Conference Paper

Smart Energy Management Systems for Households in Bahrain

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Abstract

The kingdom of Bahrain region residents enjoy a high standard of living that requires sustainable economic development, parallel to continuous improvement in the quality of life and hence a steady increase in the household's energy demand that is 51% of the total electricity consumption in Bahrain. On the other hand, the Future energy systems will be in the form of sustainable integrated smart energy systems for optimal planning, control and management. An important part of this will be the deployment of smart energy solutions in the household sector, including appliances and smart meters. However, the challenge in the designing of the smart energy technologies is the full understanding of the energy consumption and the energy losses, or leakages in the system, alongside an understanding of the consumer's behavior. This article will assess the actual deployment of smart energy solutions including a comprehensive review of the current trends and energy supply systems in Bahrain and the implementation of the smart energy management system to solve the main challenges in the household consumption sectors. Highlighting the opportunities of using ICT, such a, smart meters to enable the customers to make smart decisions regarding their power consumption and the utility providers to reshape the overall energy profile.

Keywords: Smart Energy, Renewable Energy, Household Energy

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1. Introduction

The demand for the power and water in the kingdom of Bahrain is increasing with the fast development and population growth that the country is experiencing for the last few years. In order to satisfy this increasing demands (to ensure a power and water adequacy), a reliable, efficient, economic and sustainable solutions must be introduced to handle these challenges, which can be either by expanding the existing power and water facilities by building new power stations or by introducing smart energy

systems. However, urgent studies are needed, to investigate the size of the expansion required and what type of energy resources that can be introduced to Bahrain power system considering both water and power demand.

Bahrain Economic Vision 2030 emphasized on the need to reduce the dependence on oil, improve sustainability and reduce overconsumption of water, electricity and gasoline [1]. This will help to mitigate the Green Houses Gasses (GHG) emissions, protect the natural environment, minimize pollution and promote the sourcing of more sustainable energy. Accordingly, the government has issued the Government Action Plan (2015-2018) to improve the efficiency of electricity and water and to reduce waste, and to work on finding alternative sources of energy to meet the growing demand. Furthermore, as part of the international community, Bahrain has ratified the Paris Agreement on Climate Change and adopted measures to protect the environment and the bases of sustainable development, and committed to reduce its Green House Gases (GHG) emission by the submission of its "Intended National Committed Contribution" (INDC) in 2015 [2]. In this INDC, Bahrain has included 13 strategies, plans and actions, which may contribute to low GHG emissions, and committed to the UNDP Sustainable Development Goals (SDGs), by assuring access of its nation to affordable, reliable, sustainable energy. Correspondingly, Bahrain has committed to develop and submit as part of the League of Arab State, the Ministerial Council of Electricity, the National Renewable Energy Action Plan (NREAP) and the National Energy Efficiency Action Plan (NEEAP).

The NREAP polices for promoting energy focus on the introduction of Net Metering for Residential, commercial, industrial electricity customers, and Tender-based feed-in tariff for Renewable energy developers and large electricity customers. It focused on introducing renewable energy mandate for new buildings, which aims to reduce energy demand for the building in a form of reducing the electric bill and not an actual energy consumption reduction for buildings [3].

On the other hand, and with the increase interest for diversify the energy sources, such as, the transformation toward future renewable energy systems poses challenges as it involves substantial changes in the infrastructure to carry the energy, i.e., the electricity, gas, water and cooling.

2. Bahrain Power and Water System

In the past few decades, the rapid population growth, shown in Figure 1, and the expansion in industrial activities and development of tourism in the Kingdom of Bahrain were associated with a substantial increase in power and water demands.

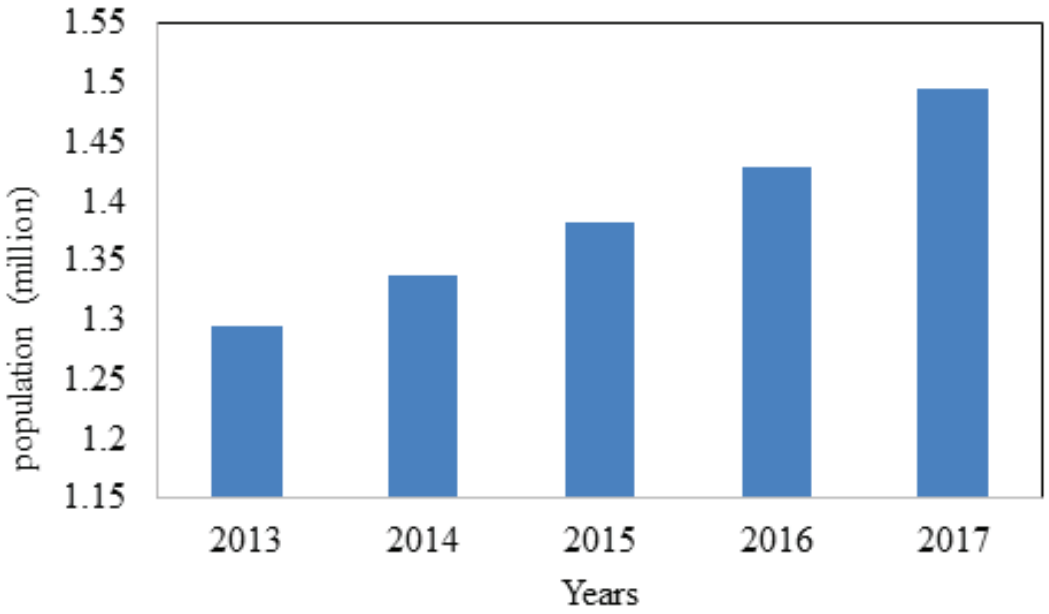


Figure 1: Population per year (2013-2017).

2.1. Production

Bahrain has five power stations, with a total installed capacity of 3920 megawatt (MW) [4]; three IPP stations with a total installed capacity of 3095 MW, and two operating by the Electricity and Water Authority (EWA) with a total installed capacity of 825 MW. Also, Bahrain is connected to the GCC interconnection with a 400kV AC cables with a capacity of 600 MW [5].

The water production is heavily integrated with the power in Bahrain through two thermal desalination stations (Sitra and Hidd), using the exhausted heat from the gas and steam turbines to operate the thermal seawater desalination units. Beside the thermal desalination, there are two membrane-based desalination stations for both brackish (high salinity groundwater) and seawater treatment. The total water and power capacity of the stations in Bahrain is given in in Table 1, showing the technologies used in each.

Table 1: The total water and power capacity per station.

Station	Power station type	Desalination technology	Power Capacity (MW)	Water Capacity (MIGD)
Riffa	OCGT		700	-
Sitra	OCGT + ST	MSF	125	25
Hidd	OCGT + CCGT	MSF	929	90
Ezzal	CCGT		942	-
Aldur	CCGT	RO (seawater)	1224	48
Ras Abu Jarjur		RO (brackish water)	-	16
GCC		Exchange	600	-
Total			4520	179

2.2. Demand

In Bahrain, the power and desalination infrastructure is well established, and the power generation and water production and storage has expanded greatly in the last ten years. The water and power demand seasonal variation is identical, however, the seasonal water variation can be considered low compared to the power seasonal variation, Figure 2. Hence, energy diversification would require a careful investigation to determine the needs and requirements for upscaling both water and power production to ensure that the introduced energy sources and technology will satisfy both the demand for water and power.

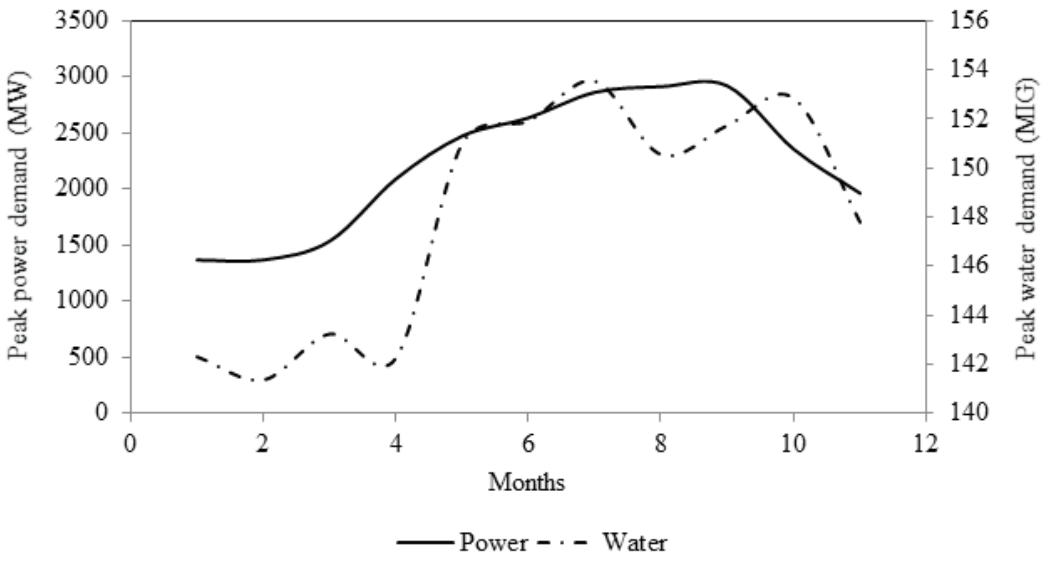


Figure 2: Average monthly peak water and power demand.

The water and power consumption in Bahrain can be divided into three main sectors; domestic, commercial and industrial. The domestic sector has a share of more than 80% of the total water demand, and around 14% and 2% for the commercial and industrial sector respectively, Figure 3. The increase in water consumption per year in the domestic sector is 837 million gallons per day (MIGD) with 460 MIGD and 74 MIGD in the in the commercial and industrial sector, respectively. The total annual per capita consumption of electric energy in Bahrain reached 11,083 kWh in 2017, with 51% of which is for the domestic sector, Figure 4

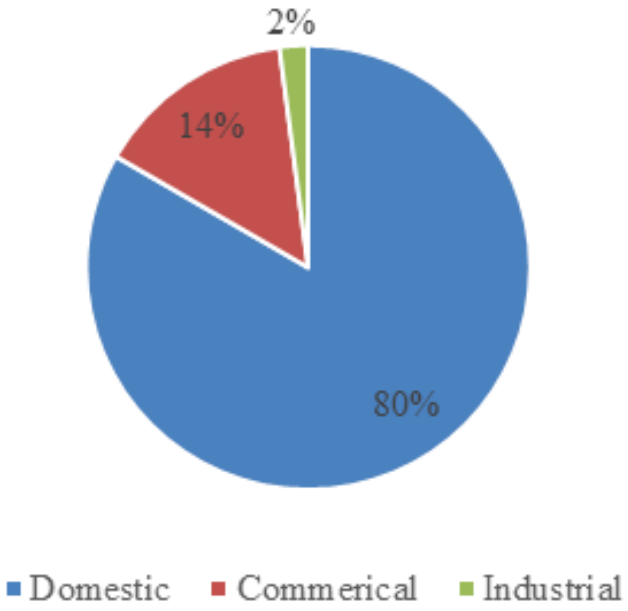


Figure 3: Percentage water consumption per sector.

Despite the Electricity and water Authority (EWA) efforts to increase the awareness in the domestic sector for energy conservation. It is noted that the electric energy consumption per capita has increased in the recent years. Since the main contributor of the electric energy consumption in the domestic sector is air-conditioning, hence the weather during these years can be a major contributor in the increase, Figure 5. The trend for temperature was increasing during the last years because of less cold days during the winter season, noting that there was no noticeable yearly increase in the ambient temperature during the summer months

3. Household Smart Energy Management System

The definition of smart energy management can be summarized by [6] to include smart electricity, smart thermal grids and smart gas grids. The smart electricity grids deliver

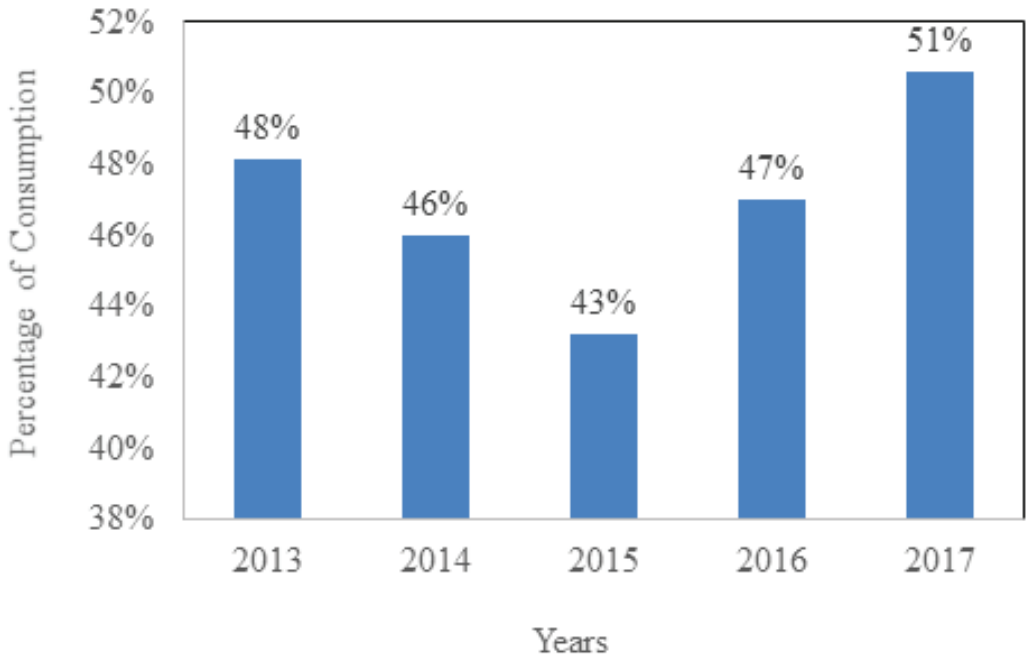


Figure 4: Per capita consumption of electric energy in the domestic sector in kWh per year.

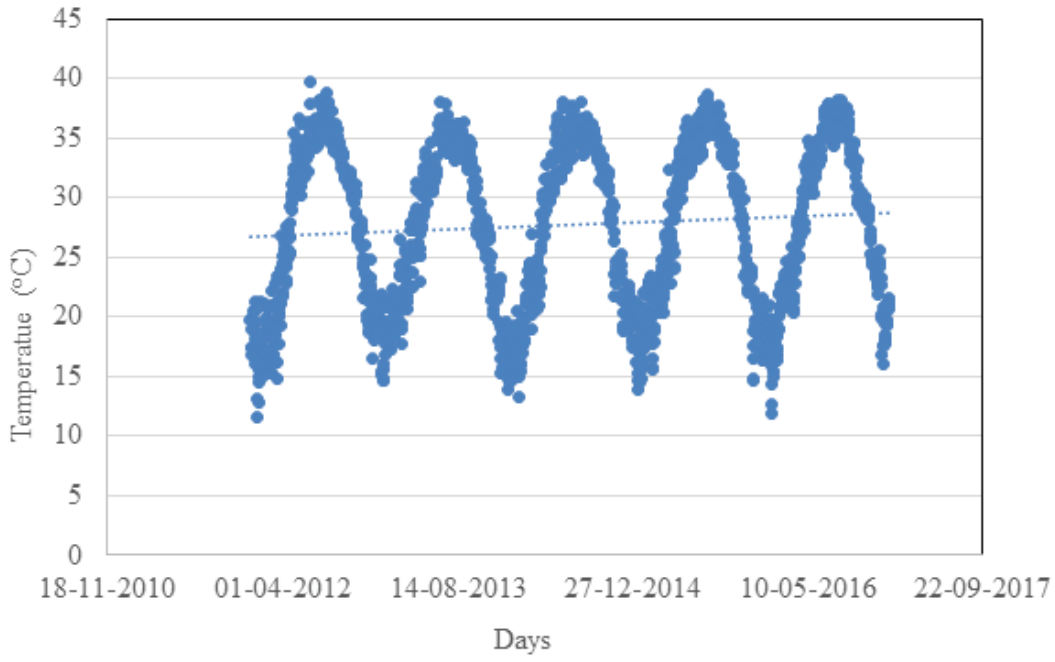


Figure 5: Temperature variation per day.

sustainable efficient economic and secure electricity supplies through an infrastructure that integrate the actions of the generators and consumers by allowing two-way communication between the power utilities and the home consumer. This will provide opportunities for demand-side-management and allow the households not

only rely on the energy from the grid, but also integrate in the energy generation using renewable energy.

The smart thermal grids, is a centralized plants or a form of a number of distributed heating or cooling producing units including individual contributions from the connected buildings. The network of pipes in the thermal grids connects the buildings in a neighborhood, town center, or whole city. The smart gas grids is an integrated action of all supplies and consumers to deliver sustainable, economic and secure gas supplies and storage.

The component of the household energy management system are summarized to; smart meters, sensors, ICT with monitoring or control unit, smart energy efficient appliances that can be monitored and controlled remotely and a platform or a software as an energy management system [7].

4. Household Smart Energy Systems in Bahrain

As shown in the previous section, the energy consumption is more than 40% of the total energy consumption in Bahrain in the domestic sector. Hence increasing energy efficiency in this sector is becoming very important.

Bahrain housing structure is hugely based around the social housing projects, which have provided more than 109,000 houses since 1961, Table 2.

Table 2: Social houses projects in Bahrain.

Project	No. of units	Year
Isa Town	5650	1963
Hamad Town	2160	1984
Zayad Town	484	2001
East Sitra	4000	2015
East Hidd	4500	2013
The South Town	4000	2013
The North Town	15600	2015
Alramli	3520	2016
Diyar Almuharraq	25000	2015

The size of the houses ranges from 189 m^2 (three rooms) to 255 m^2 (four rooms), Figure 6 shows one design of a two story social house with a total area of 213 m^2 and 4 rooms. The building regulation in Bahrain made it compulsory to provide thermal insulation in all buildings, through the Ministerial Orders of Thermal Insulation for Buildings that issued in 1999 [8]. The thermal insulation materials should be used for roofs and

walls of all buildings with overall thermal transmittance value (U-value) for the roof less than 0.6 W/m^2. °C less than 0.75 W/m^2. °C for walls. Double-glazed glass should be used for more than three floors buildings, which have a glazed surface area of the total external surface area between 10-20%.

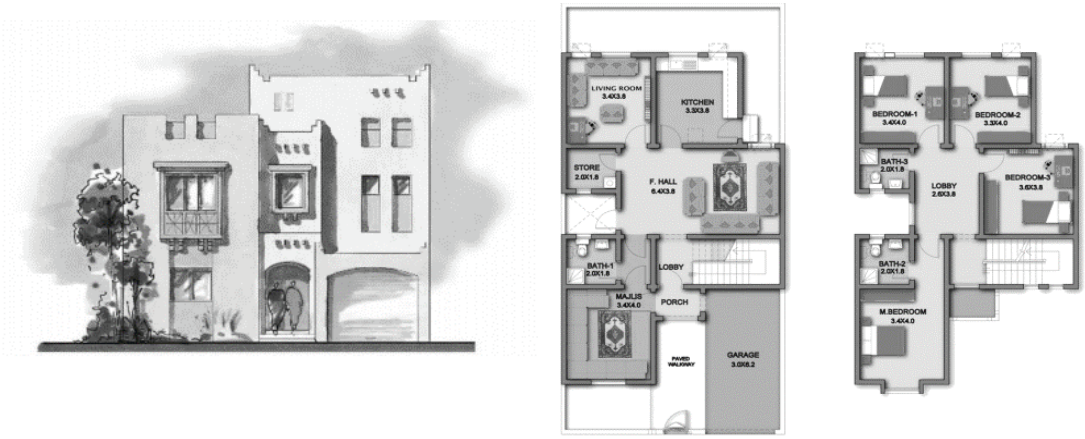


Figure 6: Design D9 houses, Ministry of Housing.

4.1. Household energy consumption

The houses in Bahrain are mainly a load points, where the energy system provided at this consumer point is consuming energy and not generating energy, although new projects of installing roof top solar PV has started on the beginning of the 2018, but still it is small number. The Energy system in Bahrain household can be divided into direct and indirect energy consumption as follows:

4.1.1. Direct energy consumption

Electricity

The major contributor to the electricity consumption in households are the cooling systems. Most houses are air-conditioned, with either a split unit, window units or central system. Despite the central system, each room in the house will have its own air-condition unit which will be operated separately and can be controlled in an individual preference. Both split and window units are common in the social houses, whereas the central systems usually found in the privately built houses. Heating systems exist only for providing hot water using electric water heaters, the hot water are mainly required during the cold weather. Other appliances in the house, such as, refrigerators, freezer,

watching machines .... etc. are also part loads that can be divided to scheduled and non-scheduled appliances.

Gas

The liquefied Petroleum Gas (LPG) used in the houses mainly for cooking, it is delivered to residential use in a 40lb cylinders. The gas consumers purchase the LPG directly from private registered suppliers. Number of LPG cylinders used in the households will vary according to social activities and size of the family.

Water

The water supplied to houses through a well-established water distribution network. Usually houses will be equipped with water storage tanks for supply that is more reliable, number and size of these tanks vary. These tanks, that are usually located on the roof of the building equipped with chillers to cool the tank during the hot months, although some of these tanks will be shaded still it is very common in the houses to have installed different cooling systems.

4.1.2. Indirect energy consumption

Waste

Divided to sewage waste and solid waste. Bahrain has nine catchments, which combine all types of wastewater inflow from all sectors, which then will be handled by wastewater facilities with a total capacity of 420,504 m^3/day [9]. Approximately 32% of the total solid waste in Bahrain are from the domestic sector. The household's solid waste is collected in a central collection point and then transported to the landfill.

Transportation

The average number of cars per house is two. Cars main fuel is that is usually gasoline produced locally, no electric cars is used in Bahrain, however hybrid cars, has been promoted by some car suppliers, the total number can considered negligible.

Other indirect household energy consumption are any gardening and maintenance activities inside and around the houses.

4.2. Smart meters

The total number of installed energy meters in for all sectors in Bahrain has reached 303,621 in 2017 of which 53,000 smart meters for houses only. The total installed smart meters in the system reached 19%, Figure 7.

Smart meters measures all type of energy consumption (electric, water) and provide additional information to power utilities. Smart meter measure both the active and reactive consumption and send the information and accept instructions. Since gas is not yet distributed through a network, it is not measured using the installed smart meters.

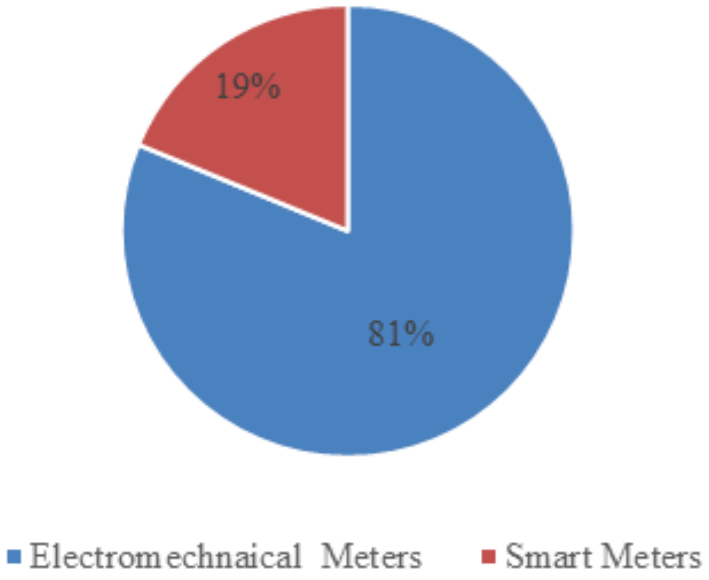


Figure 7: Percentage of installed type of energy meters in 2017.

4.3. Energy cost and tariff for households in Bahrain

Bahrain is using indirect load management based on range of consumption tariffs for both electricity and water, where the consumption is divided into three thresholds 1,2,3 and two categories, Bahraini and non-Bahraini, Table 3 and Table 4. The electricity and water in Bahrain is highly subsides for both Bahrainis and non-Bahrainis for all sectors with 55-80% subsides for electricity and 3-27% subsides for water in the domestic sector for Bahrainis. The actual cost of electricity and water is 29 files/kWh and 750 files/m^3, respectively (One files is 0.0027 US Dollars). The cost of LPG for the 40 lb gas

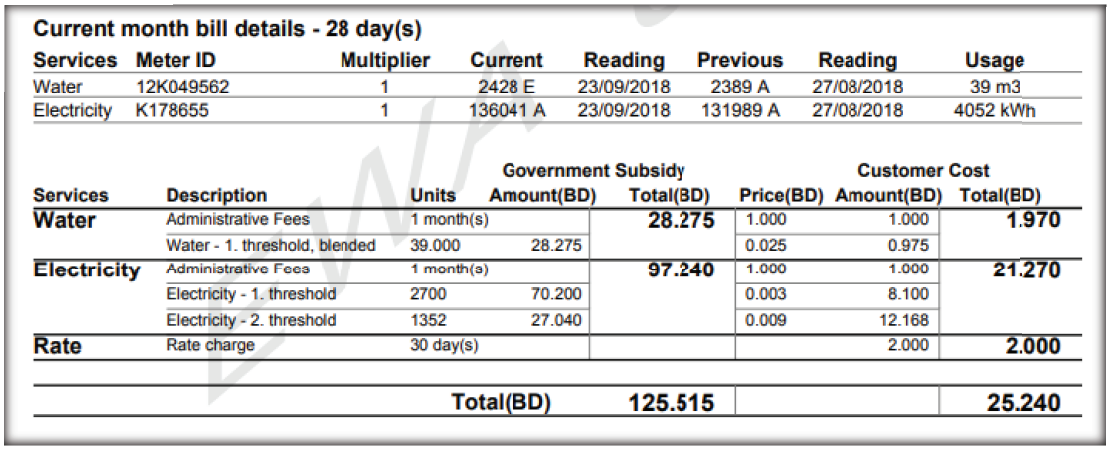
cylinder is 1.125 Bahraini Dinars (Approx. 3 US Dollars), noting that the cylinder price is not included.

Table 3: Electricity tariff and unit cost.

Category	Threshold	Consumption Range (kWh)		Tariff (files/kWh)
Bahraini	1	1	3000	3
	2	3001	5000	9
	3	5001	Above	16
Non-Bahraini	1	1	3000	13
	2	3001	5000	18
	3	5001	Above	22

Table 4: Water tariff and unit cost.

Category	Threshold	Consumption Range (m^3)		Tariff (files/m^3)
Bahraini	1	1	60	25
	2	61	100	80
	3	101	Above	200
Non-Bahraini	1	1	60	200
	2	61	100	300
	3	101	Above	400



Current month bill details - 28 day(s)

Services	Meter ID	Multiplier	Current Reading		Previous Reading		Usage
Water	12K049562	1	2428 E	23/09/2018	2389 A	27/08/2018	39 m3
Electricity	K178655	1	136041 A	23/09/2018	131989 A	27/08/2018	4052 kWh

			Government Subsidy			Customer Cost	
Services	Description	Units	Amount(BD)	Total(BD)	Price(BD)	Amount(BD)	Total(BD)
Water	Administrative Fees	1 month(s)		28.275	1.000	1.000	1.970
	Water - 1. threshold, blended	39.000	28.275		0.025	0.975	
Electricity	Administrative Fees	1 month(s)		97.240	1.000	1.000	21.270
	Electricity - 1. threshold	2700	70.200		0.003	8.100	
	Electricity - 2. threshold	1352	27.040		0.009	12.168	
Rate	Rate charge	30 day(s)				2.000	2.000
			Total(BD)	**125.515**			**25.240**

Figure 8: The electricity and water bill for a houshold for Septemeber, the total built area of the house is 200 m^2.

4.4. National programs and regulations for energy saving in households

Energy saving target of 6% by 2025 has been adopted by Bahrain, the reduction is equivalent of 5,800 GWh on primary energy equivalent basis. The National Energy

Efficiency Action plan is proposing 22 initiatives covering target efficiency improvements in both the energy demand and supply sides [10].

One of the government's first main initiatives to promote energy efficiency was the establishment of the Directorate of Electricity and Water Conservation (EWCD) under the Electricity and Water Authority, in 1999. EWCD's main objective was to sustain the water and energy resources. Alongside the energy and water conservation, the directorate also is responsible for the energy and water efficiency. The directorate conduct different activities including drafting the regulation, providing the technical support and increasing the conservation awareness in Bahrain. Moreover, in 2015 two gulf technical regulations were adopted by the Standards and Metrology Directorate (BSMD) at the Ministry of *Industry*, *Commerce* & *Tourism. These are;*

4.4.1. Regulation for non-directional household lamps

This regulation establishes requirements of the non-directional household lamps for placing on the market, including when they are marketed for non-household use or when they are integrated into other products. It also establishes product information requirements for special purpose lamps. Companies or individuals who are found to be importing or selling non-compliant products would be liable by the provision of the laws and regulation of the kingdom of Bahrain [11].

4.4.2. Regulation on energy labelling and minimum energy performance requirements for air-conditioners

The objective of this regulation is to:

1. Provide detailed information on the performance and energy labelling requirements which an air-conditioning appliance has to meet in order to carry a valid energy efficiency level, and
2. Provide detailed information on the performance requirements, which an air-conditioning appliance must meet in order to meet minimum energy performance standard requirements.

The regulation covers single-package (such as window type) and split-system non-ducted air conditioners using air and water-cooled condensers, and heat pumps employing air-cooled condensers, and ducted air-conditioners using air-to-air heat pumps for residential, commercial and industrial sector [12].

4.5. Sustainable energy sources

In order to promote alternative energy sources for Bahrain the National Renewable Energy Action Plan (NREAP) was developed [3]. The NREAP considered options such as, Solar Energy (Photovoltaic), Wind Energy, Anaerobic Digestion (AD) process and Landfill Methane Recovery.

The renewable energy action plan, which includes the development of both distributed generation and large-scale solar projects, sets the national target of renewable energy in the Kingdom of Bahrain at 5% by 2025 which will be further boosted to become 10% by 2035. To fulfil this goal, Bahrain has approved in late 2017 to develop a solar projects with the collaboration of the private sector.

In February 2018, the Minister of Electricity and Water Affairs announced the implementation of the Net metering to encourage the integration of Renewable Energy into Bahrain power system, especially for the household rooftop solar PV. The net metering will allow electricity consumers to connect their renewable energy systems to the distribution network through the Net Metering Resolution and Connection Agreement. The main objective of the Resolution is to establish a clear legislative framework regulating the Connection of Renewable Energy Generators to the Electricity Distribution System. The metering system consists of two meters; one is a bi-directional meter ('tariff meter') that will be installed by the Electricity and Water Authority (EWA) without any additional cost to the producer. The second is the "renewable energy meter" to be installed by the independent contractors approved by EWA. On 29^{th} March 2018, the government announced that Bahrain had connected the first house with the rooftop solar photovoltaic system to the national grid. As part of this initiative, the Ministry of Housing has started installing solar panels on the roofs of newly built social houses in different areas in Bahrain.

5. Socio-economic Aspect

The social awareness and acceptances are the main driver of any plans related to energy. To measure the public readiness, a survey was conducted to measure the public awareness and willingness to the use of renewable energy, especially solar energy for houses. The survey was answered by 1,044 individuals, which 94.4% are Bahraini, and 5.6% are non-Bahraini, with females majority (65.2%) and with more than 60% aged between 15-25 years. This age group are not currently responsible for paying the energy cost but, they may be the most energy consumer within the household.

Increasing the awareness among this age group will help the energy management and the deployment of the smart solutions, which will have direct impact not only on their energy bill but also the environment in general.

It was found that 95% of the respondents are willing to install solar PV on the roof of their houses with 3.3% only believing that this would help in reducing their electricity bill. This shows that although the idea of using solar energy is highly accepted by the public, the confidence level toward the direct impact on their utility bill is low.

To meet the increasing requirement of the energy load, it is highly required that the new generation work on making the current resources more efficient by deploying a national strategy to involve the young generation in the decision of the energy management, being allowed to monitor and control their houses energy consumption using the ICT technologies, for example.

6. Conclusions and Recommendations

One of the challenges that may encounter the different energy strategies for energy efficiency and energy diversification is the full understanding of the energy consumption and the energy losses, or leakages in the system. However, the energy consumption by itself is dependent on many factors based on the source of demand. In Bahrain, household's energy consumption plays a significant role in the total energy stress, which is highly dominated by the air conditioning systems. The efficiency of the cooling systems will be one the main factors, but the weather conditions contribute on justifying the total energy consumed by the cooling systems. Nevertheless, household's energy consumption varies across different building types, age, location and number of people living in that building. Consequently, assessing the relation between the different factors will help to draw a wider picture to the optimal energy consumption for the different households buildings in Bahrain, hence provide a better understanding and monitoring of the energy consumption and losses in the system, and to suggest the suitable smart energy management solutions.

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