Chapter

Local Energy Systems in Iraq: Neighbourhood Diesel Generators and Solar Photovoltaic Generation

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Abstract

Iraqis experience interruptions of the public electricity supply of up to 18 hours a day. In response, private entrepreneurs and the Local Provincial Councils (LPCs) have installed an estimated 55,000–80,000 diesel generators, each rated typically between 100 and 500 kVA. The generators supply neighbourhoods through small, isolated distribution networks to operate lighting, fans and small appliances when power is not available from the public supply. A single radial live conductor connects each customer to the generator and payment for the electricity is based on a monthly charge per ampere. The operation and regulation of the neighbourhood diesel generator networks was reviewed through a comprehensive literature survey, site visits and interviews conducted with local operators and assemblers of the generator sets. The electricity is expensive, the generators can only supply small loads, have considerable environmental impact and the unusual single wire distribution practice is potentially hazardous. However, the use of the generators is likely to continue in the absence of any alternative electricity supply. The diesels and networks are poorly regulated and there is scope to enforce existing standards and develop a new standard to address the hazards of the connection practice. The chapter goes on to assess the possibilities of using small photovoltaic systems for power generation in Iraq.

Keywords: diesel generator, informal electricity supply, neighbourhood diesel generators, photovoltaic generation

1. Introduction

Iraq has the 5th largest oil reserves in the world and exported, in October 2020, some 2.88 million barrels of oil per day [1] down from an average of 3.97 million barrels per day in 2019 [2]. The drop in oil exports comes in response to an agreement between worldwide oil producers to cut production and revive the oil market in response to the coronavirus global lockdowns and a collapsing demand for oil [3]. Iraq also has the world's 11th largest reserves of natural gas [4]. However, following four decades of war and international sanctions, the electricity supply system is now in a poor condition and unable to supply the rapidly increasing demand for electricity of a growing population [5].

The electricity infrastructure of Iraq was severely damaged during the First Gulf War in 1991. The sanctions imposed by the United Nations during the early 1990s further reduced electricity supply [6]. In 2003, following the Second Gulf War, the power generated fell from a pre-war value of 5300 MW to 3500 MW whereas the peak demand at that time was estimated to be 6000 MW [7]. Despite the rehabilitation of old power plants and construction of new ones, an annual rate of increase of electrical demand of more than 10% means there is now an estimated deficit of generating capacity of more than 10,000 MW [5].

After the Second Gulf War, the shortage of power led the Iraqi government to encourage the use of neighbourhood diesel generators and novel local distribution networks. Exact details of the numbers of these generators are not available. Reference [8] estimates there are 55,000–80,000 neighbourhood generators while reference [9] reports that the actual number of these generators is between 90,000 – 150,000. These medium sized (100–500 kVA) diesel generators supply 90–95% of households with about 20–30% of their electricity [5, 8]. This unusual community response to electricity shortages by using medium-size diesel generators serving neighbourhoods through a novel distribution network and tariff system is in contrast to some other oil-rich countries with poor public electrical infrastructure where small generators serve only individual consumers.

Over the last three years, encouraged by the falling costs of photovoltaic (PV) modules in international markets, the public have shown growing interest in installing rooftop solar PV systems. These small-sized (1–10 kW) systems are deployed to help residents supplement the public electricity supply and reduce their electricity bills by minimising their dependence upon expensive and polluting neighbourhood generators [10–12]. On the other hand, the Iraqi government has invited independent power producers (IPPs) to develop seven utility-scale PV solar power sites in the range between 30 and 300 MWp with a total power generation capacity of 755 MWp [13]. However, taking into consideration the recent dramatic drop in oil prices, a large deficit in the federal budget and the outbreak of the COVID-19 virus, it is thought to be unlikely that those utility-scale projects will become operational (as planned) by end of 2021 [12, 14].

2. Electricity supplies in Iraq

The Iraq public electricity system is divided into two networks, which have very limited interconnection. The smaller network of around 7000 MW of power generation capacity (in 2019) is owned and operated by the Ministry of Electricity in the Kurdistan Region of Iraq [15]. The larger network of around 27,300 MW of generation capacity, which is the focus of this study, covers Iraq Excluding Kurdistan (IEK) and is owned and operated by the Federal Ministry of Electricity.

The capacity of power generation installed in Iraq (IEK) in 2018 is shown in **Table 1**. It can be seen that the mean generation is considerably less than the installed capacity in spite of the high demand for electricity, indicating power plant is often unavailable. Generation is from gas and steam turbines with some hydropower. The large diesels listed in **Table 1** have capacities of up to 23 MW and are operated by the Federal Ministry of Electricity using heavy fuel oil.

Table 2 lists the types of fuel used in central power plants in 2018. The steam turbines are fuelled mainly by crude oil while most gas turbines are supplied by natural gas. Some gas turbines have been modified to burn crude oil, but these are then de-rated from a nameplate capacity of 2878 MW to a mean generation of 1178 MW.

The Iraqi transmission networks (400 kV in IEK only and 132 kV throughout Iraq) connect the central power plants with load centres [17]. Distribution networks use 33 kV and 11 kV to distribute the power supplied by the transmission network between primary and secondary substations and 0.4/0.23 kV to supply end-users

Power generation technology	All units	Operating units	
	Nameplate capacity (MW)	Mean generation (MW)	Generation capacity factor
Steam turbines	7305	3270	~ 0.448
Gas turbines	15,857	5521	~ 0.348
Large diesels	2327	376	~ 0.162
Hydroelectric turbines	1864	208	~ 0.112
IPPs and Imports	—	3627	—
Total	**27,353**	**13,002**	**0.475**

Table 1.
Nameplate and available capacities of IEK power generation in 2018 [16].

Power generation technology	% of total fuel burnt in generation plants				
	Crude oil	Heavy fuel oil	Light diesel	Gas oil	Natural gas
Steam turbines	75%	12.8%	~ 0%	~ 0%	12.2%
Gas turbines	20.3%	11.4%	2.2%	3.8%	62.3%
Large Diesels	0%	96.6%	0%	3.4%	0%

Table 2.
Type of fuel burnt in IEK central power plants in 2018 [16].

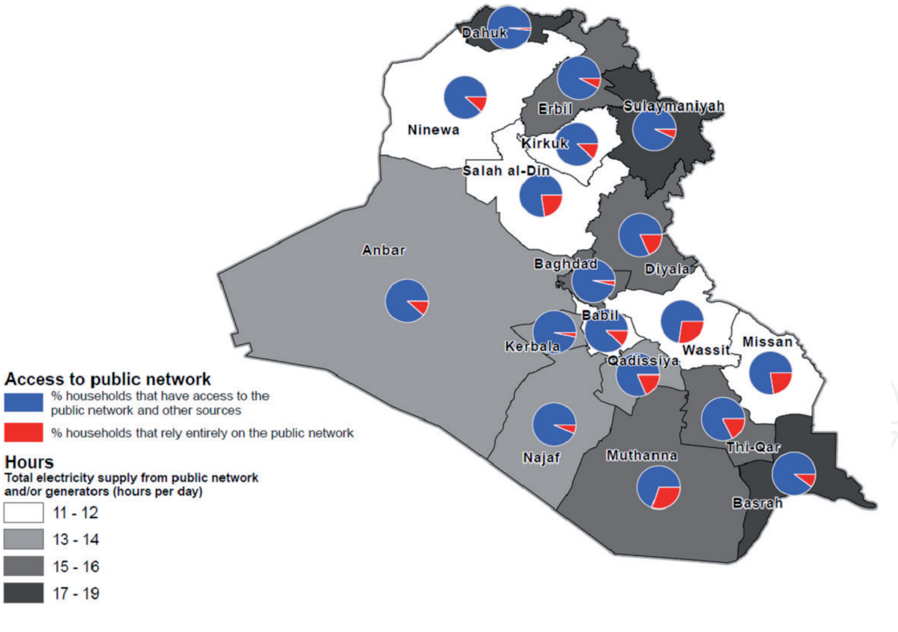

Figure 1.
Source and hours of electricity supplied to residential customers in Iraq, 2011 (Source: [18]).

with electricity. Distribution networks in Iraq are unreliable due to unplanned network growth, shortage of spare parts and lack of maintenance. The absence of effective metering and billing leads to widespread under-collection of revenues [8]. According to the International Energy Agency (IEA) [5], the aggregate technical and non-technical losses in transmission and distribution networks in IEK are between 50 and 60% of the total electrical energy generated and imported, and are among the highest in the world.

The Federal Ministry of Electricity estimated the mean power demand in 2018 to be 22,530 MW but the mean power dispatched to supply this demand was 12,109 MW [16]. For the same year, the IEA estimated the summer peak demand was about 27,000 MW and the unmet demand to be 10,500 MW [5]. The lack of electricity leads to severe hardship in a country where daytime temperatures in summer regularly exceed 45°C and has prompted most households and small businesses to rely on electricity from neighbourhood diesel generators. The source and hours of electricity supplied to residential customers in 2011 are shown in **Figure 1**. This shows that, even at that time, most households supplemented their electricity supply from the public network with a connection to the neighbourhood diesel generators or by using small individual household gasoline generators (or both). This practice of supplementing the public supply remains common. In summer 2020, electricity consumers in IEK received an average of 14–16 hours of electricity per day, with only 6–8 hours provided by the public network [19, 20].

3. Neighbourhood diesel generators in Iraq

In response to this power deficit, private entrepreneurs and the Local Provincial Councils (LPCs) have been encouraged by the government to install medium-sized diesel generators at a neighbourhood level to supplement grid supply and alleviate some power shortages particularly in the peak summer months. These generators are owned and operated either by independent entrepreneurs or by the LPCs. In Baghdad, around 18% of more than 13,000 neighbourhood generators are owned and operated by the LPCs [21]. The generating sets are usually assembled locally from reused truck diesel engines coupled to imported generators, as shown in **Figure 2**. An assembly line of a local assembler of generating sets is shown in **Figure 3**. The control panels are manufactured locally using imported components. The price of a locally assembled 250 kVA generating set is between $8500–10,000 compared to the cost of a UK made imported 220 kVA unit of $18,000 – 19,000. Larger generating sets with capacities up to 2500 kVA are imported as complete units and operated by the LPCs.

The Federal Ministry of Electricity and the LPCs regulate the installation and connection of neighbourhood diesel generators. The 'Regulations of Power

Figure 2.
Locally assembled neighbourhood generator (Source: Author).

Figure 3.
Assembly line of a local manufacturer of neighbourhood diesel generators (Source: Local assembler).

Supply to End Customers' of the Federal Ministry of Electricity [22] requires that neighbourhood diesels are electrically isolated from the public network. Electrical protection must be installed to ensure no current can flow from a generator into the public network. The Federal Ministry of Electricity records the numbers and sites of neighbourhood diesels and they cannot be relocated without obtaining permission from the Ministry and the LPCs. Apart from the technical details given in the 'Regulations of Power Supply to End Customers' and health and safety regulations, all other communications provided by the LPCs and Ministry of Electricity are guidelines only.

The LPCs provide the sites for the neighbourhood diesels, which are typically located on roadside and mid-road pavements, in public parks and near local markets [23]. **Figure 4** shows an example of a neighbourhood generator installation in urban Baghdad. Also, the LPCs define the tariffs used to charge customers and the number of hours that the neighbourhood diesels operate, but these vary between different provinces. Several campaigns by non-governmental organisations and the general public have called for clarification and enforcement of the policies and regulations for operating neighbourhood diesels.

The Ministry of Oil provides the fuel necessary to operate the neighbourhood diesels. The Ministry of Oil defines the amounts of fuel to be supplied, according to the power available from central power plants and anticipated customer electricity demand (**Table 2**). Between 2003 and 2017, fuel was provided initially free-of-charge and later at subsidised rates. After 2017, the diesel fuel was sold to entrepreneurs and LPCs at the regular retail price of 34 US cents per litre (**Table 3**).

Most residential premises in Iraq pay two monthly electricity bills, the first to the Federal Ministry of Electricity and the second to the operator of their local

Figure 4.
Neighbourhood diesel generator installed on a mid-road pavement in Baghdad (Source: Author).

Months	Amount of fuel (litre/kVA)
Summer: May, June, July, August, September	20–35
Spring: March, April	10–15
Autumn: October, November	10–15
Winter: December, January, February	5–10

Table 3.
Amount of fuel per month supplied by the Ministry of Oil to neighbourhood diesels [24].

neighbourhood diesel. Electricity from the public network is charged by energy ($/kWh) while the neighbourhood diesels sell electricity based on the maximum current the customer has chosen ($/Amp).

Table 4 shows the domestic tariffs charged by the Federal Ministry of Electricity for different levels of energy consumption. It has been recognised by the World Bank and the International Energy Agency that these very low tariffs do not promote efficient and rational use of electricity and combined with poor billing and collection, they result in very low cost recovery ratios (approximately 10%) and the electricity sector operating at a loss [5, 25].

The monthly tariffs charged by the neighbourhood diesels are divided into two types (**Table 5**). The standard tariffs of restricted hours are defined by the LPCs and apply to all generators while the premium service that provide 24-hour electricity is offered only by the private entrepreneurs. For the premium service, the entrepreneurs buy additional fuel from the Ministry of Oil at approximately 59 US cents per litre [27].

Customer type	Energy consumed (kWh) per month	Tariff (US ¢/kWh)
Residential	1–1500	0.83
	1501–3000	2.92
	3001–4000	6.67
	over 4001	10.00

All costs in this chapter have been converted from Iraqi dinars to US dollars at a rate of 1200:1.

Table 4.
Electrical energy tariffs charged by the Federal Ministry of Electricity in September 2020 [26].

		Summer	Spring & autumn	Winter	Fuel cost to operators (US ¢/litre)
Standard	*Tariffs (US $/Amp)*	10	7.5	5	34
	Hours of operation per day	10	3–10		
Premium	*Tariffs (US$/Amp)*	21	12.5		59
	Hours of operation per day	24			

Table 5.
Approximate monthly tariffs of the private neighbourhood diesel generators.

	Public network		Neighbourhood diesel generators		
	Approximate monthly		Number of amps chosen (Amp)	Approximate monthly bill (US $)	
Season (months)	Energy consumption (kWh)	Bill (US $)		Standard tariff	Premium tariff
May, June, July, August, September	1740	19.5	7	70	147
March, April	780	6.5	5	37.5	62.5
October, November					
December, January, February	1245	10.4		25	
Annual		154.7		575	1172.5

Table 6.
Approximate monthly energy consumption and bills of a typical residential customer.

There is a considerable difference in the price paid for electricity from the public network and the neighbourhood generators. **Table 6** shows the approximate monthly energy consumption and bills for electricity of a typical residential customer in IEK. The calculation assumes a 24/7 supply of electricity from the public grid with an assumed set of appliances in a typical dwelling. The electrical load is that assumed by the Federal Ministry of Electricity to estimate the consumption of households that are without a functioning meter [22]. An on-line calculator using these assumptions has recently been published by the Ministry of Electricity to help customers estimate their consumption and calculate their bills [28]. **Table 6** contrasts this cost with the charge for a neighbourhood diesel to supply only the essential loads of lighting, fans, evaporative air coolers, white goods and home entertainment systems. It can be seen that the neighbourhood diesels provide a much more expensive service to fewer appliances for reduced hours.

4. Connection of neighbourhood diesels

The circuits used for connecting the neighbourhood diesels are unusual and **Figure 5** shows how the neighbourhood diesel generators are connected using radial private wire distribution circuits of single 2.5 mm^2 or 6 mm^2 copper conductors. Single conductors connect a live phase of the neighbourhood diesels to individual

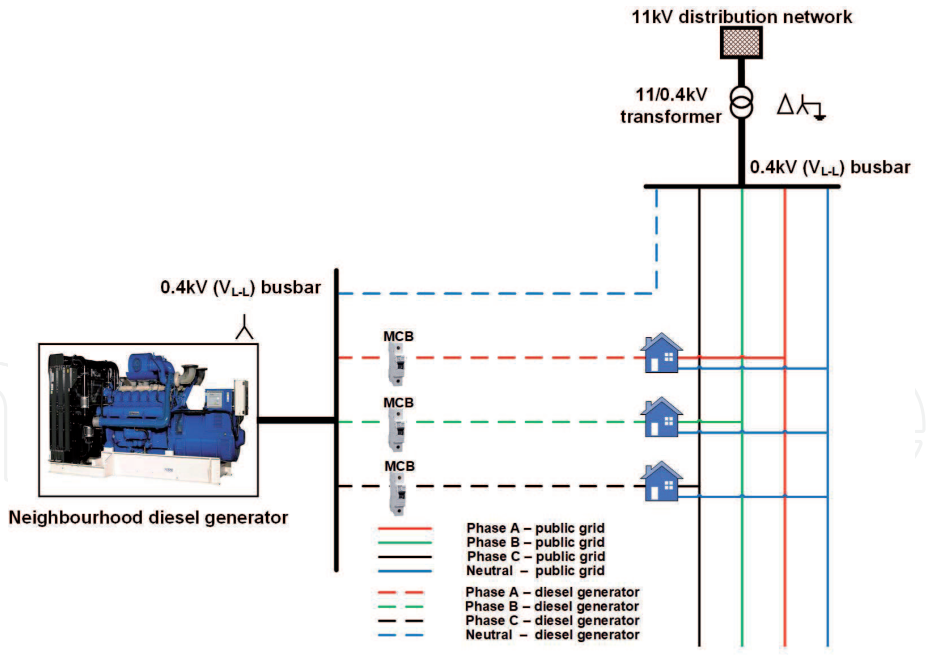

Figure 5.
Simplified diagram of neighbourhood generator connections.

Figure 6.
A miniature circuit breaker board of a neighbourhood diesel generator (Source: Author).

Figure 7.
Informal distribution circuits using redundant utility support insulators (Source: Author).

customer premises. The neutral of the generator is permanently connected to the neutral conductor of the public network. A changeover switch, either automatic or manual, is installed at the customer premises for transfer of the live phase from the public network to the neighbourhood generator when a power outage occurs. There are no clear, enforced regulations for neutral earthing (grounding) but a common practice is not to earth the generator neutral but rely on the earth of the neutral of the 11/0.4 kV distribution transformer.

This unusual neutral connection practice would contravene safety regulations in many countries. There is no means of detecting if the connection between the generator and transformer neutral is lost and, in this condition, ill-defined "floating voltages" will appear at consumers premises. If the single-phase wire to a dwelling is broken, then again there is no means of detecting this and a hazardous voltage may result. There is considerable anecdotal evidence of fires being caused by faults on these circuits and electrocution of members of the public [29–31].

Miniature circuit breakers (MCBs) in a distribution board at the generator limit the electrical current drawn by each customer. The current ratings of the MCBs are used to determine the monthly charge and also provide overcurrent protection. Most customers buy less than 10 amperes to supply only their essential loads. **Figure 6** shows an MCB distribution board supplying around 100 dwellings installed at a neighbourhood diesel generator in Baghdad.

Figure 7 shows informal distribution circuits supplying power from a neighbourhood diesel in Baghdad. In IEK, it is common for individual final circuits to radiate directly from the generator distribution board to each consumer. Problems of the distribution circuits include loose or disconnected wiring, short circuits, mal-operating changeover switches and sustained high voltages caused by poor neutral earthing.

5. Operation of neighbourhood diesels

Neither the generators nor private wire distribution networks are regulated by the Federal Ministry of Electricity and the agreements between the generator operators and customers are verbal [32]. Customers sometimes experience poor power quality with voltage and frequency falling below their rated values of 230 volts and 50 Hz when the operators reduce the running speed of their engines to save fuel. It is also known for operators to overcharge their customers [5]. The disposal of engine lubricants in public sewage systems has been reported [33] while poor handling procedures of fuel and non-compliance with electrical safety regulations have been identified as causes of fires [23, 34, 35].

5.1 Noise

It is widely recognised that neighbourhood diesel generators can create a significant noise nuisance [8, 23, 36] especially when their enclosures and canopies are removed to increase cooling (**Figure 8**).

According to the Iraq 'Law of Noise Control' of 2015 [37], the noise limits in residential areas are Sound Pressure Levels (SPLs) between 55 and 60 dBA during the day and 45–50 dBA at night, depending on the source of the noise (e.g. local crafts and industrial workshops). There are no specific limits for the noise produced by neighbourhood diesel generators. In November 2019, the LPC in Erbil (Kurdistan Region of Iraq) issued new regulations requiring that, from May 2020, all neighbourhood diesels should be fitted with soundproofing systems. Non-compliant owners of the neighbourhood diesels face fines of approximately US $ 1670 and their licences being suspended [23, 38].

Figure 8.
Neighbourhood diesel generator with enclosures removed showing exposed fan (Source: Author).

The results of national studies of noise from neighbourhood diesels are shown in **Table 7**.

In [39], the SPLs of diesel generators with and without enclosures were measured at 1.1–1.2 metre from the ground. In [40] and [41], the SPLs of neighbourhood diesels installed in the cities of Duhok and Erbil were measured at various distances from the diesel generator. In [42], the SPLs produced by 250 kVA neighbourhood diesels were measured to investigate the impacts of noise pollution in the city of Mosul using geographic information systems (GIS).

Using the data from the references in **Table 7** and a simple hemi-spherical propagation model [43], Sound Power Levels for the generating sets were estimated of between 103 and 121 dBA without enclosures and about 91 dBA with an enclosure.

5.2 Emissions of CO, SO_2, NO_x, H_2S and total suspended particles (TSP)

The location of the neighbourhood diesel generators in residential areas leads to particular concerns over local air pollution. A 'Draft Iraqi Standard' [44] defines limits on the exhaust emissions from diesel generators but the common practice of mixing the diesel or gas oil fuel with heavy oil, and poor maintenance of the engines increase the level of emissions [23, 45, 46].

Table 8 shows emissions measured in local studies. The allowable emissions from small diesel generators are shown on the top line of **Table 8** with measured

Reference	Minimum SPL (dBA) at distance (m)	Maximum SPL (dBA) at distance (m)	Notes
[39]	63.1 dBA at 10 m with enclosure	89.2 dBA at 10 m without enclosure	Size of the generator sets not provided
[40]	74.86 dBA at 50 m	98.91 dBA at 5 m	State of the enclosure not available
[41]	69 dBA at 15 m	103 dBA at 1 m	Neither the number, rating nor the state of the enclosure available
[42]	63–65 dBA at 50 m	105–109 dBA at the generator site	The number of 250 kVA generator sets is not available. All units are without enclosures

Table 7.
Measurements of noise from neighbourhood diesels.

Reference			CO	NO_x	SO_2	H_2S	TSP
[44, 47, 48]	*Maximum permitted hourly concentrations of pollutants emitted from diesel generators according to the Draft Iraqi Standard*		*(ppm)*				
			0.26	**0.05**	**0.14**	**0.005**	—
[39]	*Month of 2012*	*August*	4.25	5.98	3.40	Not measured	0.48
		September	3.50	4.60	3.15		0.42
		October	2.95	3.90	2.44		0.32
		November	2.66	2.85	2.75		0.23
[47]	*Diesel generator rating (kVA)*	*150*	1.62–2.23	0.70	0.80–1.30	0.60–1.10	Not measured
		250	2.10–2.60	0.60–0.80	0.90–1.30	0.50–1.00	
		350	2.10	0.50	1.20	0.60	
		440	3.00	0.70	1.50	1.00	
		500	2.90–3.40	0.80–0.90	1.80–2.40	1.60–2.50	
		1000	3.10	0.90	2.10	2.10	
[48]	*College of Physical Education / Al-Qadisiya University*		2.80	Not measured	0.65	0.009	Not measured

Table 8.
Concentrations of pollutants emitted from different neighbourhood diesels in ppm.

values shown on the lower 3 lines. Reference [39] records the concentrations of air pollutants from diesel generators measured between August and November 2012. Higher wind speeds in autumn spread the pollutants and reduces their concentration. Alrawi and Hazim [47] show the maximum concentrations of CO, SO_2 and H_2S pollutants emitted from new and old 150, 250 and 500 kVA generators located in Baghdad. Najib [48] measured the emissions from diesel generators installed at Al-Qadisiya University. In all cases the measured emissions exceeded those specified in the draft standard.

6. Neighbourhood diesels in Kurdistan and other countries

In the Kurdistan Region of Iraq (KRI) in June 2020 consumers received an average of 16 hours per day of electricity from the public grid [49]. Neighbourhood diesels, however, remain common with at least 5500 generators registered and operating in the region [50–52]. Connection practice differs from elsewhere in Iraq with local distribution boards mounted on utility distribution poles from which the final connections radiate to customer premises. The boards are supplied using single conductor mains of 50–95 mm^2 copper conductor. The neutral wire connection practice (employing the neutral wire of the public grid) is similar to the practice seen in other Iraqi cities. The tariffs of the neighbourhood diesels in KRI are defined in ($/Amp) for neighbourhoods that have a connection to the public distribution grid. However, the tariffs are defined in ($/kWh) for the diesel generators supplying newly built residential housing complexes which are not connected to the public distribution grid [53, 54].

In Lebanon, neighbourhood diesels (known as ishtirak or 'subscription' [55]) have been common since the early days of the civil war of 1975–1990. In 2018, these generators, described by the World Bank Group as 'illegal and informal', were used to supplement customers with 8.1 TWh of power amounting to about 37% of the total power demand in Lebanon [56]. In Beirut, which has a daily supply of about 21 hours of electricity from the public distribution grid, neighbourhood diesels make up the 24-hour supply. In other cities of Lebanon which receive less than 12 hours of public grid electricity each day, the neighbourhood diesels supply customers with electricity for up to 6–8 hours per day [57–60].

The World Bank Group and the American University of Beirut [61] report that ratings of neighbourhood diesels in Lebanon are typically below 500 kVA, similar to Iraq. The connection practice of the neighbourhood diesels employing the neutral wire of the public distribution grid is the same [58]. Also, the contracts between the private entrepreneurs and the customers are verbal. Connection practice of the neighbourhood diesels in Lebanon is to use fuse boxes (or local distribution boards) mounted on subscribing buildings rather than on poles of the public distribution grid [57, 58]. Prior to October 2018 some customers only had MCBs while others had both MCBs and energy meters. Nowadays, all Lebanese customers (old and new) are required to have MCBs (to limit the maximum current) and energy meters (for tariff charging). There is also a standing charge defined by the current rating of a customer's MCB [62].

In Syria, neighbourhood diesels (locally called 'ampere or subscription' generators [63]) supply customers with electricity due to the damage sustained by the public grid during the civil war [64]. These generators were initially employed in regions controlled by the Syrian rebels to supply customers with no more than 10 hours of electricity per day [63]. The practice was later adopted in regions controlled by the Syrian Government [65, 66]. The topology of the private wire networks of the neighbourhood diesels in Syria is similar to KRI and Lebanon with thick single live conductors supplying local distribution boards mounted on public distribution poles or subscribing buildings. The use of the public network neutral wires is similar in Iraq, KRI and Lebanon [67]. The customers in Syria are not equipped with energy meters. The tariffs of the neighbourhood diesels, regulated by the LPCs in Syrian cities, are defined in ($/Amp).

7. Current status of rooftop solar PV systems in Iraq

Iraq, located between latitude 29°.98′ and 37°.15′, has a high potential of solar energy with a mean global PV potential of approximately 4.7 kWh/kWp, global horizontal irradiation (GHI) of 5.5 kWh/m^2 and an average of 3250 of hours of sunshine per year in Baghdad [68, 69] (**Figures 9** and **10**).

However, the utilisation of solar energy for electric power generation did not receive attention until 2019 when the Iraqi government (with the aid of international organisations) became more active in formulating a solar policy for the country [12]. Licences have been awarded for private companies to install residential solar power systems [71], technical specifications for these solar systems have been defined [72], and investors (local, international and IPPs) have been invited to construct grid scale solar plants [13] and pilot rooftop residential solar systems [73].

7.1 Specifications of rooftop solar systems

The technical specifications of rooftop solar PV systems issued by the Federal Ministry of Electricity imply that when the systems are financed by soft loans, they must be hybrid systems. Hybrid solar systems (**Figure 11**) combine the functions of solar panels, inverter, maximum power point tracker (MPPT), battery charger and

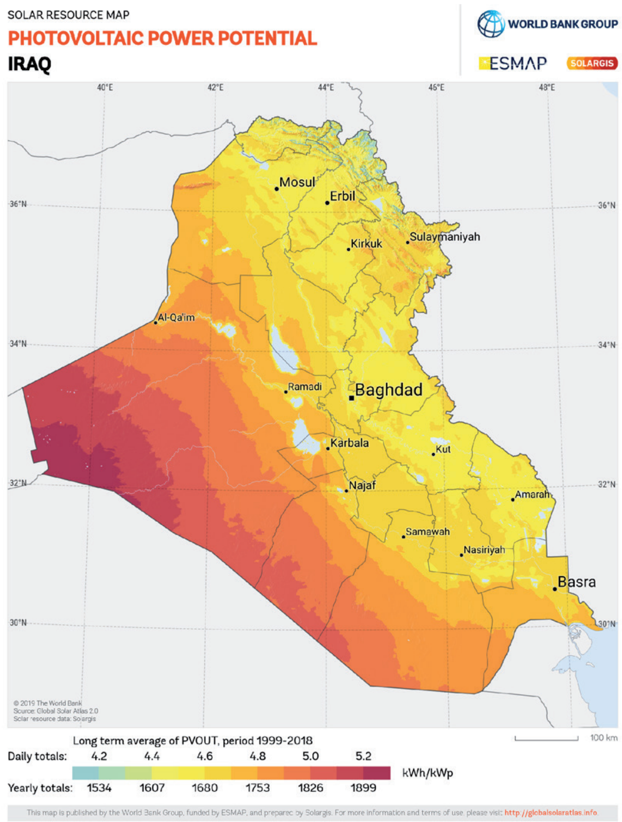

Figure 9.
PV power potential (PVOUT) in Iraq [70].

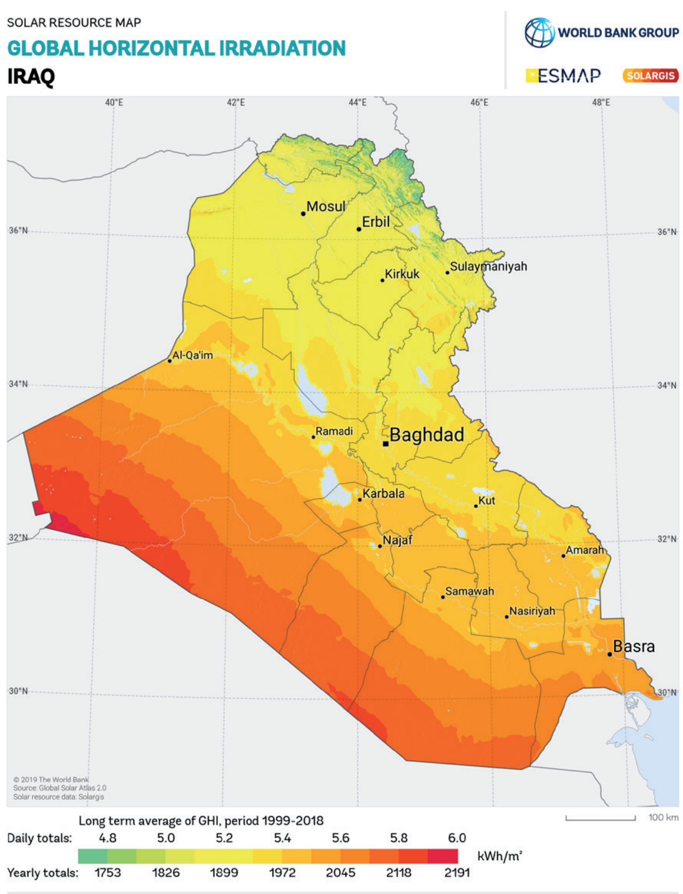

Figure 10.
Global horizontal irradiation (GHI) in Iraq [70].

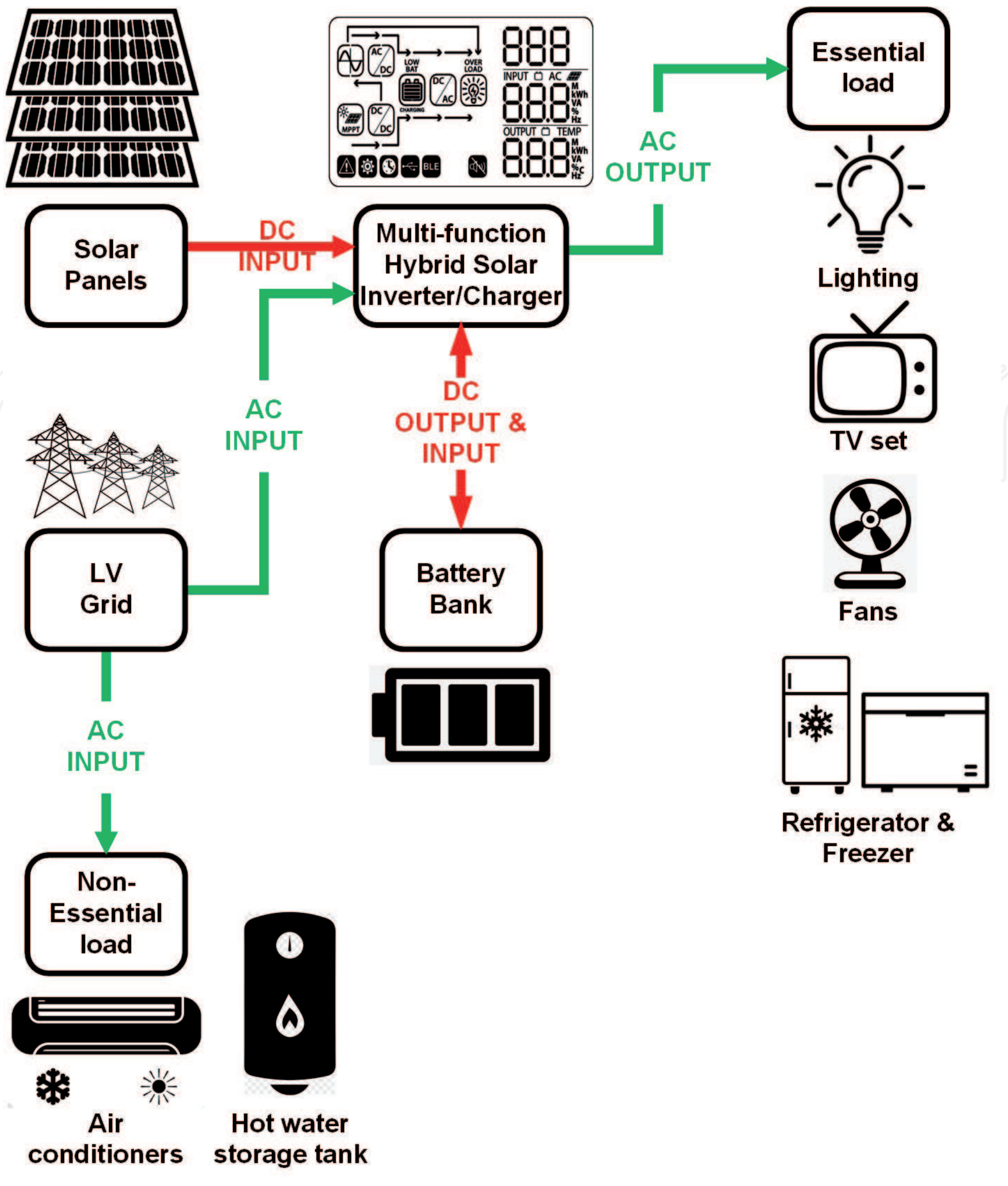

Figure 11.
Hybrid solar PV system.

battery pack to ensure that power supplied to the load is uninterrupted. A hybrid solar system can be operated as an on-grid system with battery storage or as an off-grid system with backup power from the grid. Power is never exported to the grid deliberately.

Taking into consideration the nature of loads and the power generation capacity (1–10 kW) of hybrid solar PV systems (recommended by the Federal Ministry of Electricity and commonly deployed in Iraq), the operation modes of these systems are summarised in **Figures 12–17**. It is assumed that the priority of a hybrid solar inverter/charger is to feed the essential load first and to charge the battery bank only if sufficient power is generated by the PV panels.

Besides hybrid solar PV systems, entirely on– or off–grid rooftop solar systems have been deployed in limited numbers in Iraq. On–grid systems, which are similar to hybrid systems except that they do not have battery banks, have been installed at a number of governmental buildings including the Federal Ministry of Electricity (an aggregate of 350 kW at two different sites), University of Babylon (with a 130 kW capacity) [74] and University of Technology [75].

In contrast, off–grid systems include battery banks, but are not connected to the LV distribution grid. Off–grid systems are used for rural agricultural (irrigation

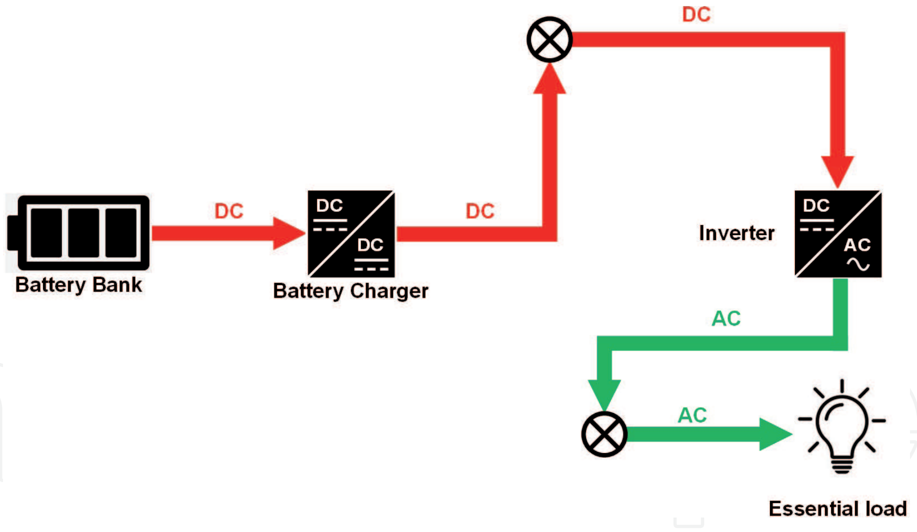

Figure 12.
Off-grid mode: PV power is not available. The essential load is fully supplied by the batteries.

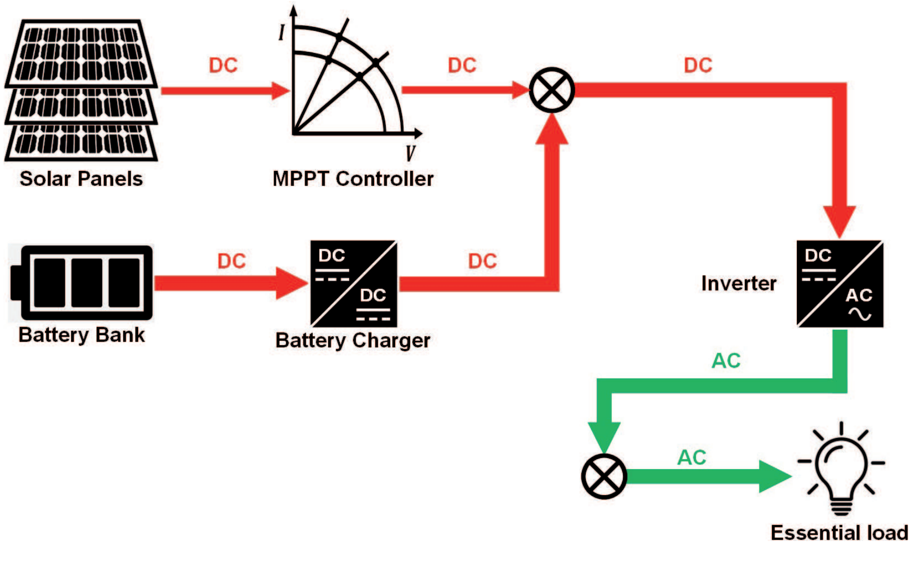

Figure 13.
Off-grid mode: PV power is not sufficient to supply the essential load which will therefore be supplied by both PV panels and batteries.

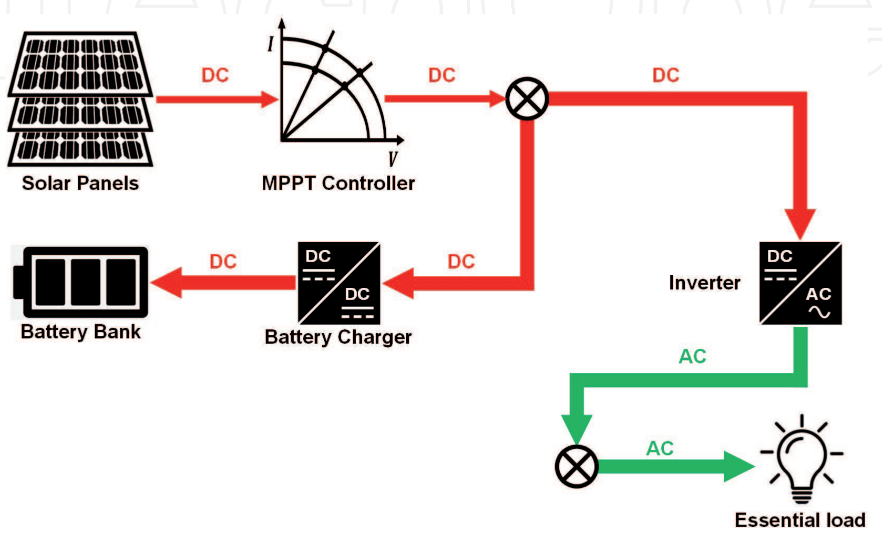

Figure 14.
Off-grid mode: PV power is sufficient to supply the essential load and charge the batteries.

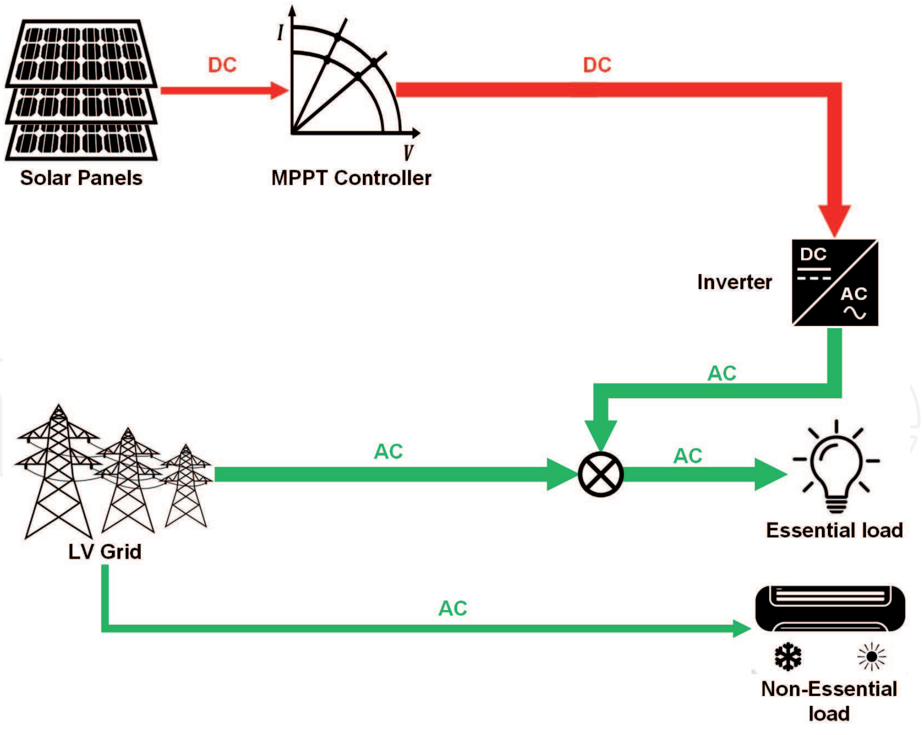

Figure 15.
On-grid mode: PV power is not sufficient to fully supply the essential load and the batteries are not connected (e.g. removed for maintenance or replacement). The essential load is supplied by both PV panels and LV grid.

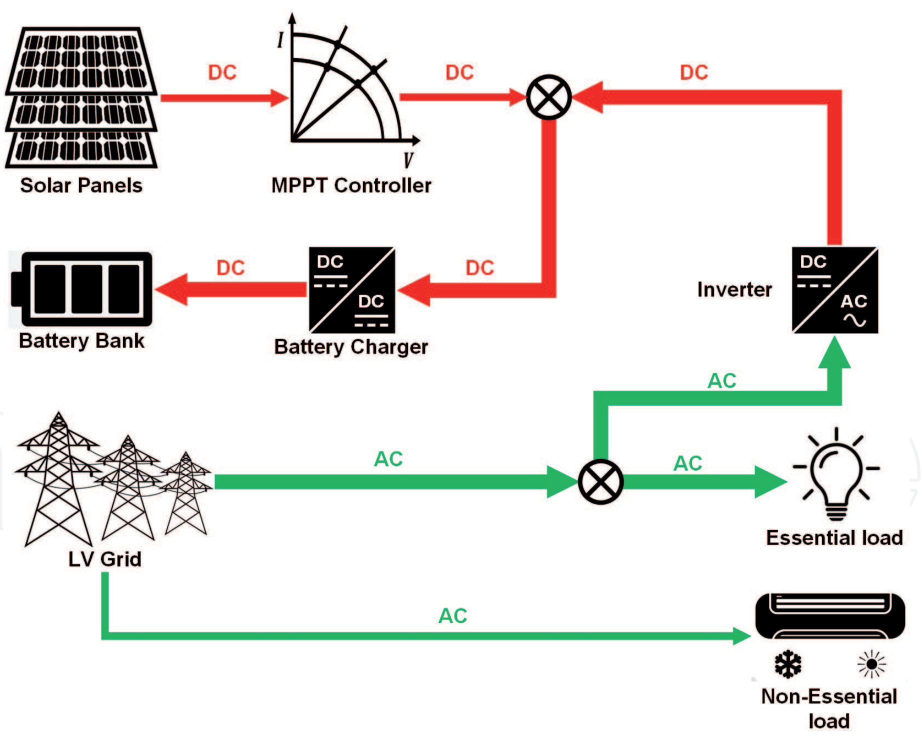

Figure 16.
On-grid mode: PV power is neither sufficient to supply essential load nor charge the batteries. LV grid supplies power to the essential load and charges the battery bank.

and drainage) applications and have also been employed for experimental studies. **Figure 18** shows an experimental off–grid system rooftop solar system installed at a residential premise in Baghdad.

A detailed illustration of the system is shown in **Figure 19**. Block (1) is the infeed cable collecting the outputs of the solar panels shown in **Figure 18**. Block (2)

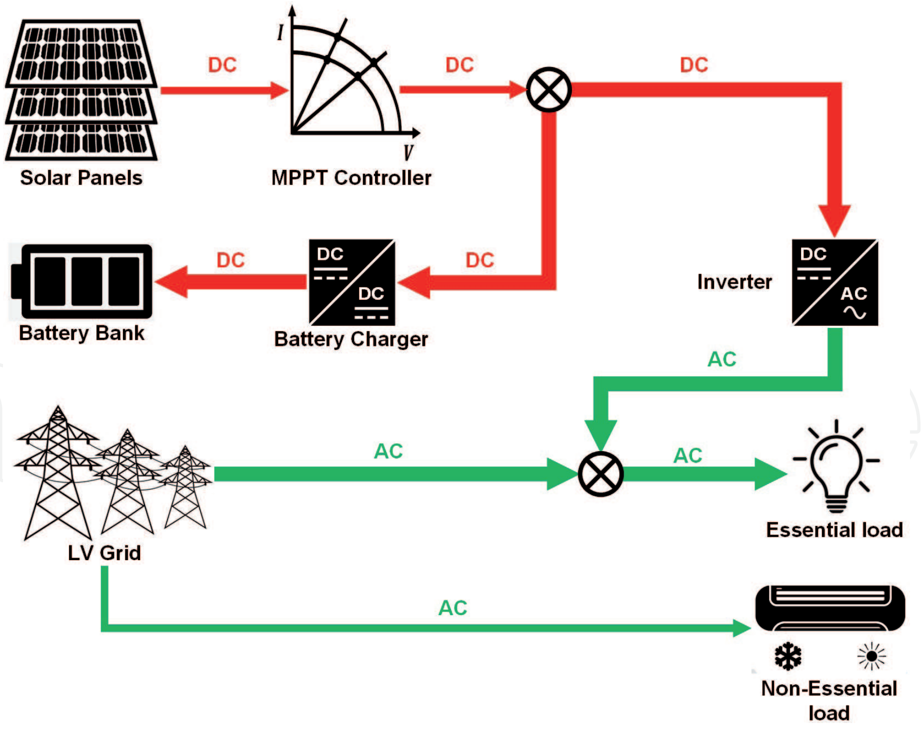

Figure 17.
On-grid mode: PV power is not sufficient to fully supply the essential load but is sufficient to charge the batteries. The essential load is supplied by both PV panels and LV grid.

Figure 18.
A rooftop array of solar panels in Baghdad (Source: Dr. Jaafar Ali Kadhum Al-Anbari).

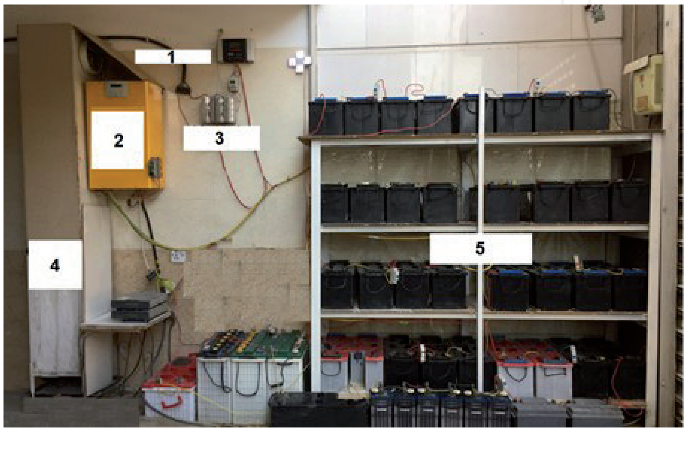

Figure 19.
Detailed illustration of a 10 kW experimental rooftop off-grid solar system in Baghdad (Source: Dr. Jaafar Ali Kadhum Al-Anbari).

is a 10 kW inverter that converts 48 volts DC to 220 volts AC to supply the essential load of the residential premise. Block (3) is an MPPT charge controller while block (4) shows the cooling system installed to cool the inverter (block (2)). Finally, block (5) is a 48 volts battery bank comprising 54 lead acid batteries (of different capacities) connected to produce an aggregated capacity of 1500 Ah.

7.2 Rooftop solar panel systems as a sustainable source of power for Iraqi residences

Solar energy, if actively exploited, has an important role in improving Iraq's energy security and could help fill the gap between the available electrical power supply and demand without using traditional power generation technologies or neighbourhood diesel generators. Oil and gas consumed for power generation can be saved which in turn allows more oil exports that will add to the government revenues [12].

A pilot project comprising six rooftop solar PV systems (each having a capacity of 5 kW) in Najaf [76] was able, over four years, to save a total of 58 tonnes of CO_2 (equivalent of consuming more than 7000 gallons of diesel) from being emitted into the atmosphere [77]. Reference [78] reports that the potential savings in CO_2 emissions would amount to approximately 804 gCO_2/kWh should a 315 kW solar power plant be constructed at Sulaymaniyah airport to replace fossil fuel based electric energy supplying the airport.

A comparison between the present levelized cost of electricity (LCOE) from open-cycle gas turbines (OCGT), combined cycle gas turbine (CCGT), neighbourhood diesel generators and solar panels (**Table 9**) shows that rooftop solar PV systems offer a competitive alternative to neighbourhood diesel generators. In **Table 9**, residential rooftop solar systems have a maximum power generation capacity of 15 kW, commercial rooftop systems can generate up to 500 kW whereas utility-scale systems are multi-megawatt solar farms [79].

In Iraq, the installation cost of rooftop solar systems can either be paid as a one-off payment or over 36–60 months with a long-term loan. A 5 kW hybrid solar system costs between US $ 3800–4800 with a one-off payment whereas the cost of the same system increases to about US $ 6450 (over 36 instalments) – 6860 (over 60 instalments) on a long-term loan [80]. The variation in costs depends upon both the number of solar panels and batteries connected. A replacement lead acid battery is usually required every two years, at a cost of US $ 210–280 per 200 Ah battery.

Comparing the installation and battery replacement costs with the approximate electricity bill of a residential customer (**Table 6**), it can be concluded that a hybrid rooftop solar system is expensive and may not deliver the financial savings anticipated over its lifetime of 20–25 years. Similar findings were reported in [51]

Power generation technology		LCOE (US $/kWh)	Reference
OCGT		0.04–0.06	[5, 12]
CCGT		0.07–0.11	
Neighbourhood diesel		0.64–1.30	
Solar PV	**Utility-scale**	0.018–0.085	[5, 11, 12, 79]
	Commercial rooftop	0.062–0.064	[79]
	Residential rooftop	0.063–0.265	

Table 9.
Comparison between LCOE of solar PV and fossil fuel based power generation technologies.

recommending the installation of rooftop off-grid solar systems only when an annual discount rate of below 9.4% was assumed for the battery bank. Analysis of different scenarios showed that investment in rooftop solar systems would not be cost effective at high battery discount rates. Alternatively, reference [12] recommends exploring community solar microgrids rather than installations on each house.

In summary, it can be seen that numbers of rooftop solar system installations in Iraq are increasing; however, these will probably not reach a tipping point to replace neighbourhood diesel generators for some time. The public are often reluctant to install rooftop solar systems because of their high upfront and maintenance costs especially with the current unstable economic conditions in the aftermath of the coronavirus outbreak and worldwide drop in oil prices. The lack of government support for soft loan mechanisms as well as high commercial interest rates (more than 40%) for loans to fund domestic solar systems are other factors that discourage widespread installations of solar systems. Also, the customers are reluctant to invest in solar PV systems because present Iraqi legislations do not support net-metering or feed-in tariffs [12].

There is some evidence that the reducing cost of photovoltaic panels may offer a partial solution to this problem of deficit of generation. Iraq has an extremely attractive solar resource but so far implementation of photovoltaic generation has been limited. For widespread adoption of rooftop systems, a more attractive commercial climate is required, through low interest loans, net metering or feed-in tariffs.

8. Conclusions

The electricity systems of Iraq, and parts of Lebanon and Syria, experience frequent power cuts caused by shortage of generation, damaged transmission and distribution networks as well as rapidly increasing demand. In response to the limited hours that electricity is available from the public supply systems, local organisations have established innovative arrangements using diesel generators and simple distribution networks. These systems operate independently and are managed separately from the public electricity supply.

The generators are typically in the range of 100–500 kVA and are often locally manufactured from reused truck engines and imported generators. The generators provide each subscribing consumer with a supplementary supply of up to several kW of electrical power through informal networks that extend over a small area of a town or city. The final connection to the consumer premises is made through a radial single wire and the neutral of the public LV network. There is no connection of the live conductors from the generators with the public network and each customer has a changeover switch to select either the public mains when supply is available or the neighbourhood diesel. Monthly tariffs are based on $/amp with miniature circuit breakers limiting the current drawn by each consumer.

Neighbourhood diesels create significant local air pollution and noise, and can only supply small amounts of power at considerable cost. However, for those areas that have only limited public electricity supply they provide some power when the public service is unavailable. In Iraq, electricity from the public network is sold to domestic customers at a price that is below the cost of supply so limiting revenue that could be used to increase the capacity of the public supply system. There is no immediate prospect of the public electricity supply in Iraq improving dramatically and of these neighbourhood generators becoming redundant. Until the public electricity supply system can fully meet the load demand, the use of neighbourhood diesels is likely to continue.

Suitable Iraqi standards exist, some in draft form, to regulate the noise and gaseous emissions from neighbourhood diesels but local studies indicate these standards are not being met. No standards to regulate the novel connection practice of using a common neutral connection from the public network were identified. There appears to be scope both to enforce existing standards and develop a new electrical standard to regulate the connection and operation of the diesel generators and the innovative networks.

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