Review of Middle East energy interconnection development

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Abstract In recent years, the Middle East region countries have experienced rapid population and economy growth, which has resulted in large increase of energy and power demand. Although the traditional fossil fuels remain the majority for supplying the domestic demand, additional generating capacity and fuel supply are necessary according to current situation and future demand forecast. The renewable energy provides an alternative resource for satisfying demand, especially in this region with high potential of solar and wind energy. Besides the development of renewable energy, interconnected electricity networks also enable the cross-border power exchange to fulfil electricity demand. Many Middle East countries have already started developing renewable energy and reforming the national power sector for regional electricity

integration. However, none of them has already implemented their targets and the challenges are still huge. This study reviews current conditions of electricity and energy interconnection development, and analyzes the process of regional electricity network integration and national power sector reforms and provides suggestion for regions' plan. Finally, the technology developments for future power grid interconnection and renewable energy integration are also reviewed.

Keywords Middle East, Energy demand, Power sector, Renewable energy, Electricity network integration, National power market reform, Global energy interconnection (GEI)

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1 Introduction

In the global economy, politics and security development, the energy always plays an important role. Each region and country in the world has to develop its own resources and establish policies based on energy. The energy consumption around the world is in the trend of rapid growing and this condition has caused both problems and opportunities. The increasing amount of carbon dioxide emissions related to energy consumption and shortage of power supply pose huge challenge to developed and developing countries. As all governments consider the energy especially electrical energy resources as the drive of country agriculture and industry, the energy development is a measure of power and the level of development in the future [1]. Due to the climate change, rising fossil fuel resource prices and increasing air pollution, the renewable energy technologies are deployed rapidly in many countries [2]. Apart from renewable energy, the reforming of

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existing power and electricity sectors in lots of countries are in process aiming at developing a more effective system for more stable power supply. In the same time, the regional electricity integrations are under studies or in operation among each huge area. The cross-border power exchange and trade make differences to each country on economy, environment and power system. A much more tied cross-border or even cross-continent power system will bring more flexibility of power supply and more opportunities of electricity market development.

The Middle East region has an important role in the global oil and gas market. Oil and natural gas resources in this region are the main source of income to countries in Middle East. However, with the rapid growing population and serious climate change, there has been a huge need for integrating the planning and design of renewable energy system [3]. At the same time, although this region is full of traditional fossil fuel, the power sectors in each country are in low level of liberalization. As the increasing demand for electricity power, a more market-oriented electricity sector structure need to be formed for flexible and stable power supply.

In this paper, Section 2 presents the current situation of energy and electricity development based on generation and consumption. This section also elaborates the potential of renewable in this region. Section 3 firstly reviews the existing regional electricity network integration in Middle East. Individual accounts of the national power sector reform are also delivered in this section. Furthermore, a review of current grid code and electricity tariff in this area is elaborated for comparison from different views. Section 4 concludes the article and provides some suggestion based on current energy and electricity development situation in Middle East.

2 Middle East energy and electricity development

The Middle East (also called Mid-East) is a Eurocentric description of region centered on Western Asia and Egypt. Formerly, the Eurocentric synonym Near East (as opposed to Far East) was commonly used. Arabs, Azeri, Kurds, Persians, and Turks constitute the largest ethnic groups in the region by population, while Armenians, Assyrians, Circassians, Copts, Druze, Jews, Maronites, Somalis, and other denominations form significant minorities [4].

The Great Middle East was a political term coined by the second Bush administration in the first decade of 21st century, to denote various countries, pertaining the Muslim world. Various Central Asian countries are sometimes also included. Some speakers may use the term to denote areas with significant Muslim majorities, but this usage is not universal. The defined Middle East in this study is in

Fig. 1 Map of Middle East

accordance with the International Energy Agency (IEA)'s regional definition as: the five North African countries (Morocco, Tunisia, Algeria, Libya and Egypt); the Arab countries in the Levant (Lebanon, Syria, Jordan and Palestine); the eight countries on the Arabian Peninsula (Saudi Arabia, Kuwait, Iraq, Bahrain, Qatar, the United Arab Emirates, Oman and Yemen) and Iran and Turkey [5]. The term 'Middle East' in the following text is defined as the countries above. The defined Middle East map is shown in Fig. 1.

2.1 Middle East energy development

The Middle East region has an important role in global energy resources especially in oil and gas agenda. Its oil and gas resources are tremendous. This region is strategically the center of Asia, Europe and Africa. Although its geographical features vary from one country to another, all countries in this region have benefited from the energy resources to different degrees. The challenges associated with this region are security, national and regional, sustainability and proper utilization of the energy resources [6].

The world's oil reserves are equal to 1706.7 billion barrels (240.7 billion tons) of oil at the end of 2016. Compared to the statistics at the end of 2015, this figure has increased from 1691.5 to 1706.7 billion barrels. As for the reserve in the Middle East region that is defined in this study, it equals to 878 billion barrels, which are 51.4% of global proven oil reserves according to [7]. The total population of the Middle East region is about 450 million. Consequently, the per-capital oil resources in this region are 1951 barrels. The reserves/production ratio is 70. Figure 2 shows the shares of oil reserve in different regions around world in 2016.

The world's natural gas reserves are equal to 186.6 trillion cubic meters (6588.8 trillion cubic feet) of natural gas at the end of 2016. According to [7], the total figure of the Middle East region proven natural gas reserves is equal to 87.2 trillion cubic meters, which are 46.7% of global natural gas reserves. The per-capital natural gas resource in

Fig. 2 World oil reserve in 2016

this region is 193777 cubic meters. The reserves/production ratio is 124.5. The proven natural gas reserve in 1980 was about 25.6 trillion cubic meters. It has been more than tripled to 87.2 trillion cubic meters in 2016. The similar pattern also applies to oil reserve in this region.

The Middle East is an important region of the world to study the energy consumption and future of energy because this region of the world has experienced impressive increases in economic growth energy demand [8]. Middle East energy consumption is increased by 2.1% in 2016, which is half less than its ten-year average (+ 4.5%). Its share of global energy consumption reaches 8.8%. The natural gas now hits a record 51.5% of energy consumption in the Middle East. Although the energy demand in this region is increased relating to great economic growth, the production of its primary energy is still larger than the consumption. More than half of the produced primary energy is exported to other region. The Middle East still plays an important role in energy exporting as it provides more 46% of global crude oil exports. The primary energy generation and consumption conditions in Middle East are shown in Fig. 3.

In the Middle East region, the oil production was 34548 thousand barrels daily (kb/d) at the end of 2016, which was

Fig. 3 Middle East energy production and consumption

37.5% of global production of oil. Iran and Iraq were the largest contributions to the growth of oil production. The oil consumption was 11582 kb/d, which was 12.0% of global consumption of oil. Oil consumption in the Middle East rose by 1.6%, driven by growth in the UAE and Turkey. Consumption in the rest of the region was flat on aggregate. The share of Oil consumption fell to 46.7% due to growth of natural gas. The oil exports rose by 1600 kb/d, which hit 46% of global crude oil exports.

The natural gas production was 781 billion cubic meters in the Middle East region at the end of 2016, which was 22.0% of global production of natural gas. The growth was led by Iran and Algeria. The natural gas consumption was 645.7 billion cubic meters, which is 18.2% of global consumption of gas. The growth was driven by Iran and Saudi Arabia. More than half of primary energy consumption in the Middle East is now sourced from natural gas. The natural gas exports increased by 1.9%, driven by an increase from Qatar, the world's largest liquefied natural gas exporter.

2.2 Middle East electricity development

Electricity is just one of several energy commodities, but its importance extends beyond serving as the source of energy for the rapidly growing number of modern micro-electronic-controlled energy end-uses [9]. An economy's production and consumption of electricity are basic indicators of its size and level of development. Although a few countries in Middle East export electric power, most production is for domestic consumption. In Middle East, the crucial role of electricity is attributable to the extreme climate. The strong interlinkage between electricity and water has come to be known as the energy-water nexus [10]. Furthermore, air conditioning is another highly electricity-intensive process guaranteeing people's life standards in summer time. The modern life in desert areas of Middle East cannot work through without the supply of electricity.

With the growing populations, rapidly developing economies and rising living standards, electricity has been the region's fastest growing energy commodity. In Fig. 4, it is shown that after 26 years, the electricity consumption in Middle East has been increased from 310 TWh to 1400 TWh. The generation is also increased at the same time. However, different to the condition of primary energy, the electricity generation and consumption is nearly balanced in this region especially before 2000, which proves that there was no extra electricity for cross-continent trade and the electricity infrastructure condition was not good enough compared to other regions in the world at that ages. However, this situation has been changed due to the growth of electricity consumption. The electricity sectors in this

Fig. 4 Middle East electricity generation and consumption

region was improved to satisfy the increasing demand after 2000. In the Middle East region, the final electricity consumption was 1400 TWh in 2016, which was 6.7% of global electricity consumption. The four highest consumers of electricity in the Middle East region in 2016, Saudi Arabia, Iran, Turkey and Egypt represented 63.2% of the Middle East region electricity consumption. The largest share was represented by Saudi Arabia at 20.5% [11]. The electricity generation was 1750 TWh in this region in 2016, which was 6.8% of global electricity generation. The four highest producer of electricity remained the same with the consumers in the Middle East region, representing 62.2% of the whole region's electricity production. The largest share was represented by Saudi Arabia at 22.2%.

In the Middle East region, the electricity capacity was 610 TW, which is 6.0% of global electricity capacity in 2016. The four highest capacity countries in the Middle East region, Iran, Turkey, Saudi Arabia and Egypt represented 62.2% of the Middle East electricity capacity. The largest share is represented by Iran at 19.1%. The electric power transmission and distribution losses in this region in 2016 were 223.1 TWh and the rate of electric power transmission and distribution losses is 12.1%, which is 150% of world standard [11]. The electricity infrastructure for generation and transmission still needs improvement.

Although the topic for developing renewable energy is quite popular among the world and lots of Middle East countries government has already invested for renewable energy due to its large potentials, the current application of renewable energy is limited. Figure 5 shows the proportion of electricity generation from fossil fuels and renewable energy in Middle East. The electricity production from fossil fuels in the Middle East region in 2016 was 1631 TWh, which was 93.2% of total electricity production in this region. The shares of oil, natural gas and coal for electricity production were 30%, 62% and 1.1% respectively [12]. While the electricity production from

Fig. 5 Proportion of electricity generation from different resources

renewable energy in the Middle East region in 2016 was 119 TWh, which was 6.7% of total electricity production [13]. The development of renewable energy in Middle East is still in beginning process especially for non-hydropower energy. Fortunately, nearly all the Middle East governments have realized the importance of renewable energy and set different policies and targets for future plan.

2.3 Middle East renewable energy development

The Middle East region is blessed with all the natural resources necessary for a vibrant renewable energy sector: Lots of sunshine, strong winds and, in a few places, powerful rivers. According to World Bank estimates, the region receives between 22%–26% of all solar energy striking the earth. This translates to a potential for solar energy per square kilometers per year equivalent to the energy generated from 1–2 million barrels of oil [14]. Direct normal radiation (DNR) and global horizontal irradiance (GHI), which are measures of suitability for concentrating solar power (CSP) and photovoltaic (PV), range between 2000 and 2500 kWh/m²/year in the Middle East region [15]. As for wind energy, it is currently the least cost type of renewable energy technology. In the Middle East region, all the countries have good wind energy potential especially Oman, Egypt and Morocco with more than 2400 hours per year full load hours for wind turbine.

From 2008 to 2016, non-hydropower renewable power generation in the region had increased tenfold to reach almost 23 TWh and grow at a much faster pace than conventional energy sources. Although wind is the largest renewable energy source in the Middle East region, the growth of solar power generation has been the fastest in recent years. Both PV and CSP plants are in commissioning in Algeria, Egypt, Iran and Morocco. In 2014, the world's largest CSP plant was also constructed in the UAE [16]. By March 2016, the total electricity capacity from

existing renewable energy projects in this region was over 57 GW. The newly built renewable power plant covers 3.4 GW. Around 66% of these projects are wind and solar, totalling 0.9 GW and 1.3 GW, respectively. Turkey, Egypt and Morocco are clear leaders in the region for operational wind capacity [17]. From 2010 to 2016, the average annual growth rate of solar PV production was at least 160%. Focusing only on the number of countries with solar PV installed capacity, it is evident that this technology is more widespread than wind power in the region [18]. In terms of renewable energy capacity in this region, Turkey, Iran, and Egypt stand out with 34, 10, 3.6 GW in current situation, respectively. Although Turkey and Iran take the top 2 positions for renewable power generation, they are both based on hydropower. When it comes to wind and solar power, Morocco and Palestine could be on the top position in this region except Turkey. Furthermore, other countries, notably Saudi Arabia, also have very significant programs under way.

The expansion and development of the region's renewable energy resources are driven by a number of crucial factors: energy security enhancement; major energy demand growth due to population increases; urbanization and economic progress [19]. With high fossil fuel prices resulting in both steep bills for net oil-importing countries (NOIC) and opportunity costs for net oil-exporting countries (NOEC), renewable have become an increasingly attractive alternative to domestic electricity consumption. Renewable energy is also cited as a potential means of industrial diversification, new value-chain and employment activities, technology transfer, and improved environmental footprints.

The trends of developing renewable energy have been accompanied and caused in part by a rapidly changing set of policies, targets, regional cooperation activities, and institutions in the Middle East region. In the middle of 2013, the Middle East countries had set renewable energy policy targets, and 18 countries had introduced renewable energy promotion policies to help achieve those targets. For most of the Middle East countries, the primary goal of setting renewable energy targets and policies relies on reducing the dependence of fossil fuels, especially for NOIC [20, 21]. However, the NOEC would concern about the rapid growth of domestic electricity consumption, which will suppress the exporting of fossil fuels [22]. The overall renewable energy share targets in the Middle East region is in [17]. Most of countries set the target renewable energy share at around 10% of electricity generation by 2020. However, due to the difference of dependence on fossil fuel, the targets of NOIC and NOEC are different. Most of NOIC set ambitious targets in order to reduce the dependence on fossil fuel importing. These targets are normally higher than the average and the details of

different renewable energy proportions in the future are set. However, the targets of NOEC are lower than the average and the details are not as specific as the ones in NOIC.

Apart from setting the policy targets, at least 18 countries had some type of policy to promote renewable energy power generation by 2013. The popular regulatory policies for renewable energy utilized in Middle East are feed-in-tariffs and net metering, which are related to power generation. For most of NOIC countries, these policies are more elaborate and better promoted, as they have strong incentives for reducing dependence of fossil fuels. As for NOEC countries, the policies about fiscal incentives and public financing are more suitable and better developed for them.

Feed-in-tariffs (FITs, also called premium payments, advanced renewable tariffs, and minimum price standards) are a common policy type in the electricity sector worldwide. Some Middle East countries have already adopted FITs for promoting renewable energy in order to meet the targets. However, the FITs policy applied in each country is different due to different purposes. According to different renewable energy resources, the Palestinian Territories implemented a new FITs in 2012 with different tariffs based on each renewable energy developing technology. Palestine modified the FITs of solar and wind power into a much cheaper stage in order to expand the production. Iran and Algeria set fixed tariffs for annual use, while it differs from day-peak times and loads. Some of the countries just adopted FITs for commissioning, Saudi Arabia and Egypt are currently discussing FITs for small-scale renewable project. Syria and Jordan both enacted new FITs for complement to renewable energy law [17].

Apart from FITs, net metering is also applied in lots of Middle East countries. As for renewable energy quota obligations, only Palestine set requirements for the addition of 110 MW of on-site generation capacity from decentralized renewable systems, as well as up to 800 MW of large wind plants, 460 MW of solar systems and 210 MW of biogas and waste generation plants, all to be grid-connected by 2014 [23]. In addition to the above regulatory policies, the fiscal incentives and public financing are also introduced for promoting renewable energy. Eleven countries have each different forms of fiscal incentives, including capital subsidy, tax reduction and investment credits. As for public financing, it is widely utilized in 15 countries in Middle East. The public competitive bidding processes for fixed quantities of renewable energy are the most common method among this region. Additionally, the public investment, loans and grants also make up for the financing.

Currently, the major challenge is not only the development of renewable energy or its related regulations, policies and investment. The grid infrastructure needs to be

enhanced to provide a reliable supply of power and integrate an increasing share of power from variable renewables. The problems with renewable energy will be focused and solved as the policies will be evolved and updated. At the same time, the integration of electricity network in the Middle East region should also be considered for better application of energy.

3 Integration of electricity network in Middle East

The Middle East countries have experienced rapid economic growth in recent years. The high economic growth has triggered a significant energy demand, especially for electricity. With the new generating capacity, the power grid infrastructure also needs to be improved for stable transmission and distribution. At the same time, the energy demands are so huge that the only domestic energy is insufficient to meet the needs of their power sectors, which has resulted in energy and electricity imports. These problems finally have led to attempts to construct cross-border electricity infrastructure facilities. Besides enabling energy imports, interconnected power networks impart a series of additional benefits such as improved system reliability, reduced reserve margins, reactive power support, and energy exchanges that take advantage of daily and seasonal demand diversity and disparities in marginal production costs. The enabled cross-border trade in power sector can also help alleviate supply constraints and reduce the investment required to meet the rapidly growing demand for power. After recognizing the benefits of regional integration, several bilateral and sub-regional initiatives are under way to interconnect the electricity networks of Middle East countries in an effort to establish integrated electricity systems for electricity exchange and trade [24]. Figure 6 shows the existing and planned grid interconnection in the Middle East. Spain and Italy are also involved in the interconnection. The primary regional energy interconnection schemes among Middle East countries include:

- 1) The Maghreb regional energy interconnection.
- 2) The Eight Countries [EIJLLPST] regional energy interconnection.
- 3) Gulf Cooperation Council (GCC) regional energy interconnection.

Although these three regional energy interconnection have been constructed for some time, electricity trade among Middle East countries has remained modest due to different challenges and problems. The Middle East region presently has one of the world's lowest levels of traded electricity production despite estimates that investment costs to meet the growing electricity demand could be

Fig. 6 Existing and planned grid interconnection in Middle East (the solid line represents “existing”; the dash line represents “not operational/island operation”; the dotted line represents “under-consideration, -study, -construction”)

reduced by up to 35% with a fully integrated Middle East electricity grid [25]. The physical challenges such as non-existent grid energy interconnection between the GCC and other Middle East countries make the trade between them currently limited. The structural and institutional challenges like the vertically integrated electricity markets in most countries in this region result in state-owned monopolies and make the international trade more complicated. Furthermore, there is few independent and informed third parties of regulatory agencies in Middle East countries, which poses regulatory challenges towards the current power sector with traditional energy system.

3.1 Maghreb regional energy interconnection

3.1.1 Whole regional overview

The Maghreb regional energy interconnection was initiated in the 1950s including Morocco, Algeria and Tunisia. The original grid connection between them was in a low level but it has evolved into the 400 kV transmission interconnection now. In the late 1990s, Morocco was connected to Spain by a 400 kV double circuit, which promoted the process of synchronization to European electricity transmission network.

After the connection between Morocco and Spain, the trend to integrating European and Maghreb electricity grid was rapidly accelerated. The increasing power demand in Maghreb needs large amount of electricity imports. As a developed regional power system, the surplus of European power system can easily satisfy the demand in Maghreb.

On the other hand, the development of renewable energy has created a lot of interest in the production of solar electricity in the Maghreb region for export to Europe. The solar electricity imports from CPS produced in Maghreb and buffered by local thermal energy storage are proved able to provide renewable base load and balancing power that is badly needed for sustainable European electricity mix [26].

All the aforementioned reasons strongly drive the Maghreb countries to merge their different national electricity systems into a larger and regional market that integrated with European electricity market. The political will for this target was expressed by the governments of the Arab Maghreb Union, which in 1989 created the Maghreb electricity committee *Comite' Maghrebin de l'Electricite'* (COMELEC). Besides the realization of a common internal electricity market, COMELEC envisages, as a long-term goal, a gradual integration and regulatory harmonization with the European electricity market [27, 28]. Particularly COMELEC members Morocco, Algeria and Tunisia have subscribed to this idea already technically interconnected with the European Network of Transmission System Operators for Electricity (ENTSO-E) since 1997. At the Euro-Mediterranean Ministerial meeting in late 2003, the European Commission and the energy ministers of the Maghreb nations signed a declaration with a protocol aimed at developing a regional energy market that would be progressively integrated into the EU electricity market. The protocol is not legally binding, but rather a declaration of intent, indicating commitment to reform. The protocol also creates a number of joint forums and institutions to bring the Maghreb countries together in the formation of an electricity market. In the protocol, each Maghreb country set its reform objective relating to introduction of competition or gradually opening of the electricity to certain eligible customers. As for the newly founded institutions: Ministerial Council; Permanent High Level Group; Expert Group; and Forum of Electricity Rules, they are composed by energy ministers from Maghreb countries, European Commission members and some energy companies. These institutions are mainly responsible for taking strategic decisions and formulating recommendations for the integration.

After several years of background work and discussion, the Ministerial Council was able to meet for the first time in Algiers on 20 June 2010 and agreed to the creation of non-discriminatory and transparent access to the transmission system. It was then agreed that the countries must work together for the improvement and harmonization of market rules for electricity. The electricity trade was required to be facilitated through harmonization of tariffs and promotion of the required infrastructure. Additionally, the development of renewables was also encouraged in the

Table 1 Electricity exports and imports of Maghreb countries in 2014

Maghreb country	Electricity export (GWh)	Electricity import (GWh)
Morocco	128	6138
Algeria	877	686
Tunisia	625	536

Fig. 7 Total amount of electricity imports and exports in Maghreb region

context of sustainable development of regional integration.

Currently, the regional energy interconnections are developed rather well but actual electricity exchanges are limited. The Maghreb grid has already been synchronized to Europe electricity grid and the energy interconnection has upgraded to multiple high-voltage transmission interconnection in the region. However, the power exchanges among Maghreb countries are still modest. Table 1 and Fig. 7 show the amount of electricity import and export in Maghreb region [29]. It shows that before the late 1990s, the balance of electricity imports and exports in this region were close to zero and the exchange amount was also in a low level. After the late 1990s, the dramatically increasing of import mainly relied on the Morocco's import from Spain, representing 20% of its power consumption. As for the export, it still remained in a low level. The region countries rely more heavily on European for power connections. The power exchange in Maghreb region was limited to mutual aid and few specific annual trade contracts. Additionally, these trades were not financially motivated due to the regional electricity market. Although the transfer capacity is efficient enough for cross-border transmission in Maghreb, the essential element to enable competition in the regional market has not been considered enough.

As the future lies with Europe, Maghreb region's immediate plans are mainly focused on expanding energy trade and transmission lines with Europe. At the same time,

the regional integration efforts are intimately related to the development of renewable energy as Europe has stronger commercial incentives for renewable energy [30, 31]. From Fig. 7, it also shows that after 2010, the amount of electricity export increased as the development of renewable energy. The synchronization with EU power grid shows a decent level of electricity interconnection within the region. However, the cross-regional interconnection with the Eight Countries region is in a low level, which limits the power exchange with this region. Consequently, a 400 kV single AC circuit is recommended to be built in order to connect Tunisia and Libya. This project is expected to enter into service in 2022.

3.1.2 Individual national power sector

The power sector in Morocco includes public and private operators. The main principle player is the Office National d'Electricité (ONE), which is responsible for managing and operating the transmission grid, generators and part of the distribution network. It serves about 50% of the nation's customers. Furthermore, it holds power-purchase agreements (PPA) with private producers [32]. The activities of the electricity market participants are regulated by various ministries, including the Ministry of Energy and Mines, the Ministry of Interior, the Ministry of Finance, and the Ministry of Economic Affairs. Since 1994 (Law Dahir 2-94-502), Morocco has a single-buyer market model with state-owned ONE purchasing all power generated in Morocco through PPAs and importing power from Spain and Algeria [33].

The power sector in Algeria was liberalized with the approval of Law no. 02-01 on 5 February 2002. The former vertically integrated utility, SONELGAZ, has since been restructured as a holding company. A single-buyer market model with SONELGAZ/OS as the independent system operator responsible for transmission grid operation has been implemented in Algeria. The government has been increasingly emphasizing efficiency and renewable energy. Algeria currently envisages the development of 2570 MW of renewable generation by 2020, including 1500 MW of concentrated solar power; 800 MW of PV and 270 MW of wind power [34].

The main power sector in Tunisia was Société Tunisienne de l'Electricité et du Gaz (STEG), which was sole supplier of electricity generation, transmission and distribution. This state-owned and vertically integrated monopoly on power generation was interrupted by introducing independent power producer to encourage private power generation in 2002. Currently, the power sector in Tunisia are STEG and two independent power producers. Nonetheless, Tunisia's power sector remains vertically integrated (STEG) without independent regulation. Tunisia

has been a pioneer among developing countries in terms of its energy management policy, having formulated and implemented a policy for the rational use of energy and the promotion of renewable energy systems as early as 1985.

3.2 Eight Countries regional energy interconnection

3.2.1 Whole regional overview

The Eight Countries regional energy interconnection was initiated in 1988 by Egypt, Iraq, Jordan, Syria, and Turkey. This energy interconnection has expanded to include Libya, Lebanon, and Palestine. At the beginning of interconnection, each country signed an agreement to commit to upgrading its electricity system to a minimum standard. After 4 years in October 1992, the original five countries signed a general trading agreement for mutual assistance through the exchange of surplus power in the region. This trading agreement was finally followed up in 1996 with a general energy interconnection agreement outlining the terms and conditions for use of the energy interconnection. The agreement also set out the scope and duties for permanent committees including a Steering Committee, a Planning Committee, and an Operating Committee. In April 2015, the power grid of Turkey was successfully synchronized with European grid, which will definitely increase the process of synchronization of power grid in Eight Countries regional energy interconnection.

Although these eight countries have undertaken tremendous efforts to improve the security of electricity and meet the remarkable demand growth, the improvement is limited in each own country's power system and the power exchange between each country is still in a low level. Nearly all initiatives of cross-border energy interconnections are limited to emergency operations instead of economical energy exchange at normal system operations. Both physical and organizational problem pose challenges and barriers for development of this region's energy interconnection. The most primary obstacle is the insufficient generating capacity. The limited surplus capacity can be only used for a moderate exchange to overcome critical system operations instead of bulk electricity trade between each country. Furthermore, the inadequate generating capacity also makes system suffer reliability and stability risk. Another physical challenge is synchronization. In this region, Libya, Egypt, and Jordan are synchronized with one another, but not with the other countries in this region. On Syria-Turkey 400 kV energy interconnection, it is operated in islanded-mode due to the synchronization problem. As for organizational problems, the single government-owned power sector in each country blocks the means for third party access to power grids, which contributes to the slow development of Eight Countries regional energy

Table 2 Electricity exports and imports of Eight Countries in 2014

Eight countries	Electricity export (GWh)	Electricity import (GWh)
Egypt	470	81
Iraq	–	12251
Jordan	64	435
Libya	–	88
Lebanon	–	136
Palestine	–	470
Syria	–	120
Turkey	2696	7953

Fig. 8 Total amount of electricity imports and exports in Eight Countries region

interconnection. The slow process of reform in power sector also make the committees unable be fully functional. The detailed power exchange in Eight Countries region is shown in Table 2 [29]. It shows the condition of each eight countries and Fig. 8 shows the condition of whole Eight Countries region.

According to Table 2 and Fig. 8, the electricity exports and imports in Egypt, Jordan, and Libya stayed at quite a low level even the power grids in three countries are synchronized. As for the majority of imports in Eight Countries region, it mainly relied on Iraq and Turkey. However, the power imported into Iraq is largely from Iran and Iran is still not in this region. The power imported into Turkey is also from Europe. Regardless, the Eight Countries energy interconnection has brought benefits. Opportunities for short-term bilateral trades have also been realized through the diversity of demand. The Turkey power grids' synchronization with Europe also promotes the process of synchronization among the whole region and provides more generating capacity. However, expanding the generating capacity could be the main target for the power development of each country and regional energy

interconnection. Different to Maghreb interconnection, the reinforcement of internal grid interconnection could be the focus of power grid construction. A second 400 kV AC circuit is recommended to be built in order to reinforce the connection between Egypt and Jordan. This recommendation also applies on the connection between Syria and Jordan. Both projects are expected to enter service in 2021.

3.2.2 Individual national power sector

The Ministry of Electricity and Energy is responsible for the electricity sector and policy formation in Egypt. The Egyptian Electricity Utility and Consumer Protection Regulatory Agency has regulatory oversight responsibility for the electricity sector without tariffs. These remain the responsibility of government. The Egyptian Electricity Holding Company (EEHC) and its affiliate are responsible for the day-to-day operation of the electricity industry including generation, transmission and distribution. The electricity market structure in Egypt is vertically integrated under the EEHC.

The Ministry of Electricity is responsible for generating, transmitting and distributing electrical energy in Iraq. Despite the separate divisions for generation, transmission and distribution under the ministry, the electricity sector acts as a vertically integrated monopoly without the benefit of independent regulation. The Ministry of Electricity is responsible for policy development, regulatory oversight, and planning for sector.

Jordan's National Electric Power Company (NEPCO) was unbundled into three operating companies, which retained responsibility for transmission. The Electricity Regulatory Commission (ERC) was formed to regulate the electricity sector in 2001. The ERC is responsible for setting tariffs and issuing licenses for activities in the sector. Jordan currently has a single-buyer market structure, but the law allows progression to a competitive market.

The General Electricity Company of Libya (GECOL) is a vertically integrated monopoly with control and ownership over all electricity generation, transmission, and distribution in Libya. The GECOL reports to the General Peoples Committee for Electricity, Water and Gas, which is responsible for policy, planning, and regulation of Libya's electricity sector. Therefore, Libya's power sector does not have an independent regulatory authority.

Lebanon's Ministry of Energy and Water (MEW) directs the country's energy policy, while Electricité du Liban (EDL) is a state-owned, vertically integrated utility with a monopoly over generation, transmission, and distribution of electricity. EDL incurs significant financial losses owing to high primary fuel costs and low retail tariffs. As a result, the utility receives significant subsidies

from the government via the Ministry of Finance. Lebanon does not have independent regulation.

The Palestinian Energy and Natural Resources Authority (PEA) manages the development of the Palestinian energy sector in West Bank and Gaza. The PEA is responsible for consolidating power supply and distribution arrangements into four electricity distribution utilities. The Palestinian Authority encourages private sector investment in energy sector especially on generation and distribution companies. Furthermore, a new law passed in May 2009 set the policy and framework for developing the Palestinian electricity sector. In this law, a new regulatory commission, a transmission company and distribution companies were established for better electricity services.

Syria's electricity sector is managed and regulated by the Ministry of Electricity, while the Public Establishment for Electricity Generation and Transmission plans, develops, operates and maintains the generation and transmission components of the electricity sector. The Public Establishment for Distribution and Exploitation of Electric Energy and its 14 regional subsidiaries are responsible for the power distribution network. The Ministry of Electricity is responsible for both policy and regulation. Although distribution is separate from generation and transmission, the electricity sector operated as a vertically integrated, monopolistic structure without competition or independent regulation.

3.3 Gulf cooperation council regional energy interconnection

3.3.1 Whole regional overview

The regional energy interconnection of the GCC involves six member states—Kuwait, Saudi Arabia, Bahrain, Qatar, the UAE and Oman. It was established in May 1981. The energy interconnection project is divided into three phases from 2009 to 2011. The regional energy interconnection now is featured with high voltage direct current (HVDC) transmission technology and high transfer capacities. The final goal of the energy interconnection is achieving the complete interlinking if the infrastructure network among the GCC states, especially in the fields of electricity, transportation, communication, and information. The GCC Interconnection Authority (GCCIA) was established in 2001 to meet the objective [35]. The GCCIA is a joint-stock commercially registered entity in acts independently of any country and organization. It has eventually become a regional player in the electricity-trade market.

The energy interconnection was targeted at sharing capacity reserve and improving supply reliability, which will reduce the need for investment in new generation

capacity at early phases. Realizing the intention in shifting towards a wholesale market structure from the traditional vertically integrated structure and the increase in private participation in the generation level, the need to engage in cross-border power exchange and trade among the GCC Countries, the GCC Interconnection Authority has developed a legal framework which defines the rights and obligations of all concerned parties, whether TSOs or the procurement arms of the GCC countries themselves [36]. The General Agreement and The Power Exchange Trading Agreement (PETA) were signed in 2009 to govern GCC countries and GCCIA. The General Agreement is a high-level agreement setting out the terms among the member states. The PETA sets out the terms in establishing a framework on which the trading parties will exchange and trade energy between their national electrical transmission systems through the GCC power grid. Apart from the legislation agreement, the additional Committees were also established for supporting a cooperative and fully regulated environment for power exchange.

Different to other two regional interconnections, the physical and regulatory environment for power exchange in GCC region is much better. The HVDC function and high transfer capacities have enabled GCCIA to achieve a high level of stability and reliability in the region [37]. The GCC region has an estimated 148 GW of installed power generation capacity representing nearly 50% of the Middle East power generating capacity [38]. It also shows technical potentials in the GCC for 65 GW of grid-connected wind energy, 34 GW of off-grid wind energy, 505 GW of grid-connected solar PV and 283 GW of off-grid solar PV for a total 888 GW of potential power generation, which is more than 6 times the current GCC installed power generation capacity [39]. Currently, there are two primary methods for trade on the GCC interconnection, which are scheduled exchanges and unscheduled exchange. The scheduled exchanges are prearranged bilateral trades between member states, which are freely negotiated between the members. The unscheduled exchanges may be needed during unforeseen contingencies [40]. However, although transfer capacities are relatively high, scheduled power exchanges to date have been limited owing to the emphasis on reserve sharing and the limited experience in trade under the new trading agreement. Compared to other regional energy interconnections, the amount of power exchange in GCC is much lower. The most important problem is lack of power grid connection with other countries outside the region. Although the grids in this region are synchronized and strongly connected, there is no connection with Maghreb or Eight Countries regions. In the year 2016, the power trading volume in GCC region has already registered 1.32 TWh with participation of five of the six member states in trading activity and concluding

Table 3 Electricity exports and imports of GCC countries in 2016

GCC countries	Electricity export (GWh)	Electricity import (GWh)
Saudi Arabia	622	560
Kuwait	238	236
Qatar	116	117
Bahrain	105	110
UAE	203	180
Oman	–	–

more than 15 contracts. The detailed power exchanges data are shown in Table 3 [41].

Actually, the amount of power exchange in GCC region in 2011 was increased by 60% compared to 2010 due to the application of new trading agreement [42]. The value of power trading in 2016 has reached US \$161 million, which made a 3.54% increase on provisions achieved to reach US \$403.81 million for whole member states. The recent work also shows that a GCC electricity market could create US \$23.57 billion in economic benefits by 2038 via reduction in fuel, operation and maintenance costs [43]. Besides the promotion of trading agreement, GCCIA plans to implement competition in generation, with vertical and horizontal unbundling of the power sectors in each GCC country. The power grid connection between Egypt and Saudi Arabia is also in consideration. Jordan has in fact signed a memorandum of understanding in 2016 with GCCIA to connect with GCC grid via Saudi Arabia as early as 2018. With all the above future plans, it would enhance the existing regional energy interconnection and fulfil full wholesale competition. The connection with other regions will definitely bring more opportunities for power exchanges [36]. Challenges for GCC electricity trade include energy price distortion due to different levels of energy subsidies across GCC countries, differences in local regulations towards cross border power trading and differences in national power sector structures [44]. As the GCC interconnection could be the most advanced one among the Middle East region, it takes more responsibility to boost the grid interconnection among the whole region. Despite the 500 kV circuit connecting Saudi Arabia and Egypt, which is in construction, three 400 kV AC double circuits projects are recommended to connect with other regional countries, which are Saudi-Jordan, Saudi-Yemen and Iraq-Kuwait connections. These projects are expected to be completed at the early of 2020s.

3.3.2 Individual national power sector

Saudi Arabia's electric supply is dominated by the Saudi Electric Company (SEC), which is a vertically integrated

monopoly. SEC is a joint-stock company with shares traded publicly in the Saudi Capital Market, though about 81% of the company is owned by the government. A 2005 law granted the ministry and the Electricity and Cogeneration Regulatory Authority joint responsibility for transitioning the power sector to a competitive market. Although Saudi Arabia is far from having a competitive electricity market at this time, unbundling plan is under way. It appears that the SEC will be unbundled into one transmission system, one distribution company and four generation companies, all under the direction of an SEC holding company. It is also anticipated that there will initially be a single-buyer market structure residing within the SEC holding company [45].

Kuwait's power sector is dominated by a vertically integrated utility owned and operated by the Ministry of Electricity and Water. There is no independent regulation and Kuwait has only recently approved its first independent power producer.

Power generation in Bahrain follows the build-own-operate (BOO) model, with several privately owned facilities. The Electricity and Water Authority acts as the single buyer of power from the BOO plants. However, it also acts as the regulatory authority for the power sector, so there is no independent regulatory agency. The Ministry of Electricity and Water is responsible for electricity production and distribution in Bahrain.

Qatar has embarked on the restructuring and privatization of its electricity sector. All power generation in Qatar is now done by the private sector and integrated water and power projects (IWPPs). Qatar General Electricity and Water Corporation buys power from the IWPPs and plan for new generating capacity. The Ministry of Energy and Industry issues licenses for power generation and transmission. The ministry monitors and ensures that licensees comply with standards, specifications and laws regulating these activities. The government has not yet appointed a regulator, so there is no independent regulation in Qatar. Owing to its small-scale of transmission and distribution system, the government is considering the implementation of a single-buyer market model.

The UAE's power sector is organized differently in each of the seven emirates. Each of the four service providers in the UAE operates as a separate entity. However, the Ministry of Energy is studying a common federal framework. The UAE's governing body, the Federal National Council, has approved a plan to privatize one of the service providers. Abu Dhabi has one of the more advanced power reform programs in the GCC, including an independent regulatory agency, the Abu Dhabi Regulation and Supervision Bureau, which regulates all companies undertaking activities associated with electricity production, transmission and distribution. Abu Dhabi is the only emirate to

implement a privatization program in the electricity sector, and the only emirate to separate the transmission function from generation.

Oman was the first GCC country to introduce the IPP and IWPP models and has successfully privatized many of its power plants. The state-owned Oman Electricity Transmission Company is responsible for the transmission network, while the state-owned Oman Power and Water Procurement Company acts as the single buyer, purchasing all electricity from generators and selling it on to the distribution companies and large consumers. There are three state-owned distribution and supply companies of which the Electricity Holding Company owns 99.99 percent and the Ministry of Finance owns the other 0.01 percent. There is a high level of private ownership in the generation sector. The regulation is the responsibility of the financially and administratively independent Authority for Electricity Regulation (AER).

3.4 Grid codes in Middle East

The grid code is a technical specification that defines the parameters a facility connected to a public electric network has to meet to ensure safe, secure and economic proper functioning of the electric system. Typically, a grid code will specify the required behaviour of a connected generator during system disturbances. In Middle East region, the countries with grid code are Algeria, Jordan, Oman, Qatar, Saudi Arabia and the UAE. As the power sectors in the Middle East countries are facing high levels of electricity demand growth, the new generating capacity and reliable power network with grid code are necessary.

3.4.1 Connection code

The Connection Code specifies the minimum technical, design and certain operational criteria for the Users for connecting to and using the transmission system. The purpose is to protect the Transmission Service Provider (TSP) facilities as well as the Plant and Apparatus of the Users, and to ensure safe, stable and secure operation of the system. The details on the performance characteristics of the transmission system and Connection Point to enable the Users to design their own facilities accordingly and to provide suitable control are also included in this code.

The transmission system shall have a nominal frequency. Due to the dynamic nature of the power system, the frequency can change rapidly under system stress or system fault conditions. Different countries have different nominal frequencies and operation requirements. In Jordan's Code, the normal operation frequency is between 49.95 to 50.05 Hz and this limitation turns to be from 48.75 to 51.25 Hz when the system is operating under stress.

Once the frequency is below 47.5 or above 51.5 Hz, the extreme fault condition is triggered and the generating units should be disconnected. Whereas in Saudi Arabia's Code, the criterion is that the plant and apparatus must be operated in accordance with to maintain the frequency within time limited. The system is allowed to work continuously between 58.8–60.5 Hz with the nominal frequency of 60 Hz. When the frequency is between 57.5 to 58.7 Hz or 60.6 to 61.5 Hz, the system is required to recover in 30 minutes. These requirements would be strictly enhanced to 30 seconds when the frequency is between 57 to 57.4 Hz or 61.6 to 62.5 Hz [46, 47].

The voltage at any point on the transmission system will normally remain within the nominal values, unless abnormal conditions prevail. In Jordan's Code, the violation is permitted in 5% of nominal voltage in the 400 kV and the 230 kV system for normal operation. This requirement turns to be 10% for the 132 kV system. Once the voltage deviates outside the above limits by a further plus or minus 5%, the system is operating under stress or the system fault is triggered. As for Saudi Arabia's Code, the nominal voltages are 110, 115, 132, 230, 380 kV. The normal operation range is between 95% and 105% of nominal voltage. However, when the voltage is between 90% to 95% or 105% to 110% of nominal voltage, the system is required to recover in 30 minutes.

3.4.2 Contingency planning

In emergencies, the security of the transmission system can come under abnormal stresses and the electricity supply systems can suffer partial or total shutdown. To deal with such eventualities, and to ensure that the system gets back to its normal state as quickly and safely as practicable, the instructions and procedure in the grid code shall be followed by the Transmission System Operator (TSO) and Users. The objective is to ensure that in the event of partial or total shutdown of the transmission system, normal supply is restored to all the users as quickly and safely as practicable in accordance with industry practices.

It is an essential requirement that the transmission system must have sufficient black start capability, which is necessary for a system recovery from a total blackout or partial blackout. This shall be achieved by allocating black start power station at number of strategic locations across the country. These kind of generating stations have the ability for at least one of their generating units to start-up from shutdown and to energize a part of the system, synchronize to the system, and energize dead bus without an external electrical power supply. The restoration plan is shown below:

- 1) TSP shall issue instructions for the generators with black start capability to initiate the start-up. The generator providing black start shall then inform TSP that its generating unit can be dispatched within 30 minutes.
- 2) Upon receipt of the instruction from the TSP, generator unit providing black start shall start-up immediately to energize a part of the system or synchronize with the system.
- 3) The TSO establishes its communication channels for the Power Island concerned and sectionalizes the transmission system into pre-determined Power Islands.
- 4) Re-energisation of Power Islands using black start stations if necessary.
- 5) Re-synchronization of the various Power Islands to restore the interconnected transmission system.
- 6) An audit of the transmission system after restoration to ensure that the overall transmission system is back to normal and all demand is connected. All data has been collected for reporting purposes.

During total blackout or partial blackout and restoration, the transmission system may be operated outside the voltage and frequency range under normal operation. Scheduling and Dispatch in accordance with the grid code should be suspended and re-implemented under the instructions of the TSO. Wherever practicable, high priority consumers such as hospitals, national and international airports shall have their demand restored first. Such a priority list, as contained in the transmission system restoration plan shall be prepared on the basis of consumer categories and the Power Island by the TSO in consultation with the TSP.

3.5 Electricity tariff

The electricity retail tariffs in the Middle East countries are generally far below the economic cost of supply. Table 4 shows the electricity tariffs for residential and industrial customers in the Middle East countries [48]. The average tariff for the residential class is based on a monthly consumption of 500 kWh. The tariff for the industrial customers is for supply at high voltage.

As can be seen, the average of the residential tariffs of the Middle East countries is only 30% of the EU benchmark tariff and the average industrial tariffs is only 37% of the EU benchmark tariff.

The main reason for this low electricity retail tariff is the subsidized energy price. Due to the subsidized energy price, the power companies are placed in a precarious position, making it difficult for them to raise funds to invest themselves or pay their suppliers. In addition to the

Table 4 Electricity tariffs comparison

Country	Residential (US cents/kWh)	Industrial (US cents/kWh)	Average (US cents/kWh)
Saudi Arabia	1.3	3.2	2.3
Kuwait	0.8	0.4	0.6
Bahrain	0.8	4.4	2.6
Qatar	2.2	1.9	2.0
UAE	5.0	15.0	10.0
Oman	2.6	4.7	2.6
Yemen	4.8	8.7	6.8
Egypt	2.5	2.5	2.5
Iraq	0.7	1.6	1.2
Libya	2.0	2.5	2.3
Jordan	7.5	6.7	7.1
Syria	1.1	8.9	5.0
Lebanon	4.6	7.6	6.1
Palestine	17.3	10.8	14.1
Turkey	15.8	15.0	15.2
Morocco	12.7	9.7	11.2
Algeria	6.2	3.6	4.9
Tunisia	12.3	6.7	9.5
Iran	1.3	2.3	1.8
Average	5.3	6.1	5.6
EU	17.3	16.5	16.9
Benchmark			

problems relating to investment and trade, subsidies lead to a number of performance, efficiency and resource allocation issues, including:

- 1) Insufficient funds for maintaining utilities.
- 2) Less optimal investment decisions and higher energy costs.
- 3) More incentives for using subsidized energy rather than alternative energy forms.

The cross-subsidization in the tariff system is also evidenced by the fact that the industrial tariff is greater than the residential tariff in many cases. The residential tariffs should be higher than the industrial tariffs because it costs more. More facilities are needed and greater losses are incurred due to the lower supply voltage. In the situation of EU, the industrial tariffs are lower than the residential tariffs. Consequently, cross-subsidization in the tariff system distorts consumption decisions and make a country's industry less competitive.

Another fundamental problem in this region is the near absence of independent and informed regulation. Tariffs are often established on the basis of political expediency and do not reflect the economic cost of supply. In some

cases, large segments of the population are unable to pay prices that reflect the economic cost of supply. Furthermore, the difficult challenge now is that the long history of subsidization and cross-subsidization in the prices of fuels and electricity have resulted in an unwillingness of the population to pay for energy.

3.5.1 Energy subsidies in Middle East

For decades, countries in the Middle East have relied heavily on the generalized energy price subsidies as their main tool to provide social protection and share hydrocarbon. The pre-tax energy subsidies in the Middle East cost about \$237 billion in 2011 according to International Monetary Fund (IMF). This amount is equivalent to 8.6% of regional GDP, or 22% of government revenue and accounts for 48% of global energy subsidies. About 50% of total energy subsidies in the region are accounted for by petroleum products, while the remainder represents subsidies on electricity and natural gas.

Energy subsidies appeal to government due to the support for direct income. However, subsidies create more problems than those they intend to address. Energy subsidies do not provide effective support to the poor and they weight on public. The distortions on economy is more directly, which leads to less concern about large energy producers. The investment of energy sector is discouraged and the incentives for waste and smuggling is created. What's more, the overconsumption of petroleum products caused by subsidies leads to negative environment externalities and slows down the development of renewable energy.

3.5.2 Reform of energy subsidies

Despite the problems caused by energy subsidies, the process of reform is difficult. The cost of subsidies is hardly reflected on the budget which makes public unaware of the magnitude and shortcomings of subsidies. If the prices of energy are increased, the short-term inflation cannot be avoided, which may give rise to expectations of further increases in prices and wages. Consequently, the government are hesitant to liberalize energy prices to avoid high volatility in other prices. Furthermore, the public are not confident of government to use savings from subsidy wisely. The politically local groups that benefit from subsidies can also block reforms. In the end, the public resistance to subsidy reform is strong especially when economic growth is slow and the history of subsidization and cross-subsidization in the prices of fuels and electricity is long [49].

There are two major approaches for reforming the energy subsidy-pricing framework – immediate and

gradual energy subsidy reforms. Immediate reform typically involves moving prices for all fuels and electricity to their respective international reference prices. Prices for traded goods such as oil, natural gas and oil products are brought into line with international prices, or above the marginal cost but below international prices [50]. Prices for non-tradable goods and essential services, such as electricity and water, equate the price with the cost of production. In this process, the immediate reform can maximize fiscal saving, freeing up funds for mitigation measures or improving competitiveness in other ways. However, it also maximizes the price shock to the economy. The regional governments may be reluctant to undertake a reform of such a magnitude.

Gradual reform of energy prices spreads price rises over multiple steps, and over a period of several months up to several years. Unlike immediate energy subsidy reform, gradual reform reduces initial fiscal savings and makes the funds available for mitigation schemes. This type of reform buys time for the economy to conduct necessary structural adjustments. However, consecutive rounds of price adjustments spread across the medium to long term increase the risk of future policy reversion due to popular opposition to the repetitive price increases. Furthermore, the government's capability of sustaining the corresponding mitigation measures are the size of price increases and the budgets of the whole government.

Jordan has followed the gradual reform approach, partially reforming its subsidy system on several occasions. The energy subsidy costs were increased from \$60 million in 2002 to \$711 million in 2005. Due to the war in Iraq, the government decided to phase out fossil fuel subsidies within three years. In 2008, the government began adjusting retail petroleum prices monthly. Based on a formula for an international benchmark netback value, its subsidy costs were reduced from 5.6% in 2005 to 0.4% of GDP in 2010. The reform went relatively smoothly due to a wide-ranging compensation package that included increasing minimum wage, cash transfers, tax exceptions for basic goods and temporary removal of sales tax for taxis and public transport. In order to protect low-income households, the subsidy on liquid petroleum gas (LPG) was not removed. A large public communication campaign and consultations with community stakeholders also contributed to the successful implementation of the reforms. Between 2010 and 2012, the government also made a few other attempts to reduce subsidies. Figure 9 shows the process of subsidy system reform in Jordan [51].

3.5.3 Electricity tariff setting

As the electricity tariffs in the Middle East region are far below than the world standard, the details of electricity

Fig. 9 Process of subsidy system reform in Jordan

tariff setting are described in this chapter for further analysis. The settings in Saudi Arabia are selected to stand for GCC region interconnection. Similarly, the settings in Tunisia and Jordan are also selected to stand for Maghreb and Eight Countries region energy interconnection.

SEC is responsible for the electricity tariff setting [52]. The basic electricity tariff differs from amount of electricity consumption in Saudi Arabia. The residential electricity tariffs change as the consumption increases for each 1000 kWh, from 5 Halalah/kWh for less than 1000 kWh to 26 Halalah/kWh for above 10000 kWh. Furthermore, the time of use (TOU) tariff is introduced which is deemed one of the best methods internationally applied in the electrical power tariff domain. Reduced prices are offered during the times when demand is low, and these prices are increased when the demand is high. The application of TOU tariff is set on industry and private commercial facilities in Saudi Arabia.

The industrial tariff is regulated by the Electricity and Cogeneration Regulatory Authority (ECRA). It provides for the application of the TOU tariff for the factories with more than 1 MVh capacity [53]. The tariffs for industry in summer are divided into 10, 15, 26 Halalah/kWh according to different daytime. The TOU tariff enables customers to optimally use electrical power during the peak hours and assists them in decreasing their electric power bills values. What's more, the rate of demand on the electricity power is accelerated to keep up with the economic growth. Another TOU tariff application is the commercial sector. Apart from the normal commercial segments, SEC also offered to the big commercial customers the option of TOU tariff for

the electric power use according to the daily consumption time, for the purpose of providing other options and ensuring continuity of service. The tariff is 17 Halalah/kWh for off-peak time in summer and 76 Halalah/kWh for peak time.

Although the process of electricity tariff regulation in Saudi Arabia has been in a decent progress, it is still difficult to estimate corresponding cost-reflective electricity tariffs in GCC countries. The subsidized prices would undermine incentives for producers in one country to export electricity via bilateral contracts to consumers in another. In addition, the bilateral contracts between producer in one country and eligible consumers in another is not allowed in current institutional arrangements [54]. The domestic pricing policies could be a barrier to active electricity trade. A suitable trading arrangement should be established in the future. The economic cost differences should also be sufficiently high to justify active electricity trade.

As a government power sector monopoly, only STEG is authorized to buy electricity fed into the network in Tunisia. Indeed, STEG is both the network manager and the buyer of electricity from both independent power producers and auto producers. In general terms, any producers which supply electricity to the STEG distribution network may command the same tariff that it pays to STEG. In principle, the electricity tariff is set annually by the state and calculated on the basis of a range of parameters according to the Tunisian government [55].

There are three separate tariffs for low, medium and high voltage electricity and different electricity tariffs calculated for different time slots. Fixed monthly tariffs are set according to different capacities with voltage levels. For low voltage levels, it is mainly applied to residential sectors. The fixed tariff is 500 Mill/kW/month and the variable tariffs differ from the amount of consumption. For medium and high voltage levels, the fixed tariffs are 8000 and 7500 Mill/kW/month respectively. The variable tariffs for both levels differ from daily time slots [56].

In addition, the STEG was also authorized to interrupt the electricity to customers from 1st June 2013. Consequently, the interruptible tariff is introduced as an optional fee that covers their clients whose contract is subject to high voltage and medium voltage tariffs. The subscribed customers agree to reduce their power demand on the request of the STEG. The maximum interruption duration is 45 hours a year in the months of June, July, August and September. The interruption will only take place between 11:00 am and 3:00 pm. The customer subscribed should consume more than 1 MW for high voltage and 100 kW for medium voltage. Finally, customers subscribing to this tariff receive compensation according to the contract power interruption and non-energy consumed. Table 5 shows the

Table 5 Electricity interruption compensation in Tunisia

Tariff level	Tariff	Interrupted subscribed capacity	No consumed variable compensation (mill/kWh)	Interrupted fixed compensation (mill/kWh/month)
High voltage	Hourly	< 3 MW	204	900
		≥ 3 MW	410	
Medium voltage	Hourly	< 400 kW	212	1050
		≥ 400 kW	416	
	Uniform	< 400 kW	212	500
		≥ 400 kW	465	

Table 6 Bulk supply tariff from NEPCO to distribution companies in Jordan

Distribution company		Peak load (JD/kW/month)	Day energy (Fils/kWh)	Night energy (Fils/kWh)
Jordanian Electric Power Company (JEPCO)		2.98	77.26	67.21
Electricity Distribution Company (EDCO)		2.98	87.13	68.08
Irbid District Electricity Company (IDECO)		2.98	66.34	56.29
Large Industries	Mining & Quarrying Industry	2.98	264	197
	Others	2.98	133	109

detailed scheme of power interruption compensation in Tunisia [57].

Although the total tariff levels in Tunisia are much higher than the ones in GCC countries and this condition can also be found in Maghreb countries, the electricity tariffs are still lower than the benchmarks of EU countries. The residential tariffs are higher than commercial tariffs in Maghreb countries, which proves that the reform of energy subsidies has received positive feedbacks. Although the electricity tariff regulation in Maghreb countries are in a better progress than other Middle East region, the Maghreb countries are heavily relying on energy export. Furthermore, the power sector monopoly in Tunisia will be a barrier for liberalization of electricity market in the future.

In 2002, a new electricity law was passed to open the system to the private sector in Jordan. The privatization process is now being completed with the privatization of the last production company. There are four major private production companies, one public transmission company (NEPCO) and three main private distribution companies (JEPCO, EDCO and IDECO). NEPCO purchase all energy from the producers and resells it to the distributors [58].

The sale price from the production companies to NEPCO is established by bilateral contracts between NEPCO and the producers. The sale price from NEPCO to the distribution companies and the tariffs for consumers are established by ERC. The sale prices applied by NEPCO to the distribution companies started to be differentiated across companies based on the size of company at the beginning of the privatization process. In addition, the

contract between NEPCO and large industries is also introduced. The detailed sale price setting from NEPCO to the distribution companies and large industries in Jordan is shown in Table 6 [59].

The retail tariffs structure for consumers in Jordan is divided into 6 levels according to monthly consumption of households. The flat retail tariff and time of use tariff are also included. The structure is not atypical by international standards. According to the structure in EU, the marginal tariffs for higher consumers tend to be decreased while Jordan have higher tariffs for higher consumers. As the process of privatization of power sector is nearly completed, the electricity tariff levels are much higher than the other Eight Countries regional countries. Although the values are still lower than the benchmark, its tariff at large consumption is higher than the one in lots of EU countries. The residential tariffs are also higher than commercial tariffs, which shows the success of reform of energy reforms. The enhancement of energy interconnection with surrounding countries could be a challenge in the future. As the electricity trade in Eight Countries energy interconnection region is limited due to regulatory and technical problems, the development of electricity market in Jordan can barely benefit from the production and consumption in Eight Countries region. Consequently, the cross-country energy interconnection could be the key in future electricity market development for every Eight Countries regional country.

3.6 Technology developments

Based on the current power interconnection situation in Middle East region, the high penetration of renewable energy poses the technological challenges for power interconnection. In order to deliver renewable energy from remote site, such as offshore wind farm, novel renewable energy integration technologies [60], energy storage technologies, power grid interconnection technologies [61, 65], and smart demand management technologies will need to be developed. In the following, we mainly briefly review the grid technologies for renewable integration and power grid interconnection.

For large scale renewable energy integration, there are two different approaches that could be developed. One is so called voltage sourced converter based HVDC Grid and fraction frequency transmission system., a fraction frequency transmission system is proposed to connect wind farm with the main grid in [62, 63]. Furthermore, the power generated from renewable energy fluctuates heavily during different periods. In order to smooth power output, a wind-wave farm system with self-energy storage is proposed in [64], which provide another method for integration of renewable energy. Despite the above researches, [66, 67] proposed some control schemes and protection sequence for an offshore integrated multi-terminal HVDC system. In addition, the unit commitment problem with utilization of wind generation is also discussed in [68] by a proposed chance-constrained two-stage stochastic programming.

Apart from the integration of renewable energy, HVDC and flexible alternating current transmission system (FACTS) are the power grid interconnection technologies to solve the system transmission challenges. The current GCC grid interconnection is already using HVDC. Many interconnection projects in construction or planning have also considered HVDC technologies [65, 71] in order to improve the reliability of connected systems. HVDC technologies mainly include line-commutated converter (LCC) HVDC and voltage source converter (VSC) based HVDC (recently this later technology is adopting a multiple modular structure, which is referred to as multi-modular-converter HVDC).

New developments in HVDC technologies are as follows. In [69, 70], a new approach was proposed to eliminate the commutation failure and provide fast dynamic reactive power/voltage control. In order to eliminate the commutation failure, a novel hybrid converter configuration for conventional LCC HVDC technology is proposed in [69]. Additionally, the control of AC voltage and reactive power in LCC HVDC system is investigated in [70] and a new control scheme is proposed, which makes the application of LCC HVDC system more flexible. LCC HVDC is preferred for power transmission over long

distance transmission, the VSC HVDC system in [66, 67] shows that it may be the preferred option for multi-terminal DC grid or offshore wind farm integration. While the major challenges for VSC HVDC system include DC circuit breakers, DC/DC converters, and fast DC Grid protection, etc.

The research of renewable energy integration and HVDC will also push the development of basic research and low-carbon technology. The potential research areas will not only rely on electrical power engineering area itself, but also on computer science, artificial intelligence and economics as well as big data science and technology.

4 Conclusion

The increasing of energy consumption in Middle East region has triggered in large increasing of primary energy production. As the development of renewable energy is still in initial stage, it cannot mitigate too much pressure on current energy demand. Seeking the opportunities for cooperation with European energy company could promote the development of renewable energy because of the state-of-the-art technology and stronger commercial incentives. The electricity development should be focused more on expanding generating capacity and improvement of electricity infrastructure as the total regional generation can only balance the regional consumption. The research on integration of renewable energy and HVDC systems would be the main focus of the region. During the same time, the basic research on power electronic devices and low-carbon technology will also be boosted.

Although the three existing regional electricity network integrations have promoted the power exchange and national power market reform to some extent, the remaining problems and challenges need to be solved. For Maghreb region, it is suggested that the institutional and regulatory reform should be put forward as the power trades between Maghreb countries are limited due to lack of regulatory. The HVDC grids are also recommended to utilize for transporting renewable electricity from Maghreb region to Europe. Although the technical support from Europe is crucial for cross-region interconnection, the regulatory and political context of Maghreb countries should be improved at first stage for the realization of electricity market. For Eight Countries region, the electricity infrastructure such as transmission line with high capacity is suggested to be the focus of developing plan. Due to political unrest and turmoil in the region, the electricity trade is barely implemented. To guarantee the basic power exchange, reinforcements of internal grid should be clearly considered under current situation. As for GCC regional integration, different local regulations and

different levels of energy subsidies in each regional country should be overcome by unit regulation and subsidy reforms. In addition, the distributed generation is suggested to improve the installation and operation of renewable energy plant. Additional cross-region energy interconnectors should be considered in the three regions' entire developing plan. The GCC region could be the key role to connect the other regions and form the whole Middle East region electricity interconnection. This work is in line with the development of global energy interconnection as proposed in [71] to build up a regional energy interconnection in Middle East Region.

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