An Overview of Smart Grids in the GCC Region

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Abstract. The members of the Gulf Cooperation Council (GCC), namely Qatar, Bahrain, Saudi Arabia, Kuwait, Oman, and United Arab Emirates (UAE), are facing challenges to meet the growing electricity demand and reduce the associated hydrocarbon emissions. Recently, there has been a pressing need for a shift towards smart power grids, as smart grids can reduce the stress on the grid, defer the investments for upgrades, improve the power system efficiency, and reduce emissions. Accordingly, the goal of this paper is to delineate an overview of current smart grid efforts in the GCC region. First, we present a detailed overview of the current state of the power grids. Then, we classify the efforts into three broad categories: (i) energy trading and exchange through GCC interconnection; (ii) integration of renewable resources; and (iii) demand side management technologies for shaping the demand profile.

Keywords: Smart grids · Gulf Cooperation Council · Qatar · Bahrain · Kingdom of Saudi Arabia · Kuwait · Oman · United Arab Emirates (UAE)

1 Introduction

Over the last few years, the fast-growing energy needs in the GCC region has intensified a central challenge: how to reduce the cost power systems operations and minimize the hydrocarbon emissions. As the significant portion of the GCC economies relies on oil and gas reserves, the GCC governments show growing amount of interest to diversify their economies for the post-carbon era. To that end, there has been a substantial amount of interest in the integration smart grids. Overall, there are three primary group of interest: (1) energy exchange among neighboring states to improve power system stability; (2) integration of renewable resources to reduce carbon emissions; and (3) demand response programs to shape the load profile and lessen the cost of system operations. One essential element of such efforts is the GCC Interconnection Grid that connects the power systems of six member countries. The integration is expected to transform the region into a significant energy hub, and the network is envisioned to expand to other parts of the world, e.g., sell electricity to North African Countries and Southern Europe. The GCC members are endowed with a significant portion

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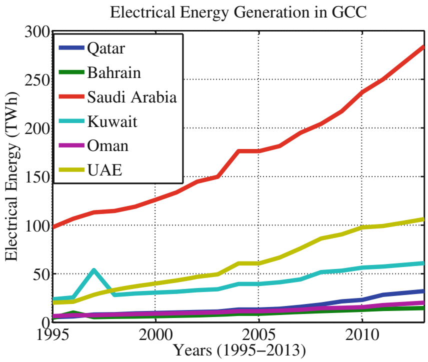
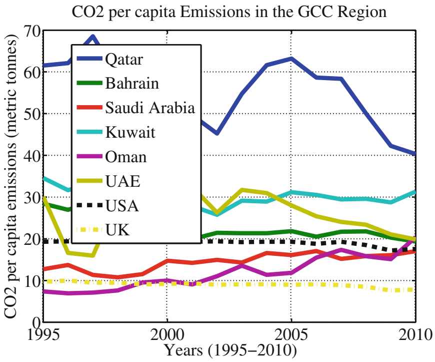


(a) Aggregated energy generation.



(b) Carbon emissions 1995-2010 [19].

Fig. 1. Energy demand and the population growth over the years. (Color figure online)

of the world's hydrocarbon resources: 33.9 % of the proven crude oil and 22.3 % of the proven natural gas resources reside in the region. Owning such abundant resources have boosted the economies and transformed the region within a mere of two decades into the world's wealthiest nations (in term of GDP per capita). In addition to the economic boom, high fertility rates, increasing population of expats, and the desire for a better standard of living have lead to a steady rise in electricity demand. The trajectory depicted in Fig. 1a shows the enormous energy demand in each country. Also, there has been a tremendous population increase respect. For instance, the population of Qatar is almost tripled within the last two decades. Moreover, gross domestic product per capita is an important determinant of energy usage. The GDP growth, not only increase the energy demand, but also rendered the region among the most carbon-intensive countries in the world. According to 2010 World Bank data, Qatar, Kuwait, Oman, and UAE are the top four nations with the highest emissions per capita [19] and an overview of carbon emissions is depicted in Fig. 1b.

Another primary driver behind the rise in energy consumption is that GCC governments provide substantial subsidies both in electricity and oil tariffs. This policy serves as a means to redistribute the wealth among the citizens. However, reduced tariffs have lead to several adverse impacts. First, low prices translated into over-consumption of energy resources. The majority of the residential energy is consumed for air-conditioning and potable water, the bulk of which comes from energy-intensive desalination of sea water. Second, the GCC governments are facing a fiscal pressure as the volatility in the international markets combined with the foregone export revenues due to over-consumption fuels represent a sizable portion of the national budgets [7]. Third, the increasing levels of carbon emissions due to high consumption raises economic concerns.

The aforementioned issues have pressed the GCC members to reform the power systems through smart grids. In order to provide the motivation for smart grids, in Sect. 2 we give an overview of the current power grids. Then, in the next three sections we present a systematic the overview of GCC interconnection grid, renewable energy integration efforts, and current demand side management programs in the region.

2 Current Power Grid Operations

2.1 Overview

The first GCC power grids were built in the early 50s when there was a need for electricity for oil drilling. With the incline of the oil prices, the region gained significant financial wealth, and the modern power grids were built in the 80s. Compared to western grids, the GCC grids are younger and equipped with modern components. On the other hand, the region often experiences excessively hot days during summers. In such periods, the demand for cooling raises tremendously thus leading to regional blackouts and threatens the security of the supply. Hence, system operators are continuously seeking ways to expand the system capacity to secure the supply.

Even though the region was served by vertically integrated utilities, typically owned by the governments, the GCC members are reforming the sector by unbundling the power generation, transmission, and the distribution segments. This will encourage private sector investments, which will allow the private sector to generate and sell electricity to the customers [3]. The primary drivers of this transformation are the need for improved operational efficiency and the fact that the private sector can quickly respond to economic and technological changes. The Sultanate of Oman is leading the privatization process. Oman is the first member country that allows independent system operators to generate and sell electricity to government authority, which handles transmission and distribution lines.

Table 1. Percentage of generation mix in the GCC. Natural Gas (NG) and Oil are considered.

	Qatar	Bahrain	Saudi Arabia		Kuwait		Oman		UAE	
	NG(%)	NG(%)	NG(%)	Oil(%)	NG(%)	Oil(%)	NG(%)	Oil(%)	NG(%)	Oil(%)
1996	100	100	44.15	55.85	62.43	37.57	82.55	17.45	96.63	3.37
2000	100	100	46.03	53.97	32.92	67.08	82.83	17.17	96.91	3.09
2004	100	100	56.95	43.05	27.68	72.32	82.00	18.00	97.66	2.34
2008	100	100	48.83	51.17	35.65	64.35	97.83	2.17	98.29	1.71
2012	100	100	44.69	55.31	36.22	63.78	97.58	2.42	98.62	1.38

The electricity dispatch curve is also an important parameter for the smart grid operations. Since, the oil and natural gas reserves are abundant in the region, the power generation depends entirely on these two sources. In Table 1, we present the generation mixture of the member countries over the years. The table reveals an interesting fact that the cost of producing electricity is quite different among the members. For instance, Qatar and Bahrain have plenty of natural gas

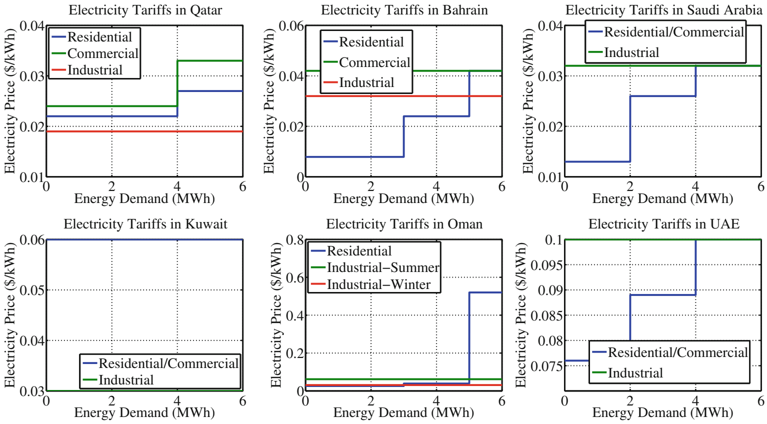


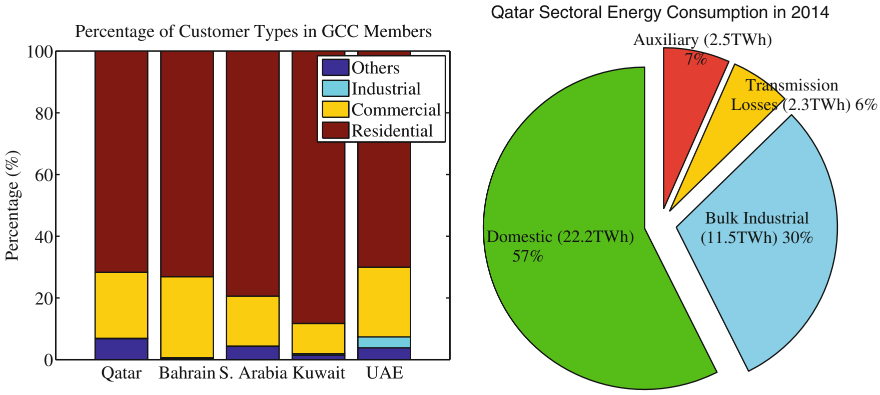
Fig. 2. Electricity tariffs obtained from Qatar [12], Bahrain [13]. Saudi Arabia [14], Kuwait [15], Oman [17], UAE [16]. (Color figure online)

resources, hence hundred percent of the electricity is generated by fossil fuels. On the other hand, countries like Saudi Arabia and Kuwait produce a significant portion of the electricity through diesel generators. Considering the cost and negative environmental impacts of such generators, the interconnection of power grids would provide a good level of savings. For instance, Kuwait and Saudi Arabia could purchase electricity from Qatar and eliminate the need for running diesel generators. Moreover, the GCC members are seeking ways to accommodate the growing demand in through diversifying their generation portfolio. United Arabic Emirates is building nuclear power plants to be operated by 2017 [20] in order to meet the 7 % annual demand growth. Also, Qatar, Saudi Arabia, and UAE have put goals to integrate gigawatt level solar farms. The details will be given in the next section.

2.2 Pricing and Customer Types

The electricity tariffs are the primary control mechanisms to shape the customer demand profile. In the business of electric utilities, the unit electricity cost is calculated through locational marginal prices (LMP) that takes into account various factors such as generator type and cost, distances to load, etc. LMP reflects the marginal cost of supplying an increment of load at each node. LMP are determined in the wholesale market via a bidding structure and details can be found in [9].

The pricing in the GCC region, however, is lower than the marginal prices as the governments provide subsidies to redistribute the wealth to the citizens. For instance, according to [7] the total subsidies in 2011 for electricity exceeded 29 billion Dollars in the GCC region. By considering the populations across the nations, the yearly subsidy per capita can be found as 556.5, 1510.1, 166.9, 1206, 522.28, and 770.81 US Dollars for Bahrain, Kuwait, Oman, Qatar, Saudi Arabia,



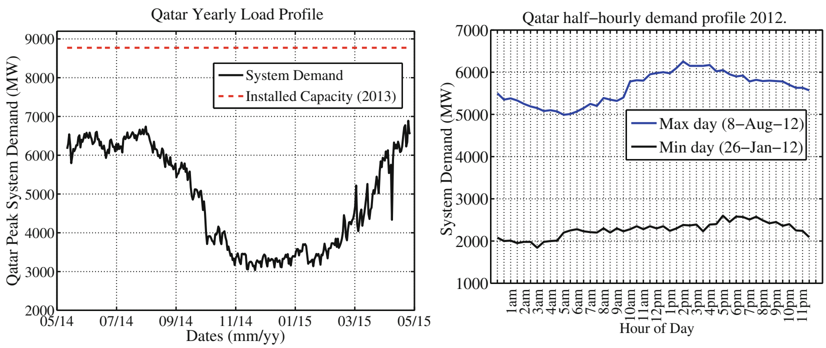
(a) Percentage of customer types [1]. (b) Energy consumption by sector in Qatar (2014).

Fig. 3. Customer types and sectoral energy usage (Color figure online)

and UAE, respectively. The current electricity prices are publicly available on the utility of each country, and we present an overview of the prices in Fig. 2. In the case of Saudi Arabia, for example, the electricity cost is one-fifth of the average US prices. Also, in the State of Qatar, the power consumption of the local citizens are entirely subsidized by the government.

Traditionally electric utilities serve three different customer types namely, residential, commercial, and industrial. The customer types are differentiated by the amount of energy/power requirements and demand curves. As depicted in Fig. 3a, residential customers constitute the vast majority of the meters. This is mainly because the industry is limited to oil and gas and severe weather and limited water resources restrict the agricultural activities. Unlike industrial and commercial customers, the energy demand of residential customers has high variability. This behavior increases the power system operating cost and reduce system utilization. Hence, this state of affairs contain an enormous potential for demand response programs for peak shaving.

Subsidized energy can, however, lead to a range of unintended adverse impacts, as it distorts price signals for consumers, with serious consequences for energy efficiency and the optimal allocation of resources. Low tariffs have lead to over-consumption of energy resources. The majority of the residential energy is consumed for air-conditioning and potable water, the bulk of which comes from energy-intensive desalination of sea water. Moreover, the GCC governments are facing a fiscal pressure as the volatility in the international markets combined with the opportunity cost incurred of exporting over-consumption fuels represent a sizable portion of the national budgets [7].



(a) Qatar demand profile in year 2014.

(b) Qatar hourly load profiles for max and min usage days in 2012.

Fig. 4. Increasing energy demand in the GCC (Color figure online)

2.3 Load Profile

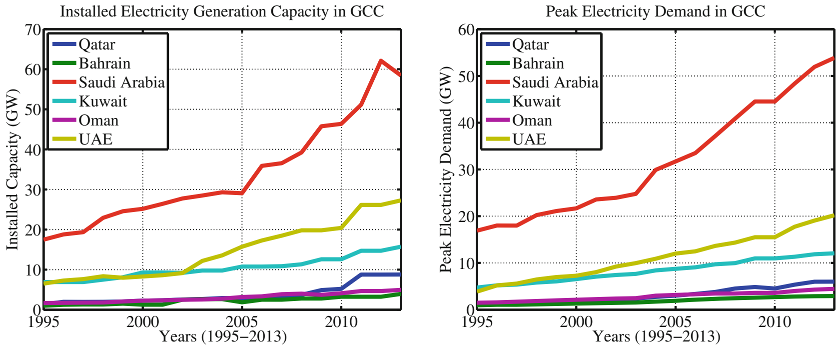
The country load profiles, daily, monthly, or yearly contain valuable information on the applicability of the potential smart grid applications. In the case of GCC members, the load profiles reveal how much energy can be exchanged and determine the potential integration renewables and demand response technologies.

Currently, there is no publicly available load profile data in any of the member states. However, the electric utility of Qatar regularly share the peak system usage on their social media page. Hence, we developed a simple data scraping software to collect the data for the last twelve months. We present the yearly load profile of Qatar in Fig. 4a. It can be seen that the peak demand occurs in August when the school season starts and there is a high demand for air conditioning. Moreover, the work in [21] states that there is a linear correlation between the daily peak temperature and the daily peak consumption for days that are warmer than 22°C. Moreover, the seasonal gap between the winter and the summer demand leads to unused system capacity that can be used trade electricity between neighboring countries. This is better depicted in Fig. 4b, where we show the half-hourly demand profile of two sample days from 2012: the first one is the day with the peak system demand (August, 8, 2012) and the second is the day with the lowest customer demand (January, 26, 2012). The results show that there is a high potential to employ demand response techniques to control electricity consumption, especially for the air conditioning load.

3 GCC Interconnected Power Grid

3.1 Overview

The interconnection of GCC power grids can be viewed as the first major smart grid activity. The main drivers of the interconnection grid are: (1) cost efficiency;



(a) Installed generation capacities. (b) Peak power generation 1995 – 2013.

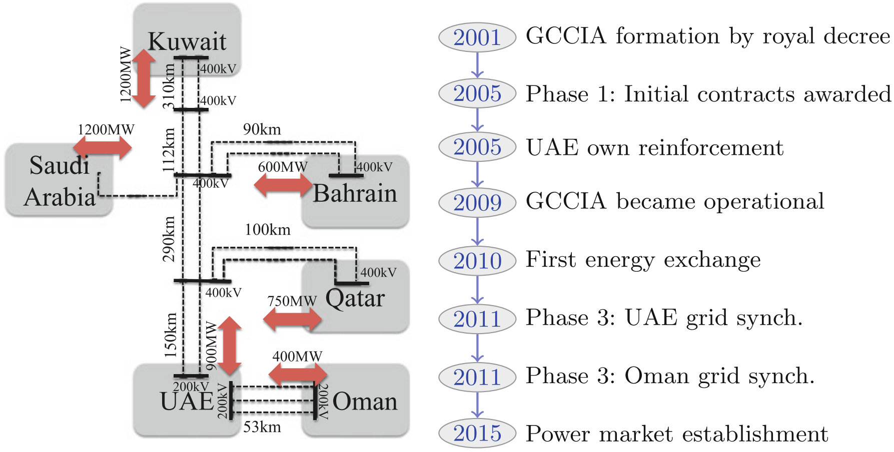
Fig. 5. Increasing energy demand in the GCC (Color figure online)

(2) shared spinning reserves; (3) deferred and reduced capacity investments; (4) lower carbon emissions; and (5) development of power markets. The growing energy demand (almost 10 % annually) and the sudden demand surges frequently threaten the supply thus requiring costly investments. For example, in Fig. 5a we present the steady increase in generation capacity expansion for each country. Consequently, as shown in Fig. 5b the peak electricity demand increases and leads to higher operation cost. Furthermore, according to the study conducted in [3], there would be a need to invest one hundred billion Dollars to meet the growing demand of GCC over the next decade.

On the other hand sharing generation and transmission resources can alleviate the upgrade requirements. Hence, the interconnection is of paramount importance. The architecture of the GCC interconnected grid presented in Fig. 6a and the milestones of the project is given in Fig. 6b. Currently, member states are in the phase of creating a power market for energy trading. The real challenge in developing this platform is to find right pricing schemes as the subsidies vary significantly across the region. The benefits of the interconnection grid summarized next.

3.2 Benefits

The benefits of the GCC interconnection grid is multifaceted. From an economic standpoint, the benefits include improved supply security, higher energy efficiency and savings through sharing spinning reserves. Also, the interconnection will reduce additional investments, and operational and maintenance cost. For instance, if Saudi Arabia can reduce total installed capacity by 2 GW, the total savings could be more than $309 million [3]. Also, it is estimated that there will be a $180 million US Dollars of savings in fuel operating costs from the entire region.



(a) Electricity map of the GCC Grid [18]

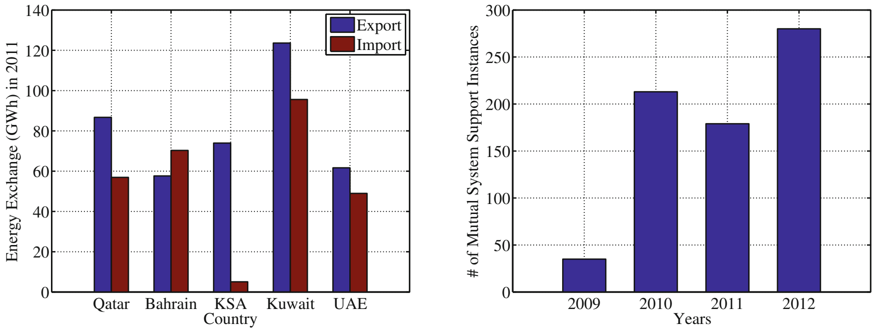
(b) GCCIA milestones.

Fig. 6. GCC interconnection grid overview

Moreover, in the case of emergencies the interconnection can provide energy supply. In fact, the security of power supply is one of the primary motivations behind the interconnection grid. According to [6], the GCC power network has prevented 250 sudden power loss incidents among the various member states. The GCC grid can also help to reduce the carbon emissions caused by the using crude oil. Countries such as Kuwait and Saudi Arabia can purchase electricity produced from natural gas, nuclear power, or solar from other countries. Also, with the help of the proper regulations, independent power producers already started to generate profit through energy exchange. Moreover, the member states are considering to create an energy market that can trade electricity with countries like Egypt, Jordan, Iraq, Lebanon, Syria, and Turkey.

3.3 Current Status

Since 2009, the GCC members invested around $1.2 billion US Dollars to build 900 km long 400 kV transmission lines and 9 substations with the same capacity. From 2009 to 2012 GCC interconnection grid has been operational and it has improved the security and reliability of the network. According to GCC Interconnection Authority 2012 annual report, more than 700 incidents occurred between 2009 and 2012. In Fig. 7b, we present the number of mutual support instances among the member states. Notice that Oman is excluded from the lists as Oman was not connected to the network until 2011. Mainly, the interconnected grid ensured that the system operates at the right frequency and voltage standards. Moreover, it prevented the system from demand disconnections. For this reason, member states exchange energy through high transmission lines. For instance



(a) Energy exchange for system support during 2011.

(b) Number of mutual support instances.

Fig. 7. The operation of GCC interconnection grid for power system stability. (Color figure online)

in 2011, 680 GWh of energy was exchanged between the members and Fig. 7a shows the amount of energy exports and imports of each GCC member.

4 Renewable Energy Integration

The GCC region is endowed with one of the world's most abundant solar resources and the integration of renewable energy has attracted systematic interest by the governments. The main drivers behind the solar energy are to minimize the electricity generation and reduce the carbon emissions. For end-users, solar generation is expected to have two applications. In the first one, consumers can install PV panels to their rooftops and generate electricity for domestic usage and sell the excess power back to the grid. Recently, UAE became the first GCC member to allow customers to employ solar rooftops.

One key issue is that the region demographics include a significant number of remote scatters farms and villages. Typically these locations operate off-grid and burn diesel generators, as the integration of the main grid is not economically viable. Hence, the second application would be to run solar panels in off-grid mode that will eliminate the need for burning crude oil.

4.1 Goals & Potential Analysis

The Global Horizontal Irradiance (GHI) defines the average electricity generated from Photovoltaic systems. The measured GHI for the GCC members are 2140, 2160, 2130, 1900, 2050, and 2120 kWh/m^2/year for Qatar, Bahrain, Saudi Arabia, Kuwait, Oman, and UAE respectively. Concentrating Solar Thermal Power (CSP) systems are also widely used for solar energy generation. For CSP technology, Direct Normal Irradiance (DNI) is used to define the average electricity generation. The measured DNI is 2000, 2050, 2000, 1900, 2200, and

2200 kWh/m^2/year for Qatar, Bahrain, Saudi Arabia, Kuwait, Oman, and UAE respectively.

The GCC governments have set solar penetration goals for solar integration. For instance, Qatar has a goal of putting 1 GW solar panels by 2020 using Photovoltaic systems. Kingdom of Saudi Arabia, on the other hand, is aiming to build 41 GW CSP by 2032. According to International Renewable Energy Agency, Kuwait seeks to create 10 MW Photovoltaic and 50 MW CSP. Similarly, Oman aims to put 700 MW solar capacity by 2020. UAE, on the other hand, seeks to generate 15 % of the total demand from solar generation by 2020.

4.2 Barriers

Even though the region has a high potential for solar integration, the aforementioned goals cannot be achieved without addressing the following issues. The first problem is with the materials of the PV panels. The efficiency of the crystalline silicon-based photovoltaic solar cells degrade with high temperature and the current technology does not perform well in the region. Hence, there has been a growing research and development interests in the region to develop new materials for PV panels for in high-temperature conditions which will also improve solar economics in the region. Another barrier to solar integration is the soiling of PV panels due to dust deposition. This is a significant factor as the region frequently experiences sand storms and the performance of the solar systems degrade significantly. For instance according to a study conducted at Qatar Foundation (QF) [22], the power loss is around $10 - 15\,\%$ per month on average. Similarly, research activities in QF include developing anti-dust technologies such as hydrophobic coatings, robotic cleaners, and electrical shields. Currently, renewable energy integration is very limited in the region because the cost of renewable energy systems compared to conventional electricity generation methods is still very costly. Hence, there is pressing need to create new policies and incentives to push the solar generation into mainstream acceptance. Also, utilities need to create a common standards and regulations and need to consider the effects of solar integration once the GCC grid is fully operational.

5 Demand Side Management

Demand side management (DSM) refers to a set of rules and policies that aim to optimize the energy consumption at the end-user side. The most popular DSM programs that have been used in practice include energy efficiency, differential tariffs (e.g., time-based tariffs, dynamic pricing), and demand response programs. Such programs are also becoming popular in the GCC region, as DSM programs can shave the peak demand and reduce the cost of system operations.

The aforementioned subsidies provided by the governments have been discouraging the investments to efficient infrastructures. Nevertheless, the GCC members recently started to invest in energy efficiency programs in buildings and transportation systems. For instance, Qatar has launched a new energy conservation program called Tarsheed, aiming to improve the energy consumption in residential and commercial buildings. Similarly, in 2012 Saudi Arabia launched the Saudi Energy Efficiency Program in order to enhance the consumption. Similar efforts are carried out in UAE: Dubai initiated a demand-side management committee to reduce energy demand by 30 % by 2030. Similarly, Sharjah of UAE has started a peak load reduction program that enforces citizens to turn off non-essential appliances during peak hours. The GCC members are gradually transforming their transportation systems from oil-based to electric-based [24,25]. Dubai is installing 100 charging stations. Qatar is considering to employ electric vehicles for public transportation for the Fifa 2022 World Cup.

Smart meters and advanced metering infrastructures are critical enablers of demand side management. Qatar utility company Kahramaa already started to deploy 17000 smart meters in Doha teamed up with Siemens for the smart meters [2]. For the case of Oman, the work presented in [23] shows that the long-term benefits of load management outweighs the required investments.

One essential characteristic of the region is that the vast majority of the energy is consumed at residential units, mostly for air-conditioning. Hence, with the help of the communication and sensor technologies, utilities can employ direct load control mechanisms to adjust the load while providing a good level of comfort. Also, the integration of social sciences could help to reduce the peak usage. Peer pressure is one of the most effective methods of reducing electricity consumption. For instance, a social study in California tries to motivate customers to reduce their consumption by comparing the individual bills with the average consumption of their neighbors. This method enables customers to reduce their consumption by 1.5 to 3.5 %. Our final recommendation is for coupling the solar generation with energy-intensive water desalination process.

Recently, the deregulation of electricity markets has provided end consumers with new opportunities to directly offer their load flexibility as a market product. For example, in the U.S., large consumers such as industrial units or commercial buildings are already eligible to participate in both the day-ahead and real-time wholesale markets, e.g., in California [26]. Such market participation is facilitated by submitting *demand bids*. As it is recently shown in [27], DSM can be co-optimized with demand bidding, leading to significant reduction in energy expenditure of time-shiftable and other flexible loads. Similar opportunities could be pursued in the near future in the GCC region once the GCC interconnection wholesale electricity market becomes operational, see Sect. 3.

6 Conclusion

In this paper, we provided an overview of the GCC power grid and smart grid efforts. We showed that the interconnection of the grid would improve grid stability, lead to efficient resource usage, and reduce the operation cost. The integration of abundant solar resources and the implementation of DSM programs can be very useful to substitute diesel generators at remote farms and villages.

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