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ABSTRACT
In this paper, various aspects of smart grids are described. These aspects include the components of smart grids, the detailed functions of the smart energy meters within the smart grids and their effects on increasing the awareness, the advantages and disadvantages of smart grids, and the requirements of utilizing smart grids. To put some light on the difference between smart grids and traditional utility grids, some aspects of the traditional utility grids are covered in this paper as well.

General Terms
Smart energy metering system, smart grids.

Keywords
Smart meter, smart grids, AMI, AMR.

1. INTRODUCTION
Saving electrical energy and finding ways of consuming it only in the most efficient ways had been the focus of scientists from a long time ago. Performing these two tasks is getting difficult nowadays because of the rapid development in the electronics world. There are many new devices and inventions recently that require factories and laboratories for development and maintenance, which all consume energy in a high rate, and that results in a huge loss of energy and in a dramatic increment in the prices of energy [1].

The electrical energy demand in the near future is expected to become double the current demand [2]. The design of the traditional utility grids is not sufficient for solving this problem [3]. It is because they demand the traditional resources of energy to a great extent in spite of the availability of alternate resources of energy such as solar energy [4].

Spreading the awareness on how to use the available energy resources efficiently, and to some extent, prefer renewable energy sources over fossil fuels are two great solutions for the energy problem. Fortunately, there are many efforts nowadays towards utilizing renewable sources [5]. Unfortunately, these efforts are not spread worldwide either because of installation cost, or because they cannot be implemented in some areas. In summary, there are two approaches for solving the problem of energy, these approaches are:

1- The use of renewable energy sources, like solar energy, wind energy, … etc.

2- Another approach is to spread the awareness on how to consume the energy more efficiently, and utilizing the available technology to manufacture devices that consume less energy, and devices that facilitates consuming less energy [2]. It should be mentioned that the first approach can be utilized along with the second approach.

This paper deals with the second approach, and it can be achieved not only by using the available technology to make the consumers pay for the amount of energy they consume, but also by introducing techniques that reduce the consumption of excessive amounts of energy by increasing the information the consumers have about the energy. That is because increasing the information is increasing the awareness.

The rest of the paper is organized as follows, the traditional utility grids are introduced and their disadvantages are covered in section 2. The components of smart grids, and the functions of smart meters are described in a very detailed way in section 3. The advantages of utilizing the smart grids are given in section 4. While the disadvantages are described in section 5. The requirements for implementing smart grids are given in section 6. Finally the paper is concluded in section 7.

2. TRADITIONAL UTILITY GRIDS
The traditional utility grids are characterized mainly by the traditional energy meter, which is a device that measures the amount of consumed energy by a building, and stores the consumption data such that it can be read later for the purpose of billing. The traditional energy meter used nowadays (which is electromechanical) can only measure the amount of energy that is being consumed. This single function is insufficient to make the consumers aware of the high energy consumption [2]. Other than its single functionality, there are a number of disadvantages for the traditional energy meters, these disadvantages include:

1- They give faulty readings because of their relatively low accuracy level [6], where the reading of traditional meters is proportional to the number of times that the rotating coil (which is the main part of the meter) has rotated. Therefore, the energy consumption can be obtained as the following equation [7]:

Energy consumption = α N

*Where: α is a resolution coefficient determined by the quality of the meter.

N is the number of rotations of the rotating coil.

Most of these meters have a resolution of 1 kilo-Watt-hour (kWh). So, energies lower than 1kWh are truncated and not calculated, which causes calculation errors [8].

2- They are subjected to electricity theft by tampering [9]. Utility grids lose large amounts of money each year due to electricity theft. Electricity theft can be defined as an illegal way of using electrical equipments or services without paying the bills, or to acquire reduced bills [10].

Most of the utility grids in developing countries suffer huge losses because of the Non-Technical Losses (NTL), where the NTL are the losses due to electricity theft. Corruption in the billing procedure is another reason for such losses. A worker that is hired to read the consumed energy value might not read the actual value, or may intentionally give lower value than the exact one for receiving bribes [11].

3- Having to hire workers to read the value of the consumed energy and issue the bill, where this requires additional financial resources for salaries [12].

4- They cannot limit the amount of consumed energy by the building when a certain limit is reached due to devices left unnecessarily on or other reasons. It is estimated that appliances left unnecessarily on waste 900 million dollars of bills a year [1].

5- They cannot control the operation of the building appliances, such as turning them on or off at some pre-specified times by the residence [2].

6- They have poor support for providing electricity from the consumers to the utility grids. This is because they have poor decision making ability on which energy source power lines to connect to the building power lines.

7- They cannot support multi tariff schemes in order to solve the problem of peak demand of energy. The peak demand problem happens when the energy demand reaches a maximum peak value such that the utility grid generators are unable to provide the necessary amount of energy to consumers during that time period. In other words, it occurs when the consumers are turning on their appliances at the same time period. It should be mentioned that the peak demand time periods might vary according to the weather, type of the region (Industrial or agricultural) and other factors [2].

A good solution is to find a way to make the consumers turn on their appliances at different times such that the energy demand is almost flat. A good way for achieving this goal is by introducing the multi tariff scheme such that the price of energy is generally high at peak demand times, and low at relaxed demand times, which flattens the energy demand curve.

8- It does not support remote connection and disconnection, so if the consumers did not pay the bills, the worker needs to go to their buildings to perform disconnection [13]. Also, if an energy meter stops working, then the utility grid knows only after a long time depending on the worker who takes the reading of consumer to report the issue [14].

A good approach to solve these issues and to make the consumers more aware of their energy consumption is by accurately billing them for the energy, and possibly prior to its consumption (such as the prepaid energy cards), showing them the prices of energy they are consuming and the required bills, facilitating the process of controlling the home appliances, and supporting other required features. These result in spreading the energy demand on a wider time period in order to get a flat energy demand profile. All of the previously mentioned can be achieved by utilizing the smart grids instead of the traditional utility grids.

3. SMART GRIDS

The primary objective of utilizing the smart grids is to enable the consumers to show their desire to become participants in the energy market. This is achieved by giving them the opportunity to make better choices about their energy consumption plans, and increasing their awareness about the various conditions and status of energy [3].

A targeted goal is attempting to solve the peak demand issue, where the power generation units must be designed to meet peak demand, and not only the average demand. The ability of smart grids to ensure a bidirectional flow of both energy and information between power generation units and the buildings of the consumers participates greatly in solving the problem of peak demand [3].

The personnel of utility grids are always searching for new ways for facilitating their operations, including providing flexible billing deadlines for consumers, performing scheduled bills reading for obtaining a better understanding, implementing multi-tariff billing for flattening peak demand, forecasting energy demand profile, notifying of special conditions, detecting theft, and remote connecting and disconnecting [15].

In order to perform all of these operations, the smart grids consist of a control center located inside the utility grid, a billing center that collects the bills, a number of smart energy meters distributed among buildings, and a communication infrastructure.

3.1 The control center:

The function of the control center is to control and monitor all of the systems of the smart grid, including the power generation units and their various conditions. It monitors the condition of the billing centers including billing irregularities, and the conditions of the smart energy meters including tampering and measurement errors.

The control center also stores a database for various parameters of the smart grid, where it sends and receives various data from the billing center and the smart energy meters. Its functions also include cutting off the power from a building when the bills are overdue for a specific period of time [2].

3.2 The billing center:

The function of the billing center is to collect the bills from the smart energy meters. Smart grids allow the billing center to utilize various technologies that facilitate the billing process, while manual bills reading in traditional utility grids is difficult and costly [2].

One of the technologies that facilitates the billing process in the smart grids is the utilization of smart cards. The smart card can be used as a credit card to pay money, which allows it to be used in various applications. One of the applications in this particular point of view is using the smart card to buy energy. Consumers can buy energy from any energy supplier wherever and whenever they desire, and at a price based on their previous demand profile, which helps in increasing their awareness to a great extent [1]. The consumers can also demand at any time to check the amount of consumed energy so that a record of their energy usage can be obtained. This ensures the awareness of consumers of their energy consumption, and enables them to reduce their bills [4].

3.3 The Smart energy meter:

Instead of the traditional energy meter, the smart energy meter is utilized in the smart grid. The smart energy meter is a developed energy meter that measures the amount of consumed energy while providing additional features compared to a traditional energy meter [2].

Smart meters can measure various data including the value of voltage, current, phase angle, frequency, amount of consumed energy and the price of that energy, and securely delivers that data. It should be mentioned that the design of smart meters involves utilization of a number of technologies for both hardware and software depending on the requirements of the suppliers as well as the consumers [2].

The advantages of smart grids over the traditional utility grids result from the various functions that are performed by the smart energy meters compared to the traditional energy meters, these functions include:

1- Calculating the amount of consumed energy, where the function of an energy meter (Whether traditional or smart) is to measure and calculate the amount of consumed energy by the buildings. A disadvantage of traditional energy meters is their limited accuracy of measuring the amount of consumed energy. Large amounts of energy are consumed every day; therefore, accurate measurement of consumption is very important for obtaining accurate billing [16].

Smart energy meters provide improved accuracy compared to the traditional energy meters mostly because of the utilization of a processing unit within the design of smart energy meters [6]. However, there is no smart meter that gives an accuracy percentage of 100%, but accuracy must be as high as possible for achieving reliability [9].

2- Displaying additional information, where smart energy meters display various vital information to the consumers. Regarding this function, there was a questionnaire survey made in 2005 in the United States, the result of this survey showed that when the consumers are offered with much information about their typical energy consumption and their consumption in the peak demand hours, energy consumption was reduced by 11% [17].

Smart meters can display energy conversation and bills savings because of utilizing the energy from renewable energy sources. Displaying such information encourages the consumers to use renewable energy resources [2].

3- Supporting multi-tariff scheme. This participates by shifting some loads, which helps in flattening the energy consumption profile [2]. The idea of the multi-tariff scheme is making the price of energy high at peak demand areas and low at relaxed demand areas, which encourages the consumers to turn on only their mostly needed devices at peak demand times, while turning on most of their appliances at relaxed demand times to acquire low bills.

4- Increasing the detection of electricity theft in order to get less energy losses. So, theft detection in electrical energy systems is a targeted goal for utility grids. However, it should be mentioned that the losses of energy are not only due to energy theft, but they are divided into two different types, Technical Losses (TL) and Non-Technical Losses (NTL) [18].

TL are related to problems in the physical characteristics of the devices used in the system, where TL represent the energy lost in the generation, the transmission and the equipment of measurement, which can become quite costly to the utility grids [18]. In order to reduce TL, replacing the old equipment by more efficient equipment stands out as a valuable way [5].

The NTL on the other hand are those associated with energy theft and they refer to the supplied amount of energy that were not billed. They are also defined as the difference between total losses and TL [18].

Total losses = Supplied energy - Billed energy

NTL = Supplied energy - Billed energy - TL

The reason of energy theft is the lack of awareness among the consumers about the high losses they are causing the utility grids. Unfortunately, energy theft is performed in lots of areas worldwide [9]. It is usually performed by taking the electrical connections of the building directly from the mains power lines, where the traditional energy meter does not measure the amount of consumed energy by the building since there are no power lines passing through it.

A good way for reducing the NTL is by increasing the observing ability of the smart meters and the billing center. A solution is to observe all the consumers' energy meters to check them in order to find out if they have any problem. However, the estimated cost of these observations is high, so utility grids might follow a probability approach for selecting the energy meters to be checked; therefore, they do not detect the problems with all the energy meters [5].

Because of its excellent resistance towards many of theft methods in traditional meters, smart meters offer a great way to solve the energy theft issue, where smart energy meters have the ability to record zero reading and inform the utility grid of energy theft [9].

A common way for detecting theft is by utilizing a central observer meter that is installed next to the mains distribution transformer, where this observer meter is responsible for metering the overall consumed energy by a group of consumers. By comparing the reading of the overall energy consumption of this observer meter with the sum of the readings of all the individual meters connected to the same power line distribution transformer, any irregularity can be discovered instantly [5].

All this attention is focused to the energy theft issue nowadays is because its detection is very complex, and it results in large amount of losses worldwide [18]. In many developing countries, NTL's are a very serious problem for utility grids as they are estimated to have a range about 10% - 40% of the total generation capacity. It is estimated that utility grids lose more than 20 billion dollars every year due to energy theft [11].

Also, The excessive amount of overload of utility grid generators due to energy theft might result in unstable voltages that can damage the appliances, and might yield to cutting the power supply from consumers [11].

Unfortunately, even the smart meters cannot provide a fully theft-free metering. There are a number of ways for tampering the smart meters. These methods include hacking and reprogramming the smart meter to give lower readings; However, since performing these tampering ways is harder to achieve than those in the traditional energy meters, it is considered that utilizing the smart energy meters is an efficient way for decreasing energy theft. So, illegal consumption of energy and tampering with energy meters can be battled only with public participation [11].

5- Notifying the consumers of excessive energy consumption, where the smart energy meters can be equipped with various technologies such as alarm buzzers, or Global System for Mobile communications (GSM) based Short Message Service (SMS) tranceivers. The smart meter can be programmed to give a notification to the consumers when the amount of consumed energy by the building appliances exceed a pre-specified limit that is previously set by the consumers [13].

Also, if there are unusual conditions that could lead to failures, it activates alerts to cut off the power from the building to recover its proper operation [17].

6- Controlling building appliances, where the smart meters can be programmed to control the devices to turn them on or off at pre-specified times that are previously set by the consumers. This reduces energy consumption and bills [17].

House appliances can be divided into two types, they are real-time and schedulable. Real-time appliances must be turned on whenever needed such that they energy as desired, while schedulable appliances can be turned on at a later time and still not affect the comfort level of the consumers [19].

The real-time house appliances include televisions, radios and other devices, where their operation while the consumers are outside the building is not beneficial. The schedulable house appliances include washing machines, air conditioners and other devices, where the operation of these devices while the consumers are outside the house can be beneficial, So their operation can be delayed from the peak demand time to the relaxed demand time. Reduced peak demand benefits utility grids by reducing complexity such that the probability of occurrence of equipment failure is reduced greatly [19].

The smart energy meter can turn off the devices with least priority when it receives a message from the control center that the available energy is restricted to a limited amount. The sequence of the priority load-shedding is set according to the devices priority of operation that is previously set by the consumers [17].

7- Supporting bidirectional communication, where the smart energy meter provides additional information to the consumers in the buildings and the personnel at both the billing center and the control center by utilizing a bidirectional communication path with the billing center, and also with the control center within the smart grid.

The communication path between the smart energy meter and the billing center is utilized in two directions, they are:

A) From the smart energy meter to the billing center to perform the following:

- Sending the data regarding the amount of consumed energy and other related data.

- Paying the bills.

B) From the billing center to the smart energy meter to perform the following:

- Informing of the time before which the bills should be paid. This function eliminates the need for a employee to read the consumption data of each smart energy meter in the smart grid [5].

- Informing of any updates on the price of the energy such as the case for multi-tariff scheme.

It should be mentioned that the smart meter does not send only its own consumption data to the billing center, but it also forwards the consumption data of other smart meters in case they are unable to reach the billing center using their own communication technology [5].

The communication path between the smart energy meter and the control center is also utilized in two directions, they are:

A) From the smart energy meter to the control center to perform the following:

- Informing of energy theft.

- Informing of a certain failure.

B) From the control center to the smart energy meter to perform the following:

- Switching the power on or off the building.

- Informing of the times of electricity outage.

- In some cases, it can be used to control the time of operation of building devices by a table of operation that is pre-specified by the consumers [2].

For the smart energy meter to send and/or receive any data with the billing center or the control center, it utilizes the communication infrastructure of the smart grid.

3.4 The communication infrastructure:

Utilization of smart grids needs proper selection and implementation of a communication technology that achieves various requirements [2].

Communication technologies are divided into two types, they are wired and wireless. For each of these types, there are diverse choices for implementation. This diversity is necessary because of the large number of properties desired from them, which include range, bandwidth, cost of implementation [20]. Other properties that are also required from the communication technologies include security, simplicity, and low energy consumption [2].

Selecting a suitable communication technology for a particular application is very important to designers, and since the wireless communication is a fast growing field of science, this further complicates the task of selection [21].

Common wireless communication technologies include Bluetooth (over IEEE 802.15.1), ZigBee (over IEEE 802.15.4), Wi-Fi (over IEEE 802.11), Wi-MAX (over IEEE 802.16), and Ultra-WideBand (UWB) (over IEEE 802.15.3) [21].

Bluetooth standard is for short-range and low-cost devices to replace cables for peripherals of Personal Computers (PC's), such as mice and earphones. This range of applications is usually called Wireless Personal Area Network (WPAN) [21].

Bluetooth utilizes Frequency Hopping Spread Spectrum (FHSS) with 79 channels and 1 MHz bandwidth. The maximum number of devices belonging to a single network is 8, which are 7 slaves and one master [21]. This technology can be a possible choice for communication of control signals, energy consumption data and bills in smart grids [2].

Wi-Fi stands for Wireless Fidelity; However since most of the Wireless Local Area Network (WLAN's) are based on Wi-Fi, the term Wi-Fi is used generally as a synonym for WLAN [20].

Any device that has a Wi-Fi tranceiver like a PC, a smart phone and a tablet can connect to the internet through an access point [20]. Because its network is often established without planning, it is often referred to as an ad hoc network. The maximum number of devices in a Wi-Fi network is 2007, where it utilizes 24 channels for communication [21].

There are various types of IEEE 802.11, these types include (but are not limited to) IEEE 802.11a, IEEE 802.11b and IEEE 802.11g [21]. The IEEE 802.11a operates in the 5 GHz band, while the IEEE 802.11b operates on 2.4 GHz and it uses the Direct Sequence Spread Spectrum (DSSS) modulation technique. The IEEE 802.11g also operates on the 2.4 GHz band and has similar characteristics to the 802.11b. It differs from 802.11b in the modulation technique, where it uses Orthogonal Frequency Division Multiplexing (OFDM) [20].

A disadvantage in establishing 802.11a with the 802.11b and 802.11g is that they cannot coexist because they operate in different frequency bands. 802.11b/g operate in the 2.4 GHz frequency spectrum, while 802.11a operates in the 5 GHz frequency spectrum [20]. A common application of Wi-Fi is an implementation of WLAN within a short range network such as a small building or a college.

World Interoperability for Microwave Access (Wi-MAX) is a standard based on IEEE802.16 high data rate standard. Wi-MAX is popular because it delivers higher speed communication at a lower cost than Wi-Fi and covers larger distances. Other advantages of Wi-MAX over Wi-Fi include having a better reflection tolerance and penetration of obstacles. It operates on the unlicensed bandwidths 2.4 GHz and 5.8 GHz frequency spectrum and the licensed bandwidths 2.5 GHz, 3.5 GHz, and 10.5 GHz. Its maximum data rate is up to 75 Mbps. An application of Wi-MAX is to interconnect houses, buildings and access points to allow communication between them [20].

UWB is a short-range, high-speed communication technology with a bandwidth up to 480 Mbps, which can achieve high Quality of Service (QoS) with the multimedia applications such as audio and video. The maximum number of devices belonging to a single UWB network is 8, which are 7 slaves and one master [21]. The relatively high power consumption makes UWB less attractive for implementation in smart grids.

ZigBee is a wireless communication technology based on the IEEE 802.15.4 standard. It offers long battery life, high security, multi-hopping, and low cost [8]. The maximum number of devices belonging to a network is over 65000 [21].

When compared with Bluetooth, UWB, Wi-Fi, and Wi-MAX, the simplicity of ZigBee makes it very suitable for various applications due to the simple required memory and processing ability. ZigBee is suitable for portable products with short range and limited battery power [21]. The self-forming and self-healing features of ZigBee makes it more attractive for implementation than other technologies when simplicity is required [15].

Considering the node's energy consumption, using demand-based wake-up mode of operation, ZigBee is concluded to be quite an efficient choice for implementing the communication infrastructure in smart grids. In most of the time, ZigBee nodes stay in sleep mode (which is also called power-saving mode) that ensures a long battery life. Only when there is a required task, the tranceiver wakes up from sleep and performs it [22].

Two other communication technologies that are commonly used with smart grids are Power Line Carrier (PLC) and GSM. PLC is a popular method of communicating information between power line terminals as it is based on communicating the data signals and control signals by sending them on a modulated carrier on the power lines [23]. When comparing with other communication technologies, PLC has the advantages of low cost infrastructure because it does not require the installation of costly devices [2].

However, the future use of PLC appears to be decreasing at a high rate. It is estimated that only 8% of utility grids will utilize PLC in the future more than other types of communication technologies [23]. According to the estimated requirements of utility grids, GSM is a good option for implementing the communication infrastructure of the smart grids [15].

In some cases, the GSM shows an advantage over ZigBee communication technology, one of these cases is when it is to be utilized in rural areas. Most of the buildings in rural areas are not placed near each other, so the attractive multi-hopping feature of ZigBee becomes inefficient, while the GSM could be an efficient choice. However, a GSM based smart energy meter sends its energy consumption data and bills and receives the commands from the control center using SMS, which is considered to be costly on the long term [13].

It should be mentioned that in some cases, some functions of the smart energy meter can be performed by a device that is connected to the smart energy meter from one side and to the appliances of the building on the other side. This device is called the Energy Management Controller (EMC), which uses both prices and user preferences of devices operation to perform its functions. These functions usually include controlling of the devices according to a schedule, displaying information to the residence, the notification ability, and some other functions based on the requirements of consumers [19].

4. ADVANTAGES OF SMART GRIDS

Other than the additional functions when compared to the traditional utility grid, there are other advantages from implementing the smart grids, these advantages include:

1- Better support for bidirectional energy flow, where implementing smart grids contributes to acquiring a better understanding of the value of renewable resources of energy, such as solar energy and wind energy because using these resources instead of the traditional resources helps in providing the energy from the consumers to the utility grids, while the traditional utility grids are designed for unidirectional flow of energy [2].

2- Reduced amounts of exhausted toxic gases in the atmosphere, where electric power generation accounts for approximately 25% of the world's CO_2 emissions, where CO_2 is a major cause for global warming, while CO is toxic and unhealthy for the environment [3].

3- Reduced bills, and more comfort level for the personnel at the utility grids and the consumers.

5. DISADVANTAGES OF SMART GRIDS

Unfortunately, the smart grids do not offer only advantages to the energy market, but it also imposes a number of disadvantages as well, these disadvantages include:

1- Since the smart energy meter sends not only its own data to the billing center and control center, but it also sends the data of neighbors, it is considered as a spy within the building that discloses vital information according to the point of view of the consumers [9].

2- Depending on the used communication technology to implement the communication infrastructure, an antenna might transmit radiations that are dangerous to humans lives. It might also interfere the Radio Frequency (RF) of some devices such as the baby monitors and the police radios, which decreases the efficiency of the devices [9].

3- The performance of the included Integrated Circuits (IC's) within the smart energy meter can be affected greatly by extreme temperatures, which might lead to calculation errors [24].

4- The maintenance of the hardware and software components of the smart grids to prevent failures is considered to be relatively complex when compared to that of traditional utility grids [2].

6. REQUIREMENTS OF SMART GRIDS

There is a number of design issues and requirements that affect the deployment of the smart grids, they include:

1- The installation cost, where the benefits of utilizing the smart grids can only be seen after years of installation [2].

2- The extent of technology to be included within the smart grids during the installation, where the design of the smart energy meters can be quite tedious in some cases because of having to support additional features. These features include providing additional security, remote controlling of house appliances, … etc [2].

3- Integration of smart grids becomes harder with an increasing number of consumers, and the establishment of communication infrastructure in some areas might be difficult due to terrestrial difficulties [2].

7. CONCLUSION

Smart grids offer a good number of advantages for solving the energy problems when compared to the traditional utility grids. One of these issues that is fairly covered due to its high rate in Iraq is the energy theft. However, implementing the smart grids is a tedious task that demands a number of requirements that might not be feasible to be achieved. Selection of which communication technology to be implemented is one of those areas because every situation has its own requirements and conditions, which means that there is no such optimum selection of a communication technology for all smart grids worldwide. Although smart grids impose a number of disadvantages, it is concluded that implementing them is a must for solving the various energy problems in Iraq.

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