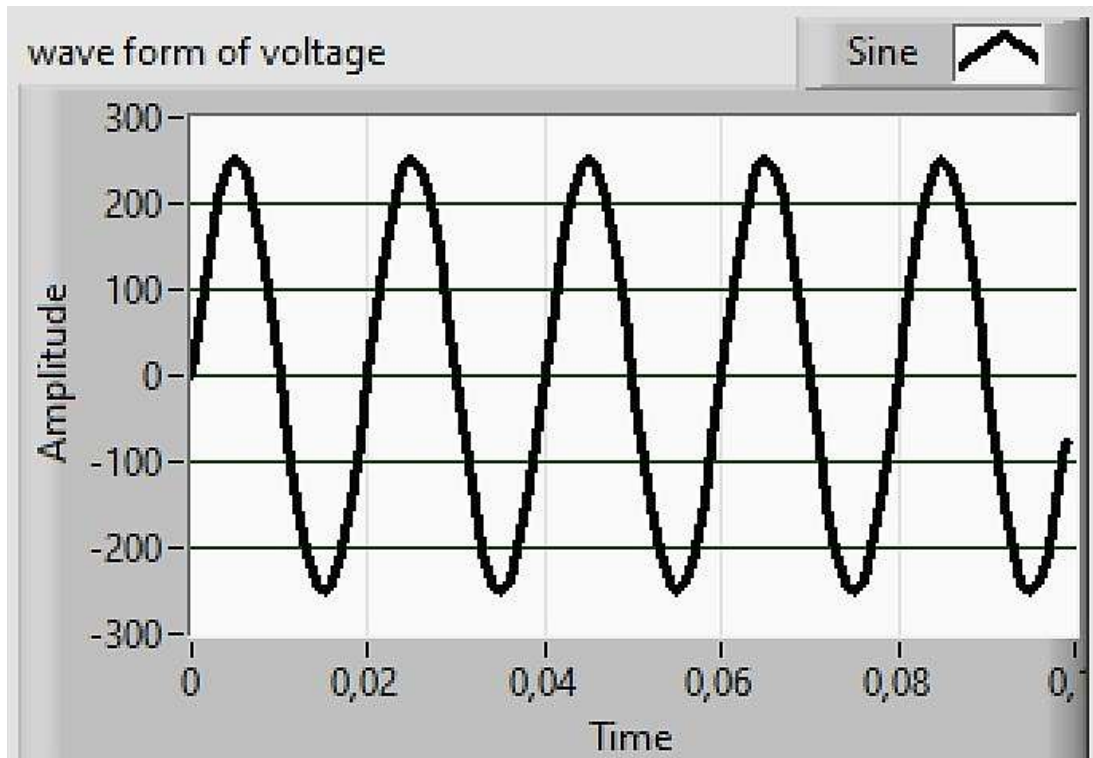


Figure 3- 21 Voltage Graph of House 23 with Voltage 252

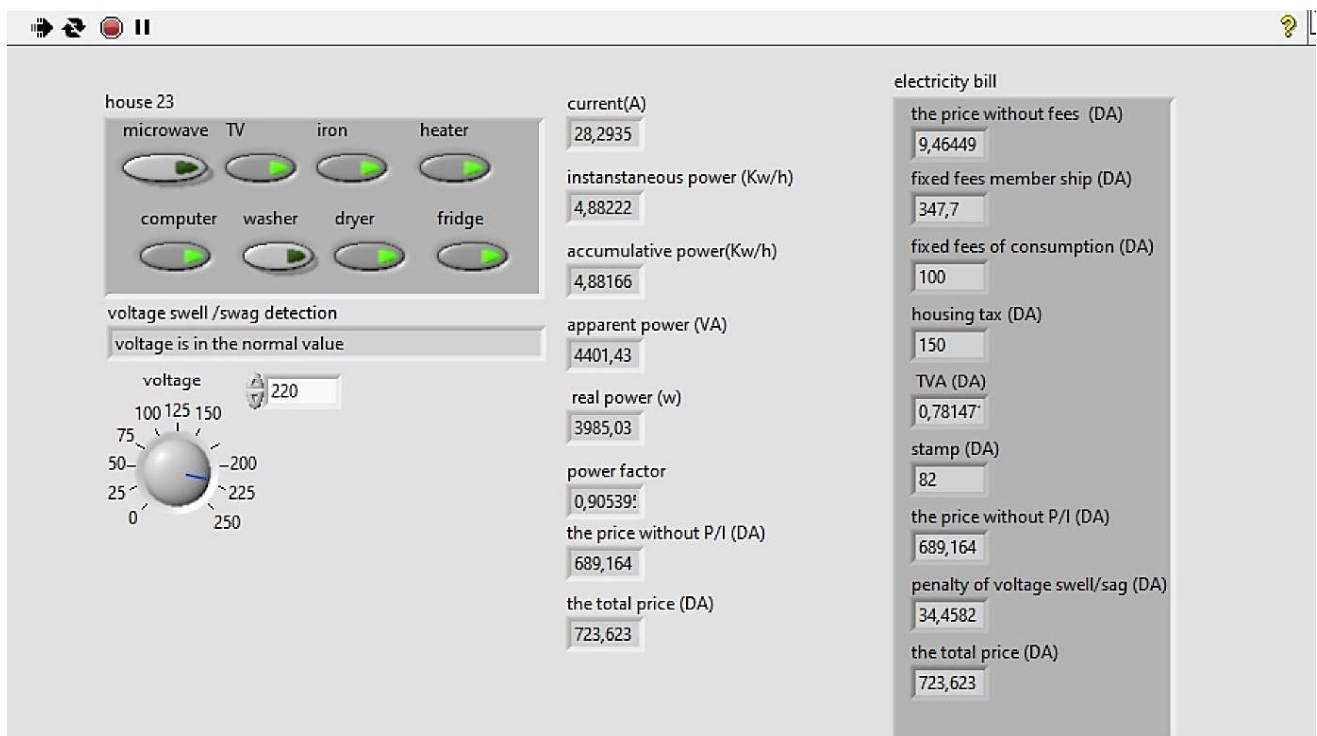


Figure 3- 22 Front Panel of House 23 at the End of Simulation

The previous (figure 3-22) shows a house that is exposed to certain number (5 times) of voltage swells.

Along the period of simulation. A raise in the accumulative power and real power has been observed compare to the ones of the healthy house due to the short duration increase in the voltage level.

e) House with voltage sag

This (figure 3-23) presents a house that is incurred to voltage sag for 5 times where the time between each voltage sag is randomly chosen. A decrement has been notified in the both accumulative power and the real power compared to the values of the healthy house which can be explained by the diminution in the voltage value due to the voltage sag issue.

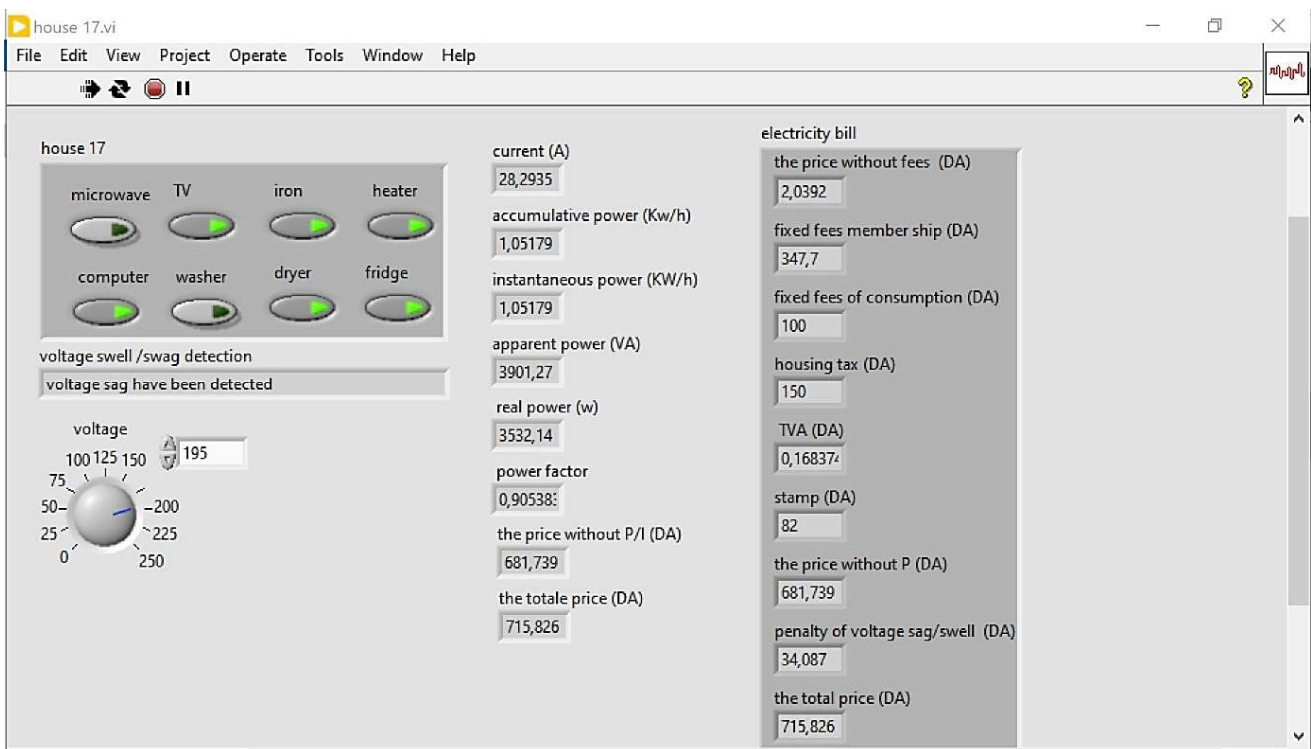


Figure 3- 23 Front Panel of House 17 with Voltage of 194

f) Voltage sag

These figures present a house that is incurred to voltage sag for 5 times where the time between each voltage sag is randomly chosen.

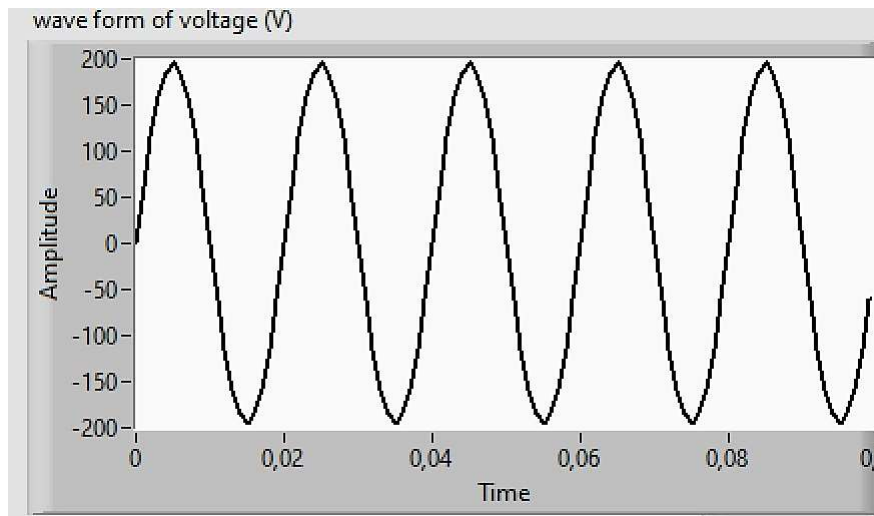


Figure 3- 24 Voltage Graph of House 17 with Voltage 195

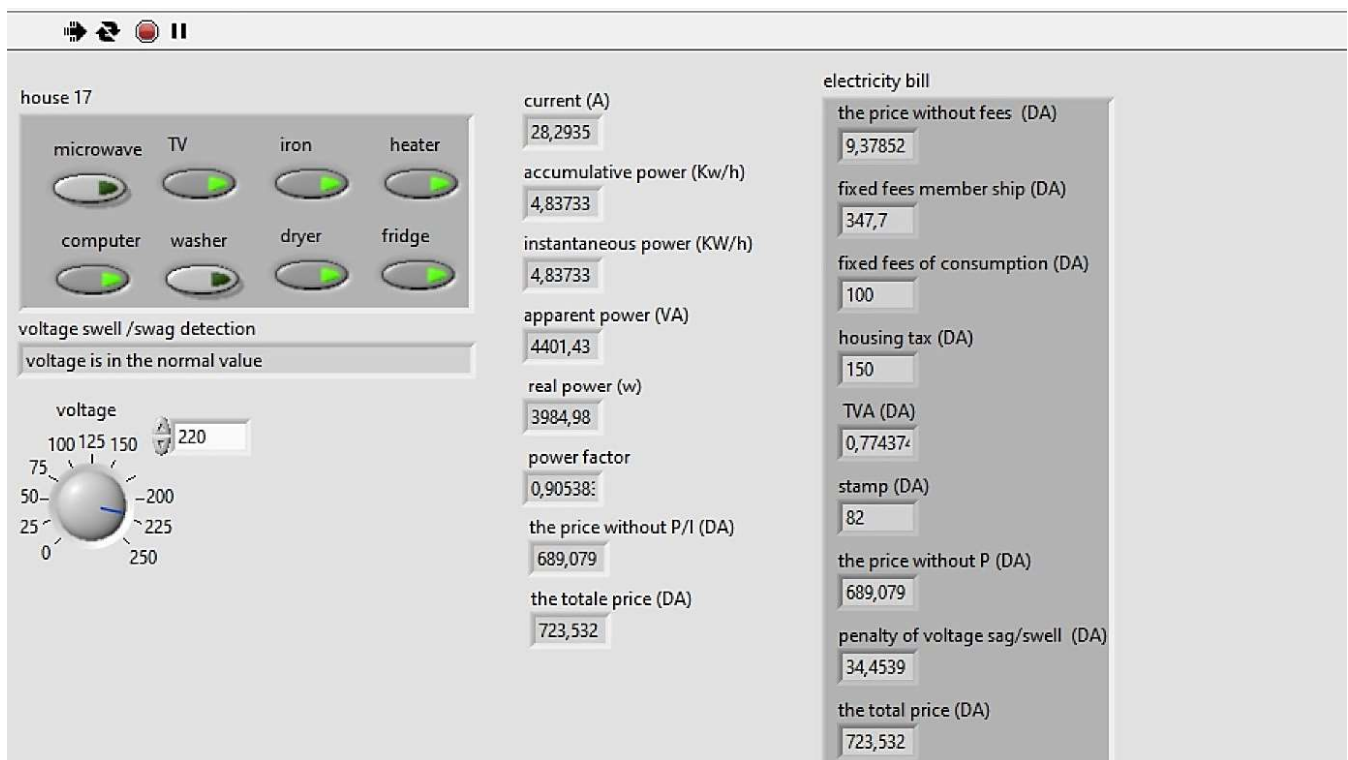


Figure 3- 25 Front Panel of House 17 with Voltage of 220 at the Ending of Simulation

A decrement has been notified in the both accumulative power and the real power compared to the values of the healthy house which can be explained by the diminution in the voltage value due to the voltage sag issue.

g) House with poor power factor, voltage sag, voltage swell and harmonics

These coming figures demonstrate house 44 that is exposed to all 4 power quality problems: harmonics, voltage, sag, voltage swell and poor power factor.

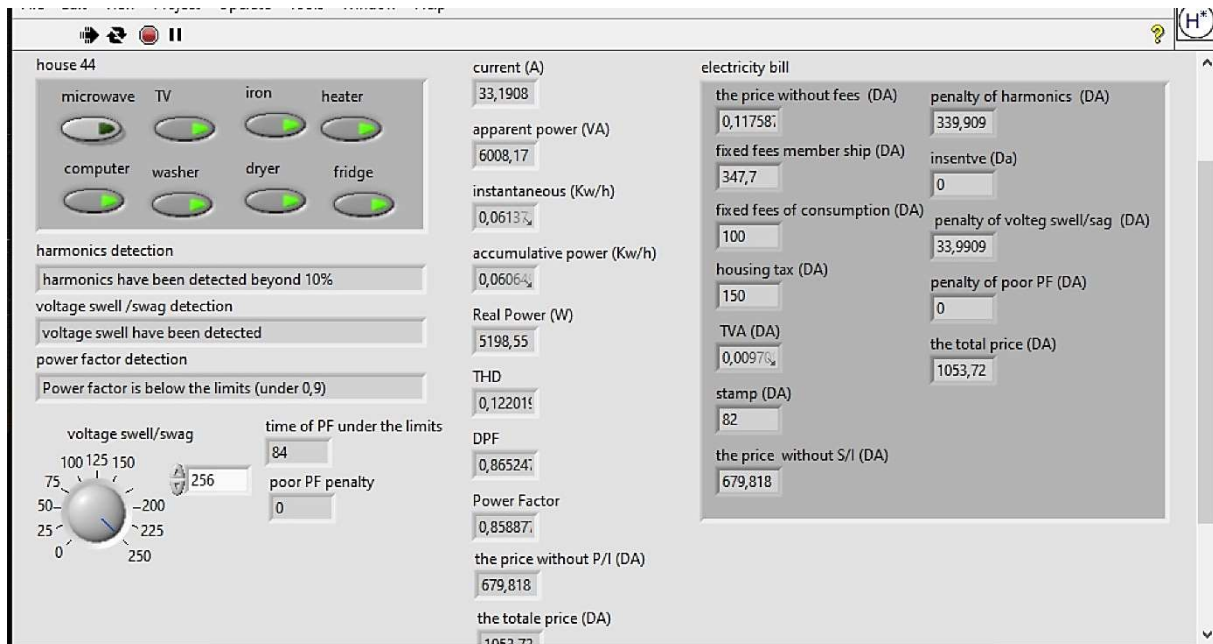


Figure 3- 26 Front Panel of House 44 with Voltage Swell of 256

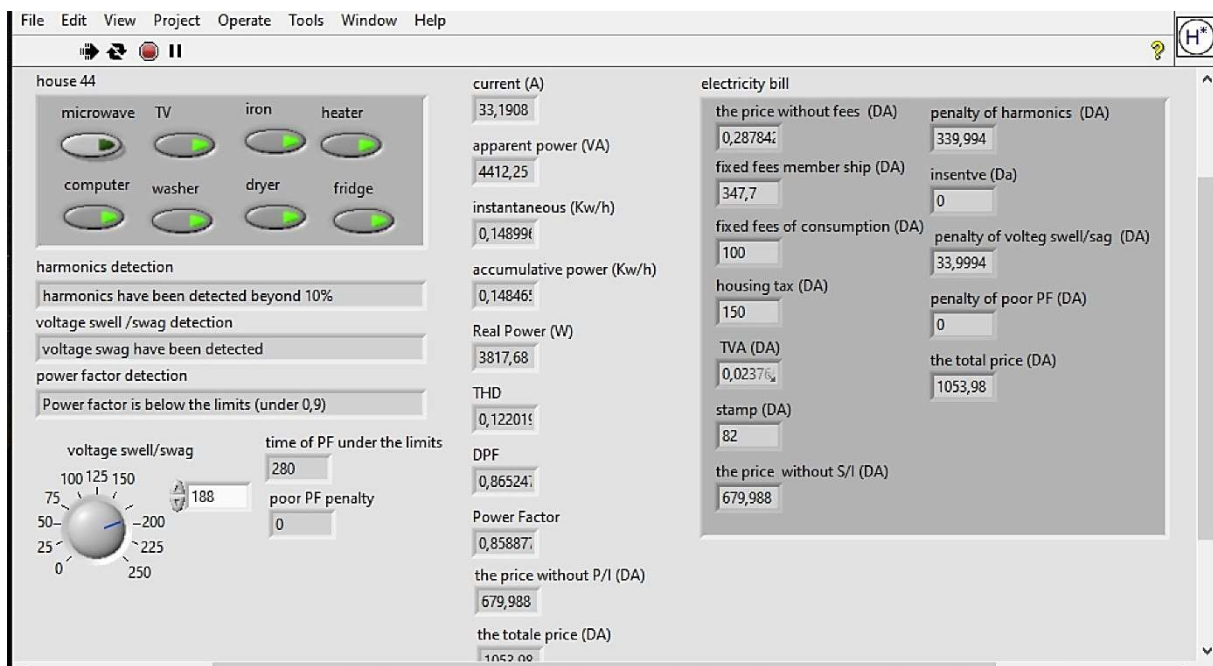


Figure 3- 27 Front Panel of House 44 with Voltage Sag of 188

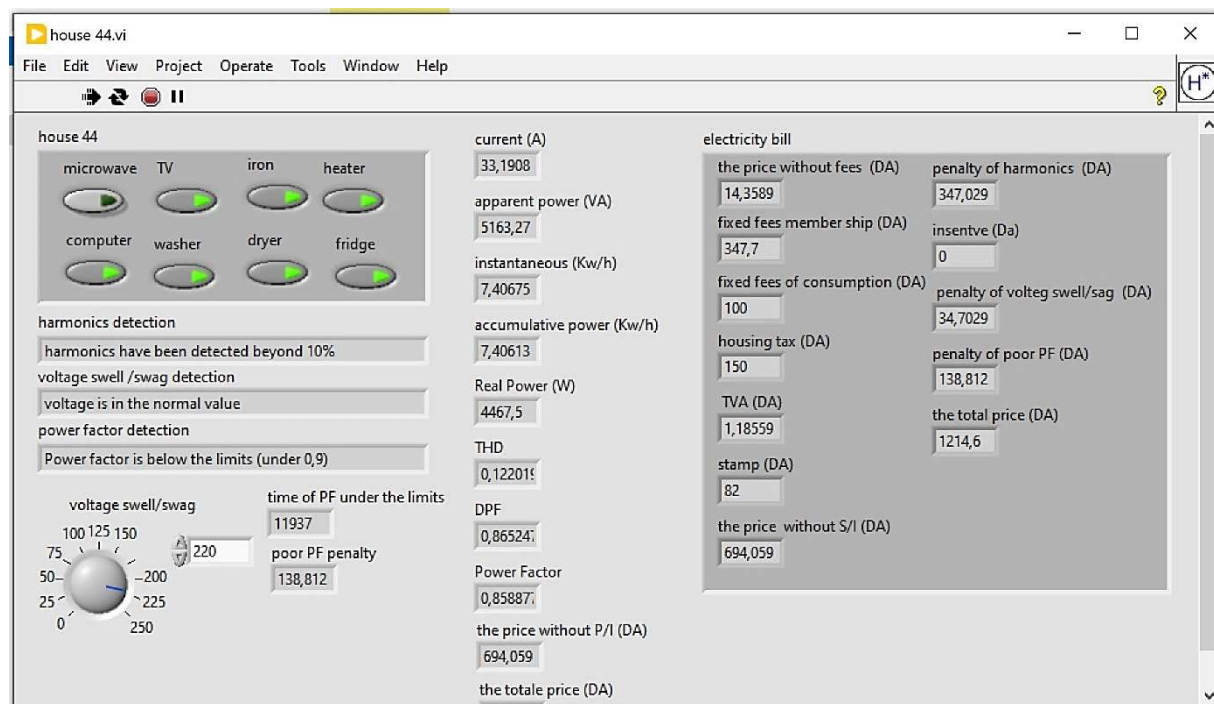


Figure 3- 28 Front Panel of House 44 at the Ending of Simulation

A great deal of real power is observed, it leads to a rise in the consumed accumulative power where it reaches the largest value in comparison to the other houses. After plenty of consideration and analysis, and with relying on the simulation results, a penalty and incentive pricing policy that is shown below has been deduced in the goal of stirring and stimulating electricity consumers to provide devices that correct and eliminates these harmful power quality issues alongside with regarding their consumption manners and change it to consumption ways that respect the criteria of healthy electric grid.

h) Penalty /incentive LabVIEW codes

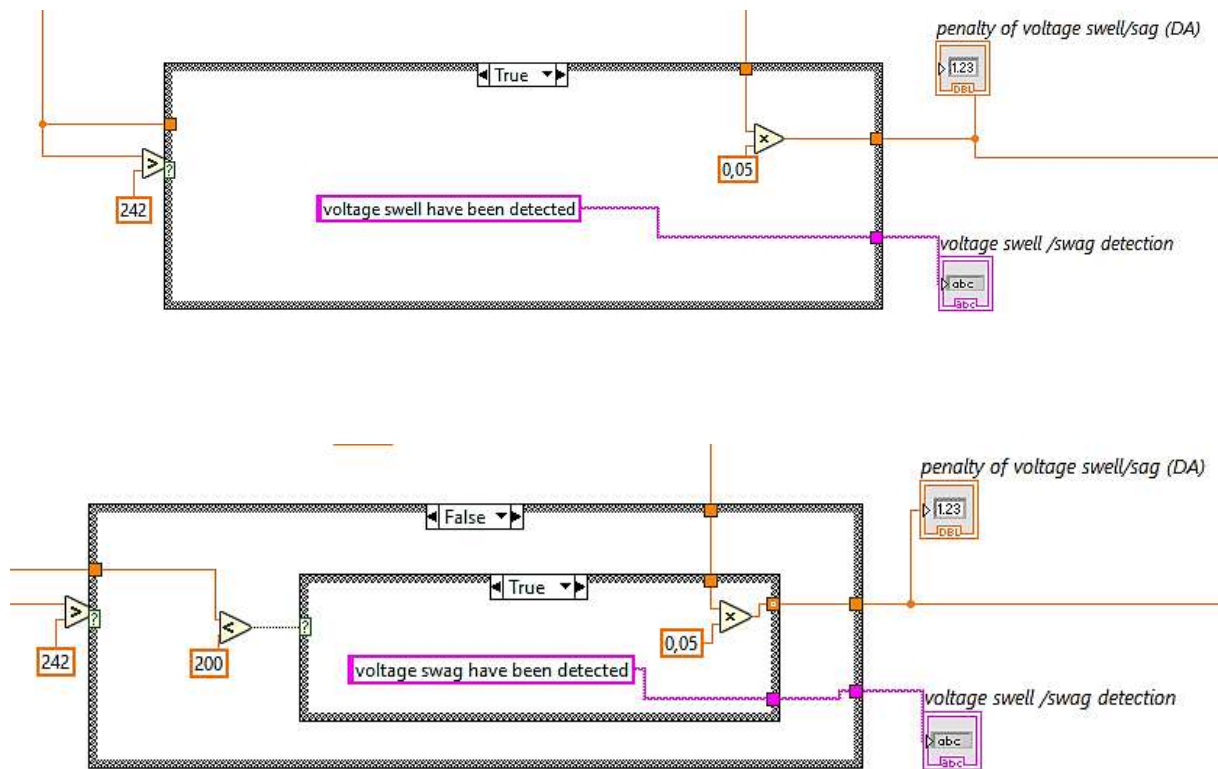


Figure 3- 30 Block Diagram of Voltage Swell/Sag Penalty

This figure shows case structure that integrates the penalty of 5% from the total bill, if the voltage is beyond the range of 10% than the nominal value of the voltage 220 V [200 V- 242V] [16].

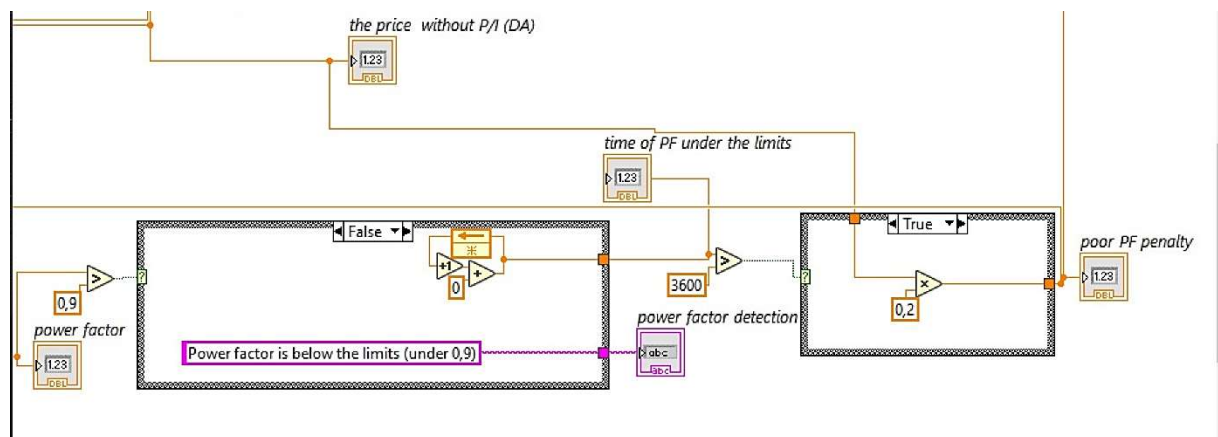


Figure 3- 31Block Diagram of Poor Power Factor Penalty

The figure above describes case structure that contains a counter, it increments if the power factor is under the primitive limit (0,9) [35]. Because the power factor can be changed according to the combination of appliances that is ON or OFF, applying a penalty of 20% from the total price can be triggered if the counter value exceeds 3600 which represents the time of PF under the limits, this value is chosen to fit the time of simulation.

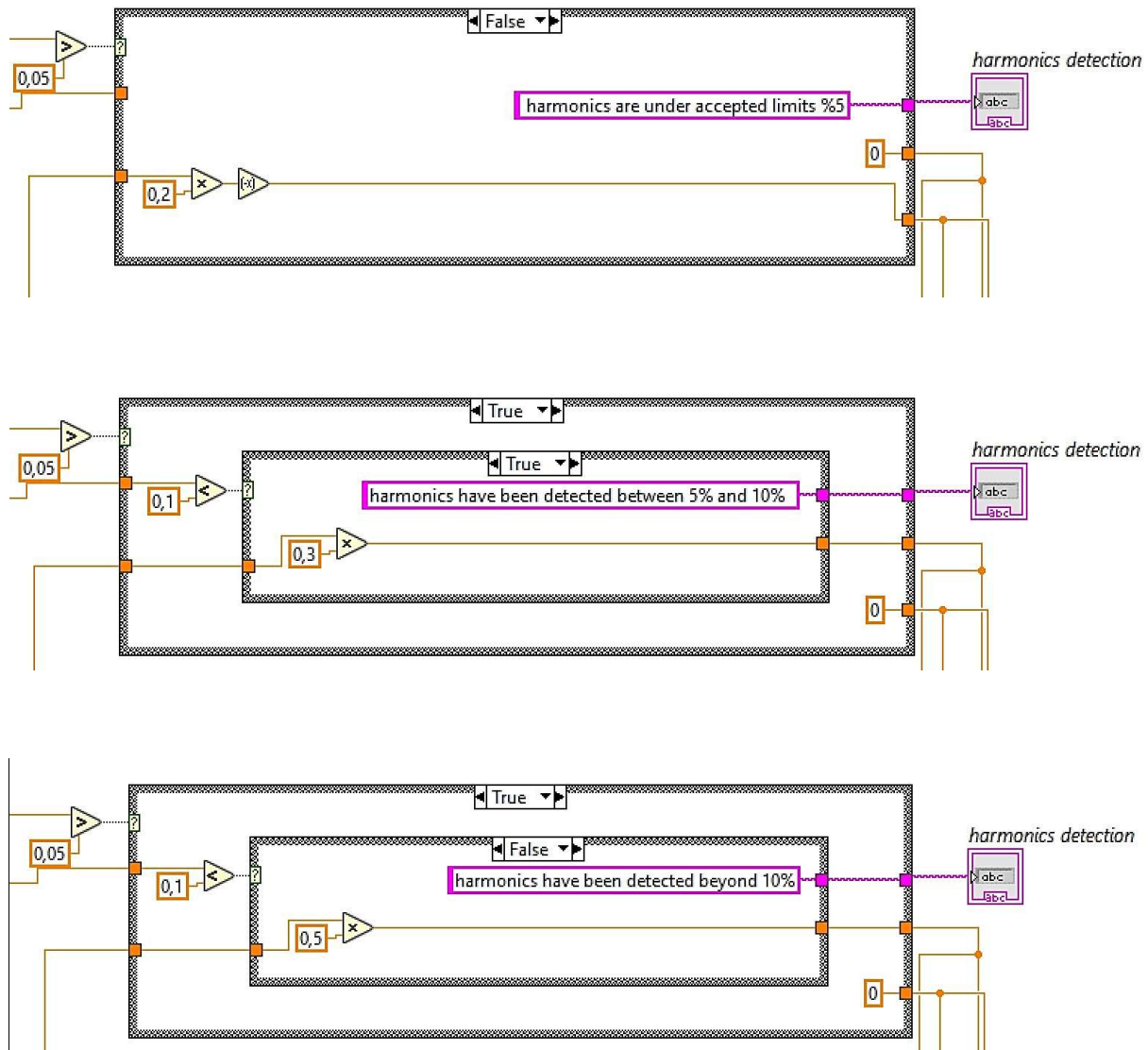


Figure 3- 32 Block Diagram of Harmonic Penalty/Incentive

The figure shown above demonstrates a case structure that generates an incentive of 20% from the total price, if the total harmonic distortion is less than the respectful value of 5% [35], and a 2 type of penalties ;one of 30% of the total price such that THD is inside the range of [5%- 10%], and another of 50% from the total price when the THD is above 10%.

i) Smart grid with power quality problems

This figure represent front panel of the Residential Area's electrical grid.

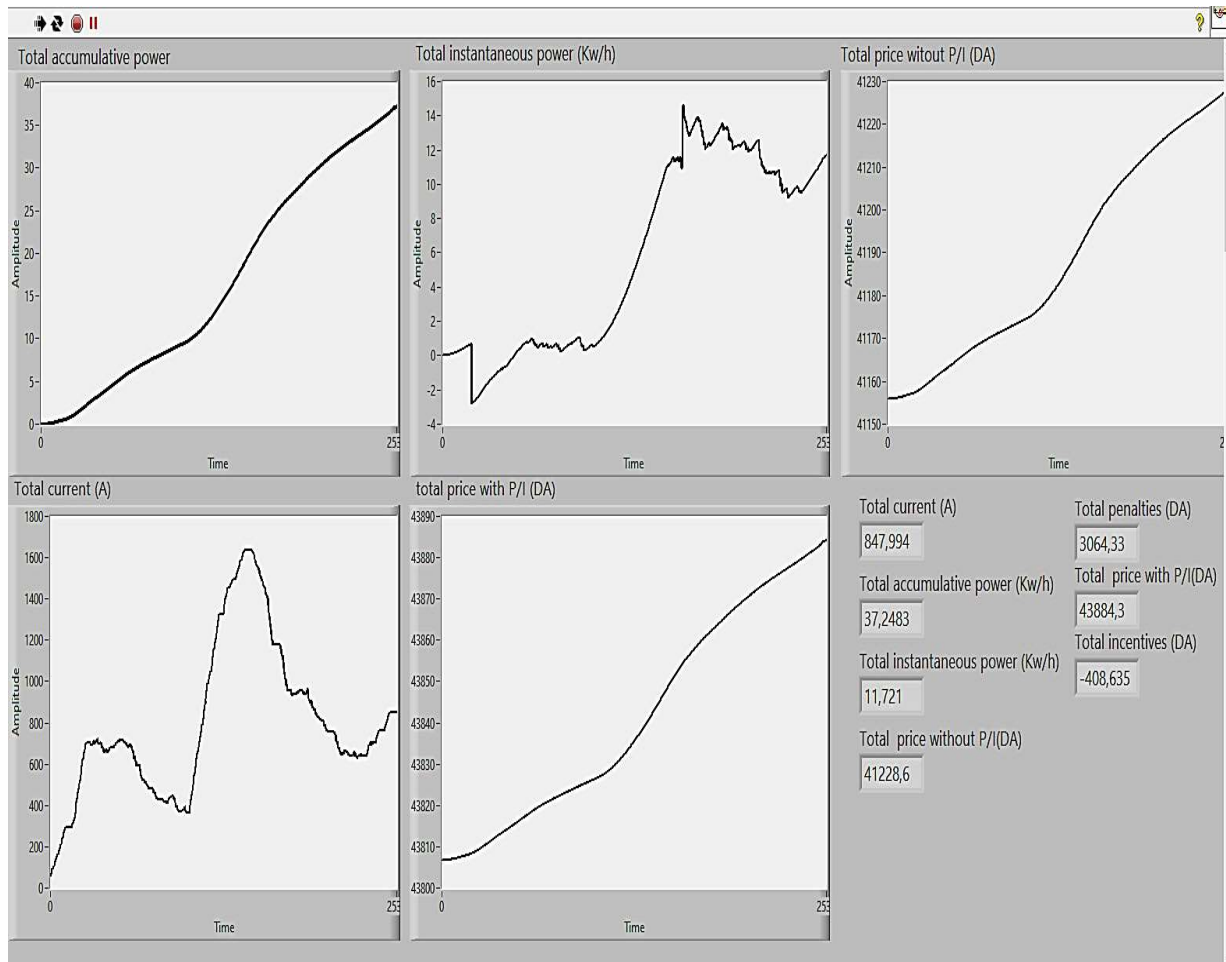


Figure 3- 33 Front Panel of Residential Area with Problems at the End of Simulation

It provides accumulative and instantaneous power consumption ,total current, total incentive prices, total penalties prices ,total price with penalty/incentive, and total price without penalty/incentive numeric indicators along with graphs , it is noticed that at the peak hours the total current reaches its greatest values which indicates that the demand on power has peaked due to the increase in the power consumption of the houses . In the end of the simulation it has been observed that the amount of accumulative power and the total price without incentive/penalty was significant which can be explained by the effect of power quality issues that raised the voltage and the current leading the power consumption to be magnified which means that the supplier is obliged to provide more power than the needed to fulfill the demand by investing more money to produce it, using the incentive and penalty pricing policy shows that more money is earned by the supplying enterprise which can be

used to cover the additional expenses of the additional power and entice the faulty consumers to correct their PQ issues .

j) Smart grid with correction of PQ problems

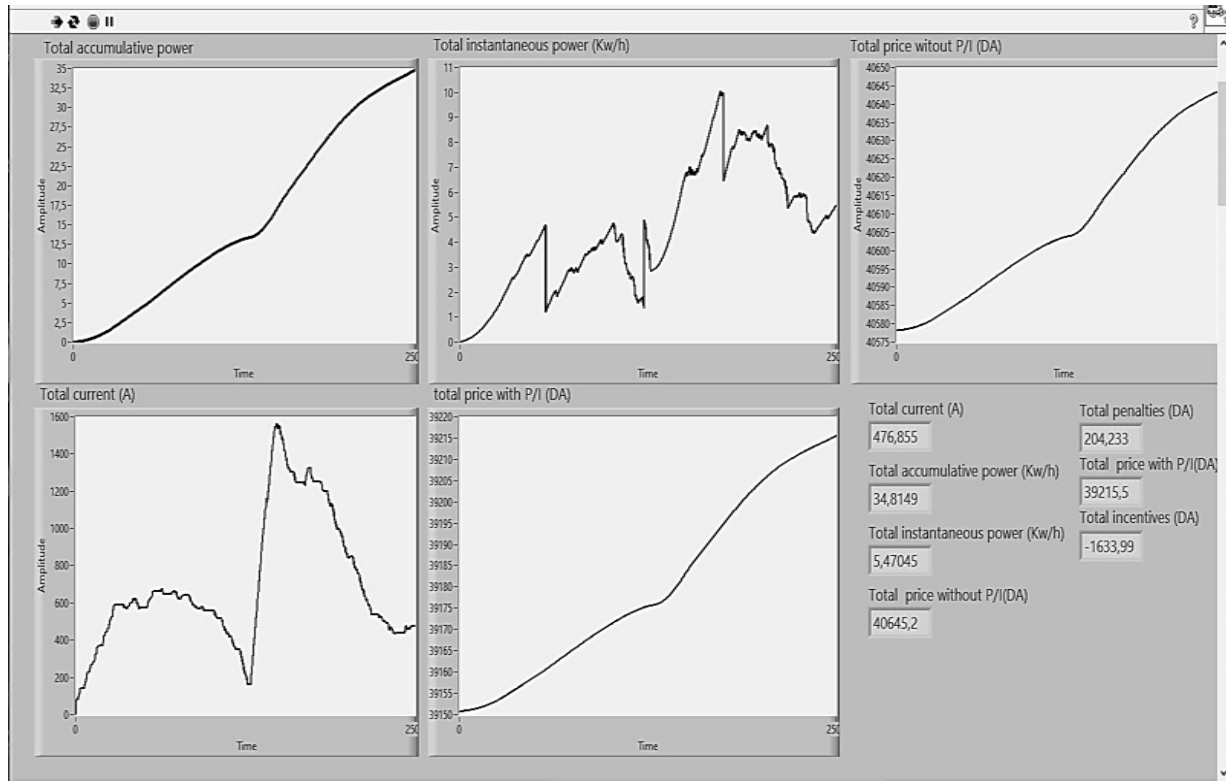


Figure 3- 34 Front Panel of Residential Area after PQ Problems Correction at the End of Simulation

These figures shows the front panel of smart grid after the correction of PQ problems, where the total penalties are insignificant and the incentives are considerable, indicating that a major number of houses have fixed their PQ problems. it seems that the peak power demand and the final accumulative power have lessen compared to the values of the system with the power quality problems due to the enhancement and the adjustment of the electrical system, which reduced the amount of additional power that is consumed by the PQ problems resulting a decrement in the amount of producing electricity financials. A slight difference is detected between the total price with incentive and penalty policy and without it referring that there exist no loss in an economical perspective.

3.4 Conclusion

This chapter presents a simulation of a smart area containing healthy houses, in other words, houses with no power quality problems plus houses that are effected by 4 kinds of power quality problems to be accurate which are: voltage swell, voltage sag, poor power factor and harmonics. In the purpose of spotting the effect of PQ problems at the level of houses and electrical grid, the simulation has been operated for a healthy house, a house with poor power quality problem, a house with harmonics, a house with voltage deterioration, and also for the whole system. Using the results obtained from the simulation, a pricing policy has been employed to shorten the effect of these problems by encouraging and raising awareness of consumers to adapt healthy consumption behaviors.

General Conclusion

General Conclusion

General Conclusion

The objective of this project is to understand and deal with the power quality disturbances in the smart area, precisely in the smart electric grid, and their effect on the power consumption and pricing at both consumer and supplier perspectives.

This project focuses on 4 most common types of power quality problems in the smart grid which are: harmonics, voltage swell, voltage sag and poor power factor.

The bloom of power electronic equipment and nonlinear devices in addition to the integration of renewable energy facilitates the existence of harmonics in the power systems and electrical networks, which leads to the appearance of the poor power factor problem because of the relationship between the total harmonic distortion and the power factor.

To fulfill the goals of this study, a simulation of residential area with a composition of 60 houses equipped with 8 appliances with houses influenced by the earlier cited power quality problems has been developed to clarify and detect the slight change in the electrical system parameters, which revealed that power quality problems increase the power demand and the pricing bills for the consumer and the supplier, Since the Harmonics are signals with positive integer multiple of the fundamental signal frequency that are added to the current or voltage signals, deforming shape of the signal is generated ,the more the harmonics take place the more the distortion of the fundamental signal is, in addition to the deterioration of voltage for short time, a non-stable power flow is created which effect the power flow by augmenting its value which means utilizing and paying for more power than the needed leading to both electrical and economic issues .

The results that are obtained from the applied simulation fortified the basic idea that this work is established for, which is that the pricing policy used by the supplier companies is not practical in the process of fixing power quality problems because it does not provide a strategy that urge clients to correct their PQ problems by not covering penalties and incentives in the bill, in other words, the ordinary billing counts the exceeded power that is a repercussion of the PQ issues as an ordinary power with the same price as the consumed one , this pricing policy influences in a bad way both the supplier company by investing more money in the aim of generating the exceeded power to satisfy the power demand, and the client by paying for extra unneeded power, this can be seen in the simulation with the existence of PQ problems where the consumption power is much larger than the one with the correction, also because, the price of the consumption is proportional to the consumed power the same remark is shown for the total price .

General Conclusion

Using the simulation outcomes and results, a pricing policy has been proposed in order to prevent the impact of these power quality issues by guiding consumers with penalty and incentive prices to reduce and eliminate PQ problems from there residential electrical network.

Future Work:

The scope of the future work that must take place and use the results drawn from this work is in detection and mitigation, because in this study detection by the root mean square of values method is used for its simplicity and rapidity of performance, however there exist numerous methods of detection, more sophisticated and more complicated that can be used instead of the applied method in the simulation to name a few : Kalman Filter ,Wavelet Transform technique, Stockwell Transform, and Hilbert transform, not to mention that the study did not include the implementation and the techniques used in correcting and mitigating PQ problems devices.

References

- [1] S.Khalid, Bharti Dwivedi, "Power Quality: an important aspect", International Journal on Engineering Science and Technology, 2010
- [2] Bollen, Math HJ, JinZhong, FranciscZavoda, Jan Meyer, Alex McEachern, and Felipe CórcolesLópez. "Power quality aspects of smart grids." In International Conference on Renewable Energies and Power Quality (ICREPQ'10), Granada 23-25 March, 2010, pp. 1-6. 2010.
- [3] Gungor, V. C., Sahin, D., Kocak, T., Ergut, S., Buccella, C., Cecati, C., & Hancke, G. P. (2011). Smart Grid Technologies: Communication Technologies and Standards. IEEE Transactions on Industrial Informatics, 7(4), 529–539.
- [4] https://energyeducation.ca/encyclopedia/Electrical_grid, accessed in June 14, 2022
- [5] https://energyeducation.ca/encyclopedia/Distribution_grid#:~:text=Distribution%20grid%20refers%20to%20the,to%20safe%20customer%20Dusable%20levels. , accessed in June 14, 2022
- [6] Jenkins, Nick, Chao Long, and Jianzhong Wu. "An overview of the smart grid in Great Britain." Engineering 1, no. 4 (2015): 413-421.
- [7] Kabalci, Yasin. "A survey on smart metering and smart grid communication." Renewable and Sustainable Energy Reviews 57 (2016): 302-318.
- [8] Yinka-Banjo, Chika, and Ogban-AsuquoUgot. "A predictive model for automatic generation control in smart grids using artificial neural networks." In International Conference on Emerging Technologies for Developing Countries, pp. 57-69. Springer, Cham, 2018.
- [9] Zheng, Jixuan, David WenzhongGao, and Li Lin. "Smart meters in smart grid: An overview." In 2013 IEEE Green Technologies Conference (GreenTech), pp. 57-64. IEEE, 2013.
- [10] <https://www.ovoenergy.com/guides/energy-guides/smets-1-and-2-new-smart-meter-generation>, accessed in June 14, 2022
- [11] <https://bhl.co.uk/landgyr-smets1-g470-671-gas-meter-g47067106112261es1w556326.html>, accessed in June 14, 2022
- [12] <https://www.itron.com/na/solutions/product-catalog/smets2-electricity-em425uk2-5t>, accessed in June 14, 2022
- [13] De Almeida, A., L. Moreira, and J. Delgado. "Power quality problems and new solutions." In International conference on renewable energies and power quality, vol. 3, pp. 1-45. 2003.

-
- [14] J.Arrillaga, N.R.Watson, S.Chen, "Power System Quality Assessment", "1.2 Disturbances "
- [15]<https://engineering.electrical-equipment.org/safety/protection-voltage-spikes-lv-systems.html> , accessed in June 14, 2022.
- [16] Bingham, Richard P. "Sags and swells." Manager of Technology and Products Dranetz-BMI 1994, Original Draft September 1994 Revised February 16, 1998, New Durham Road Edison, NJ 08818-4019 USA (1998).
- [17] https://www.researchgate.net/figure/A-Normal-120Vrms-Voltage-Experiencing-Voltage-Swell-and-Recovery_fig3_3183116, accessed in June 14, 2022.
- [18] Ruban, Nikolay, Aleksey Kinshin, and AleksandrGusev. "Review of grid codes: Ranges of frequency variation." In AIP Conference Proceedings, vol. 2135, no. 1, p. 020049. AIP Publishing LLC, 2019.
- [19] https://www.researchgate.net/figure/Definition-of-40-voltage-sag-with-a-duration-of-80-ms_fig1_242484783, accessed in June 14, 2022.
- [20] https://www.researchgate.net/figure/Per-unit-load-voltage-profile-at-45-km-for-3-phase-unbalanced-load_fig7_321229156, accessed in June 14, 2022.
- [21]https://www.researchgate.net/figure/Sinusoidal-voltage-flicker-50Hz-ac-voltage-modulated-with-8Hz-sinusoidal-waveform-and-a_fig1_254440418, accessed in June 14, 2022.
- [22] <https://pq-as-a-service.com/en/grid-phenomena/>, accessed in June 14, 2022.
- [23] J.Arrillaga, N.R.Watson, S.Chen, "Power System Quality Assessment", "4.6.1 The Wavelet Transform" .
- [24]Abdelsalam, Abdelazeem A., Almoataz Y. Abdelaziz, and Mohamed Z. Kamh. "A generalized approach for power quality disturbances recognition based on Kalman filter." IEEE Access 9 (2021): 93614-93628.
- [25]<https://onlinesale.cheaps2022.ru/category?name=kalman%20filter%20c%20limit%20number%20of%20measurments.>, accessed in June 14, 2022.
- [26]<https://www.semanticscholar.org/paper/Power-grid-integration-using-Kalman-filtering-Djerf/81812c774883543faf10d003b83980ed2c2cc994>, accessed in June 14, 2022.
- [27] <https://www.intechopen.com/chapters/61538>, accessed in June 14, 2022.
- [28] Wei, Deyun, and Yijie Zhang. "Fractional Stockwell transform: Theory and applications." Digital Signal Processing 115 (2021): 103090.

-
- [29] Kumar, V., S. K. Gawre, and T. Kumar. "Power quality analysis using wavelet transform: a review." *International Journal of Innovative Research in Science, Engineering and Technology* 3, no. 3 (2014): 130-136.
- [30]https://www.researchgate.net/figure/Multi-resolution-analysis-using-the-wavelet-transform-15_fig6_233657890, accessed in June 14, 2022.
- [31] Feldman, M. (2001). HILBERT TRANSFORMS. *Encyclopedia of Vibration*, 642–648.
- [32] Rick Orman, "Power Factor Correction Solutions & Applications". Eaton Corporation, 2012.
- [33] Abidullah, N. A., A. R. Abdullah, A. ZuriSha'ameri, N. H. Shamsudin, N. H. H. Ahmad, and M. H. Jopri. "Real-time power quality disturbances detection and classification system." *World Applied Sciences Journal* 32, no. 8 (2014): 1637-51.
- [34] Balwani, MayurkumarRajkumar, KarthikThirumala, Vivek Mohan, Siqi Bu, and Mini Shaji Thomas. "Development of a Smart Meter for Power Quality-Based Tariff Implementation in a Smart Grid." *Energies* 14, no. 19 (2021): 6171.
- [35] Richard Hutchins, "Efficiency/Power Factor/Harmonics", <https://web.lamarchemfg.com/userfiles/technical-papers/Charger's%20Efficiency-Power%20Factor%20-%20THD.pdf>, accessed in June 14, 2022.
- [36] Bhatia, A. "Power factor in electrical energy Management." PDH online course E 144 (2012).
- [37] "Unit V: Energy, economic and Environmental Issues of Power Plants" <https://stannescet.ac.in/cms/staff/qbank/EEE/Notes/>, accessed in June 14, 2022.
- [38] <https://www.ni.com/en-lb/shop/labview.html>, accessed in June 14, 2022.
- [39] Chandra P Pahuja P, "Power Quality Monitoring Using LabVIEW," *International Journal Of Electrical Electronics & Computer Engineering*, vol. 4, no. 2, p. p. 59, 2015.
- [40]https://www.researchgate.net/figure/Properties-of-the-set-of-test-appliances-as-measured-by-the-Allegro-PM3000a-Universal_tbl5_267642671?fbclid=IwAR0CTL21QIJgwYO4LtVcaeSSVeXpPeELJOKrIWk_c6LHNb1o-CoQiTDw2so, accessed in June 14, 2022.
- [41]https://www.semanticscholar.org/paper/Load-Flow-Analysis-and-Reactive-Power-Compensation-Mukherjee-Ganguly/cb53e8775e2189a06dfa35247429a167974ca4bf/figure/5?fbclid=IwAR2Cb4y_VenHbuvn3YDT46a03Y-EUVzqHpq1ynbhO-U-eiB43i0FfJ7KbvK, accessed in June 14, 2022.
-

[42] <https://www.donrowe.com/usage-chart-a/259.htm?fbclid=IwAR0K-qTdTV7p7-5LyxKuSiWQoj6YGB6X3N4XUd4nh75weQqkuJXF90q2cI8>, accessed in June 14, 2022.

[43] <https://algerie-electricite.com/faq/prix-kwh>, accessed in June 14, 2022.