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Adaptation of Grid Tied Photovoltaic (GT-PV) System as Retrofit Renewable Energy Model for Single-Family House in UAE

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Abstract: Gulf Cooperation Council (GCC) governments are encouraging advances in renewable energy and its deployment to reform domestic energy market policy. GCC countries including United Arab Emirates (UAE) all have begun to explore renewable energy technologies. This research intended to develop a framework model to use Grid Tied photovoltaic renewable energy (GT-PV) in the housing design of the GCC region particularly in UAE. In this regard, research has analyzed the various types of housing plans and worked out the possibilities of retrofit design to adapt renewable energy model to implement (GT-PV) in existing housing for their energy needs. This study has determined the total energy need of each type of house, data of energy need was statically analyzed, and renewable energy output was calculated. The end-result of research has surfaced a comprehensive model to design a grid-tied photovoltaic renewable energy system to cater the need for private housing in UAE. This research demonstrated that GT-PV is a sustainable and renewable energy system and its adaptation of in existing housing would bring substantial reduction in national energy usage. This research also shared the opinion that, principal cost of GT-PV system is a key drawback in adaptation of this system. However, study determined that high principal cost would be payback within 08 years and principal cost could be termed as the investment cost.

Keywords: Housing, Renewable energy, Grid-tied system, Electrification.

1. Introduction

It has always been an undeniable fact that complexities such as rapid languishing of the environment, variability in fuel prices, an ascending demand of economic development in rural areas enables world nations to invest and signify in alternate sources of fuel. Alternate fuel is deemed to up fill their nation's standardized energy intake, as conventional means of attaining fuel have yet again leaded to high prices and extravagant compromises even for the leading world nations [1,2,3,4]. In global perspective, the power companies and regional governments are considering promoting alternate energy source to provide electrification in remote areas and to minimize the carbon footprints [5,6]. This development is also sprouting in an oil-rich Gulf Cooperation Councils (GCC) region, who for a prolonged period relied primarily on mineral fuels to maximize their national economic growth plus energy production. Standing out from major gulf regions, The UAE maintains its superiority across the region by utilizing the advanced civilian nuclear program to initiate its energy production by 2020. Saudi Arabia on the other hand has fixated the use of its nuclear development

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primarily for medical use in terms of research laboratories and hospitals furthermore elevating its Nuclear Power capacity to 18GW by 2032 in the process to attain an overly simplified prospective to share renewable energy by 2040 [7].

This developing scenario indicates that the UAE is keen to work out the alternate source of energy to meet its needs. In fact, The UAE is extravagantly locomoting towards nuclear, solar and other renewables with the sole conceptual of replacing renewable plants with gas power plants in a electricity generation system with an intimate goal to downsize its carbon emissions. It is also rolling out electric vehicle charging infrastructure [8]. It is quite evident that UAE initiated promptly, and government surfaced the various policies to transform from traditional energy mode to renewable energy generation. According to Ventures (2018), The UAE is the first GCC country to start on the new energy strategy, which involves the nuclear power and solar energy in addition to natural gas, capable to comply with power need of UAE. The UAE provides lucrative opportunities for launching solar energy generation projects. Moreover, UAE's Clean Energy Strategy (CES) aims to provide 44 percent of the country's energy needs by 2050, including 7% of power to be produced from solar over the period between 2018-2020 [9].

In line with multiple sustainability projects, the GCC also minimizes Greenhouse gas emissions and in this context solar is an especially attractive alternative to using fossil fuels. Because GCC have abundance of sunshine in the region and recent developments in solar technology has made it affordable. Aligned to vision 2030, Moreover, Saudi Arabia has given utmost importance to maximizing energy generation under its national transformation program which would accredit Saudi Arabia to generate an estimate of 3.45GW of renewable energy by 2020 and ultimately 9.5GW by 2023 henceforth amplifying the share of renewable energy in the National Renewable Energy Program. Another reason Saudi Arabia is focusing on solar electricity is to prevent the risk of rising power prices in country [10].

Qatar has been examining the potential of renewables in its energy mix for over a decade, in year 2008 a long-term economic development plan title "Qatar National Vision 2030" was announced by government. It has priorities environmental protection alongside the need to harness and optimize the country's abundant hydrocarbons reserves. Renewables energy sector in Qatar is still in development stage; however, the country has fixated its interests upon upscaling its electricity production by 20% via solar energy.

Oman is quite efficient and prompt to integrate renewables energy in country's power mix and in year 2017 started 50 MW Harweel wind farm. In addition, Oman has also tendered 200 MW of solar PV in 2017. Oman Power and Water Procurement Company (OPWP) has recently signed up a consortium of international consultants for a large-scale solar project, which will be developed on a Build-Own-Operate (BOO) model. A small GCC country Bahrain has relocated its priorities and economic interests in renewable energy and emphasized on solar photovoltaic (PV) systems. Dating to October 2016, an energy efficiency national program was initialized under the direct control of Bahrain government whose end goal is to upscale the national electricity energy efficiency by 6% by 2025, which seeks a 6% national electrical energy efficiency by 2025. It also calls for a 5% contribution from renewable energies by 2025, rising further to 10% by 2035 [10].

Whereas, in Kuwait transformation to renewables energy is still at the initial stage, however, it is a high focus area of interest on the government's development agenda. According to KUNA, Kuwait's Ministry of Electricity and Water is planning renewable energy projects with the help of the private sector. This is in line with its Vision 2030 plan to transform Kuwait as an alternate power-dependent country, which aims to generate 15% total consumption of energy from renewables by 2035 that is over 4.5 GW capacity. The discussion above can be summarized as, GCC is acting fast on transformation to alternative energy generation systems and governments in GCC consider it as a fundamental component to cater its future energy needs through the development of its renewable energy resources. In this regard, GCC countries are keen to deploy new tested renewable generation technologies. GCC also considers that the implementation of RE policies will educate the people to minimize the energy use and helps them to have control over their energy supply and consumption.

In addition to above mentioned facts, worldwide growth of photovoltaic energy is extremely dynamic and varies strongly by country. There are at least 37 countries around the world with a cumulative PV capacity of more than one gigawatt. By the end of 2019, a cumulative amount of 629 GW of solar power was installed throughout the world [25]. Table 1 highlights the major contributors in usage of PV energy system.

Table 1 – Top 10 countries by cumulative solar PV capacity in 2019

Top 10 countries by cumulative solar PV capacity in 2019		
China	204,700 MW	(32.6%)
United States	75,900 MW	(12.1%)
Japan	63,000 MW	(10.0%)
Germany	49,200 MW	(7.8%)
India	42,800 MW	(6.8%)
Italy	20,800 MW	(3.3%)
Australia	14,600 MW	(2.3%)
United Kingdom	13,300 MW	(2.1%)
South Korea	11,200 MW	(1.8%)
France	9,900 MW	(1.6%)

Source: Improved from [24]

2. Perspective of (GT-PV) Renewable Energy House

It is well-acknowledged fact that adaption of renewable energy is the future of energy production. Globally, potential nations are exploring various befitting PV technologies and resources to cater their energy needs. One of the studies demonstrating this is done by Alarcón-Castro et al. [11] in Santiago de Chile which looking into the photovoltaic windows with luminescent solar concentrators. The effective use of renewable energy in developing countries could be accomplished through the implementation of special policy instruments to promote use of energy mix for new and existing built environment. PV energy system is particularly successful in daytime buildings such as schools, universities, public offices etc. the policy should emphasis use of PV RE system in these types of buildings. Widespread use of PV RE system in densely populated countries like India, Pakistan and Bangladesh also promote local industry producing renewable energy generation technologies and equipment thus ensures variety of new job openings. In addition, use of PV RE system in developing countries will help to minimize the dependence of fossil fuels and promote sustainable environment and economic growth.

According to Chohan et. al [12] complexities such as rapid languishing of the environment, variability in fuel prices, an ascending demand of economic development in rural areas enables world nations to invest and signify in alternate fuel sources to upfill their nation's standardized energy intake. The Study further emphasized on the possibility of explicit use of conventional fuel, climate change and damaging environmental scenarios ultimately leading to a massive build in momentum of the afore mentioned complexities.

Ohler and Fetters [13] further showcased the significance of renewable energy by asserting them as future essentials along with economic boosters and hence forth leading to a just and developed society. Renewable energy is quite clear for many however, smart electrification or smart grid is still new buzzwords for housing electrification.

A smart grid plays a essential role in electricity transmission as it consolidates sources along with boosting transmission efficiency hence simultaneously narrowing power shortages and greenhouse emissions and conclusively standardize consumer affordability. [14,15,16,17]. Moreover, greater measures such as smart meters are substantialized to regulate electricity use based on price units leading to reduced use during times of maximal intake. Doing so improvises on the system efficiency and diminishing of strain on system. [16]. Not only does Smart grid provide efficiency but also emphasizes on electricity production using compact and budgeted fuel-based generators, wind turbines and solar arrays. Utilizing these decentralized units of electricity more commonly referred as Distributed generation (DG) systems ultimately minimizes strain plus also acts as a standard backup support of electricity during optimal load times [14].

Learning from above can be precise as, a commercial and indigenous level smart grid or grid-tied renewable power generators are capable to comply with immediate energy needs and transmit additional power to other consumers through national power lines and transmission stations, as shown in Fig. 1. In order to cater to the installation of GT renewable power system, it is required to update existing grids need to integrate power generators such as solar photovoltaic cells, wind turbines, etc.

Fig. 1 - GT-PV Smart Metering System

Fig. 1 illustrates how GT-PV works. The PV panel generates energy in the form of DC (direct current) from the sun, which is directed to DC-AC Inverter, whereby DC energy is converted to the AC (alternate current). This AC current then directs to the distribution board which distributes electricity to the house and to the bi-direction meter. Energy produces will be used to fulfill the electricity requirement of the house. Whereas, extra available energy would be sold to the national grid via smart energy meter. The transmission path from the meter to the grid is bi-directional; For example, if sold electricity units are equal to consumed national grid units, it means breakeven of electricity units and there will be no electricity bill.

Various studies suggested that renewable sources are a viable way to meet the energy need of an independent house. The energy produced can be utilized by house owner and excess or idle energy can feed to the national grid. Study of a high-performance residential building by Thiers & Peuportier [18] revealed that energy recovery from local renewable resources can provide part or the whole building energy demand including heating load and hot water production and can supply remaining unconsumed power to feed the electricity grid.

There is an argument prevails that RE based energy system is high in cost and is not comparable with conventional mode of energy production. Conversely, the study of Parker [19] suggests that principal investment for RE system is higher but in general it is cost-effective to depend on solar electricity (PV), the study stressed that annual cost of RE is half or less of conventional energy source in standard housing.

However, the lack of information on PV energy system act as a barrier in its employment by individual house owners. A study titled "Solar Patriot" or "Hathaway home" was conducted to showcase portability of RE in a variably changing climate. The study presented a model house measuring 2,800 square foot (268 m2) and In addition to emphasis upon quality upscaled insulated walls, the model house offered energy streamlined appliances and standard based lightning across the structure Furthermore, with an overly simplified objective of attaining Zero energy on annual bases, a 6 KW PV system was implemented. Moving onto setting the credibility of the project, the performance was surveilled on a massive scale with attention to details. As a result, a Sum of 10585 KW was consumed in opposition to 7510 KWH produced by PV systems. (Norton 2005). Another study of Greenspec [20] suggests that a typical 1m^2 module will generate anywhere between 60 – 110 kWh per year and a typical maximum efficiency will be 40%. The immediate output will be as DC and an inverter will be required to convert the current to AC.

Conceivably the most impressive example of RE based house was designed in 2007 measuring 1,280 square foot (119m2) Colorado, commenced by National Renewable Energy Laboratory (NREL). This compact project was super insulated with R-60 ceiling, R-40 double-stud walls and R-30 floor insulation. The means of ventilation were accomplished by a portable heat recovery ventilator, an optimal performance based Low-E solar glass plus argon fill along with East, west and north faces being covered with U-factor 0.2 while as the southern region used U-factor 0.3 glass. The home was mated with a 4 kW rooftop PV system. During a year of data collection stretching from April 2005 to the end of March 2007, the PV system produced 1,542 kWh more than the electricity used in the home even though blizzards reducing PV output were experienced in January 2007 [21].

Discussion on PV energy-based house can be summarized as, that zero energy house or RE based house is a reality. However, designing of such house requires tested information and data in the domain of renewable energy technology and its application. In addition, to the account of functional design consideration RE (PV) house also requires contemplation of construction and material selection in the context of heating and cooling conservation. For example; for a PV energy-based house it is highly necessary to use high-grade insulation (R-30-R60) is required under the attic, flooring and wall system to block the heat or cold mitigation, high U factor (0.2-0.3) glass is needed in windows particularly southern side.

3. Retrofit Energy-Efficient Framework of (GT-PV) For Single-Family Housing in UAE

This research considers that typically electricity is generated through burning carbon-emitting fuels, an environment damaging and always remain inadequate because of a growing population, theft and line losses. However, there is a niche to adapt hybrid (GT-PV) renewable source of energy in independent housing units. Independent and hybrid renewable power generation units will minimize the dependency on the national grid and provide the uninterrupted power supply. Nevertheless, (GT-PV) is a multifaceted phenomenon for (indigenous) electrical power production, which is different from small-scale renewable energy employment such as, solar water heaters and lighting system. It requires an understanding of architectural planning, complex load calculations and requires sovereign capital investment. Furthermore, designing and installation of renewable power technologies as part of a refurbishment or retrofit project also require considering the implications and potentials on exiting built environment.

It is a general understanding that despite higher principle investment, renewable energy costs less than conventional energy. Admiring the monetary benefit of retrofit energy Kelly [22] mentioned that, a retrofit energy project that pays back in five years, clients are effectively receiving a low risk 20% return on investment. Whereas, Quigley et al. [23] mentioned that, retrofitting provides benefits for building tenants who will enjoy reduced energy costs, reduced maintenance costs and improved plant reliability.

After reviewing the various models of available GT-PV models, this research is proposing a retrofit model for single-family house capable to produce electricity requires by the house and additional produce can be sold to National Grid, as shown in Fig. 2. For this purpose, existing housing units at Sheikh Zayed Housing scheme in UAE was considered for the case study.

Sheikh Zayed Housing (SZH) scheme is a governmental project for the provision of the single-family house for nationals of United Arab Emirates. At present, the SZH housing units are fulfilling power needs through conventional power system of the national grid. This research has analyzed the possibilities of adapting GT-PV system as a retrofit system for power generation in SZH. In this regard, architectural planning of 2, 3 and 4-bed single-family villas were appraised in the context of power loads and to propose a retrofit (GT-PV) system for each type of unit.

Literature review in sections 1.0 & 2.0 suggests that available PV technology can provide 1kw of PV power/1m2 of the roof surface. Round the year (summer & winter), the efficiency of PV panel is calculated, as 15-22% i.e. each $1m^2$ will provide 150 watts. However, this research is considering 15% of PV panel efficiency. The life cycle of PV system is being calculated at 20 years and it takes approximately 8-10 years to recover the total investment. Therefore, the remaining ten years' power production through the PV system will be considered as free power.

Fig. 2 - Framework of GT-PV System for Single Unit House

This GT-PV model will minimize or exclude the dependence on grid electricity at a single residential unit in Sheikh Zayed Housing (SZH) models. Existing housing of SZH can use this model through retrofit designing and planning efficient use of household power. This proposal would help to replace power guzzler conventional appliances to high tech appliances & fixture and promote a time-controlled use of electricity. This study has considered 2, 3 and 4 bedded houses of SZH program. SZH program has used the RCC post & lintel structural system with RCC flat slab system. This structural arrangement is ideal for fixing PV panels on roof surface, because of flat roof provides almost 85% of covered area on rooftops.

Whereas, consumption of electricity in all types of SZH are based on UAE standards prescribed by power generation and distribution companies such as Sharjah electric and water authority (SEWA) [26], Dubai electric & water authority (DEWA) [27] and Federal electric & water authority (FEWA) [28] . Tables 1, 2 & 3 and subsequent power requirement calculations in sections 3.1.1, 3.2.1 & 3.3.1 are based on standard defined by [26] [27] [28]. In addition to simple arithmetic, power requirement calculations in 3.1.1, 3.2.1 & 3.3.1 have five significant features as given below;

- Calculation of roof surface area (L x W) [29]
- Roof surface area (m^2) vs 150w /m^2 power generation [30]
- Principal cost of panels calculated per UAE market rates [31]
- Power price regulated by [26] [27] [28]
- Power consumption hourly data suggested by [26] [27] [28]

This study has established the following types of tables for each type of house to determine the factors such as,

- Total load calculation as per UAE standards
- Total PV power generation of a house,
- Total power requirement & per person consumption of house,
- Total PV power saving,
- Power sale to net metering,
- Cost of PV panels
- PV panels payback period & panel deficiency impact

This study has considered that average sunshine of 5 hours per day to get max energy average prescribed for UAE and considered the minimum efficiency of 15 % for PV panels; however, it is possible to increase the total power production by using more efficient & (expensive) PV panels. [33].

3. 1 Two-Bed Villa

Two-bed villa is consist of RCC post and lintel structure with flat slab system. Architectural planning of two-bed villa features 2 bedrooms with attached bathroom, a kitchen, a living room, a majlis (guest room) with attached toilet/powder room, maid's room with attached bathroom and a laundry. Fig. 3 illustrates a 2-Bed Villa layout plan. In a two-bedroom villa, entrance lobby is placed into center creating a sense of symmetrical planning. Main entrance lobby is a positioned to connect guest room with rest of villa. In addition, to guest room the entrance lobby also connects two bedrooms, a kitchen and a living room. Guest room is designed with two entrances, to maintain the level of privacy, first entrance is for guests at foyer and second entrance for family members operates at end of lobby inside house.

Fig. 3 - 2-Bedrooms Villa Plan

To maintain privacy for family members, living room is planned parallel to the guest room without any viable connection to it. Living area is accessible from deep inside the house, in some cases serves as a female gathering area. Living area have plenty of glazed surfaces, providing view and natural light. This villa has a secondary entrance at the right side, principally designed as separate entrance for maid's room, in addition contacting laundry and kitchen. All bathrooms' have direct ventilation and natural light provision and all bedrooms have plenty of natural light and view. Kitchen is connected with secondary entrance allowing the ease of services and have plenty of natural light. Cooking and preparation surface/decks are well placed at parallel walls.

Consumption of electricity in two-bed house has calculated through UAE standards prescribed by power generation and distribution companies such as Sharjah electric and water authority (SEWA) [26], Dubai electric & water authority (DEWA) [27] and Federal electric & water authority (FEWA) [28] as shown in Table 2.

Table 2 - Load Calculation for Two-Bed Villa

Source: Improved from [26] [27] [28]

3.1.1 Feasibility of GT-PV system for Two Bed Villa

In context of adapting GT-PV power generation system in two-bed house of Sheikh Zayed Housing program, following tables from 3 to 9 are produced to show the various aspect, i.e. PV power generation, consumption, power saving, PV power & panels costing and their payback time.

Table 3 - Total power generation of two-bed villa

House Type	Area available m2	Energy produced / m2 (Watts)	System required area x watts/m2 (kW)	Sun hours/day	Total energy produced System x sun shine hours/day (kW)
Two bed	184	150	27.6	5	138

Table 4 - Total household power load calculation of two-bed villa

House Type	Number of occupants	Power consumption per house/day (kWh)	Power consumption per person/day (kWh)	Power consumption per person/year (kWh)
Two bed	4-5	94.4	31.4	11485

Table 5 - Total power produced & saved

House Type	Energy produced/day (kWh)	Energy consumed/day (kWh)	Energy saved/day (kWh)	Energy consumed/year (kWh)	Energy saved /year (kWh)
Two-bed house	138	94.4	43.6	34,456	15,914

Table 6 - The following table shows the total PV energy consumed & its cost

House Type	No. of Occupants	Energy consumed/year (kWh)	Energy Price @ 0.2 AED/unit (AED)
Two bed house	4-5	34,380	6876

Table 7 - Power sale through net metering

House Type	Energy sold to utility/year (kWh)	Price of energy sold to utility @ 0.2 AED/unit (AED)
Two bed house	15,914	3189

Table 8 - Principal cost PV system

House Type	System required (kW)	Price/ kW (AED as 2019)	Total cost (AED)
Two bed house	27.6	3000	82,800

Table 9 - PV panels payback period & panel deficiency impact

House Type	Price of Power used in house/year (AED)	Price of Power sold to utility /year (AED)	Total amount recovered /year (AED)	Cost of system (AED)	Proposed Payback period	PV Panel deficiency vs 8 years of payback Impact *Solar panels degrade at 0.5%/ Year
Two bed house	6876	3189	10065	82,800	8.1 year	4 %

3.2 Three bed Villa

Three-bed villa is consisting of RCC post and lintel structure with flat slab system, architectural plan is shown in Fig. 4. In a three-bedrooms villa, an entrance foyer is place in center of plan flanked by guest room (majlis) at left and an open space at its right side. Central placement of entrance creates a sense of symmetry in planning and façade development. In addition to main entrance, a secondary entrance is also planned through maid room and kitchen. In order to accomplish the cultural setup and privacy of occupants' guest room access is planned outside the main building i.e. on entrance foyer. Central location entrance lobby allows connecting three bedrooms (with attached bathroom), a kitchen and a living room. Overall, the architectural planning of three bed villa features 3 bedrooms with attached bathrooms, a kitchen, a living room, a majlis with attached bathroom, maid's room with attached bathroom and a laundry.

Fig. 4 – Three Bedrooms Villa Plan

Consumption of electricity in three-bed house has calculated through UAE standards prescribed by power generation and distribution companies such as Sharjah electric and water authority (SEWA) [26] , Dubai electric & water authority (DEWA) [27] and Federal electric & water authority (FEWA) [28] as shown in Table 10.

Table 10 - Load Calculation for Three-Bed Villa

Source: Improved from [26] [27] [28]

3.2.1 Feasibility of GT-PV system for Three Bed Villa Total Power Generation of Three-Bed Villa

In context of adapting GT-PV power generation system in three-bed house of Sheikh Zayed Housing program, following tables from 11 to 17 produced to show the various aspect, i.e. PV power generation, consumption, power saving, PV power & panels costing and their payback time.

Table 11 - Total power generation of three-bed villa

House Type	Area available m2	Energy produced / m2 (Watts)	System required area x watts/m2 (kW)	Sun hours/day	Total energy produced System x sun shine hours/day (kW)
Three bed house	230	150	34.5	5	172.5

Table 12 - Total household power need & load calculation of three-bed villa

House Type	Number of occupants	Power consumption per house/day (kWh)	Power consumption per person/day (kWh)	Power consumption per person/year (kWh)
Three bed house	6-7	112	18	10220

Table 13 - Total power produced & saved three-bed villa

House Type	Energy produced/day (kWh)	Energy consumed/day (kWh)	Energy saved/day (kWh)	Energy consumed/year (kWh)	Energy saved /year (kWh)
Three bed house	172.5	112	60.5	40,880	27,557

Table 14 - The following table shows the total PV energy consumed & its cost three-bed villa

House Type	No. of Occupants	Energy consumed/year (kWh)	Energy Price @ 0.2 AED/unit (AED)
Three bed house	6-7	40,621	8124

Table 15 - Power sale through net metering three-bed villa

House Type	Energy sold to utility/year (kWh)	Price of energy sold to utility @ 0.2 AED/unit (AED)
Three bed house	27,557	5,511

Table 16 - Principal cost PV system three-bed villa

House Type	System required (kW)	Price/ kW (AED as 2019)	Total cost (AED)
Three bed house	34.5	3000	103,500

Table 17 - PV panels payback period & panel deficiency impact three-bed villa

House Type	Price of Power used in house/year (AED)	Price of Power sold to utility /year (AED)	Total amount recovered /year (AED)	Cost of system (AED)	Proposed Payback period	PV Panel deficiency vs 8 years of payback Impact *Solar panels degrade at 0.5%/ Year
Three bed house	8124	5,511	13635	103,500	7.5 years	3.5 %

3.3 Four Bed Villa

Four-bed villa is consisting of RCC post and lintel structure with flat slab system, Fig. 5 illustrates the architectural planning of a four-bed room villa. Unlike two and three bed villas, entrance is planned away from center of main building. Entrance foyer is leading directly into living room, which is also different from precedent planning features of two and three bed villa. In this planning living room is acting as core of planning connecting all other spaces of villa through narrow and unvented corridor. Secondary entrance is planned to the house at the rare end of villa, accessible through maid room and kitchen. Kitchen is accessible through central corridor and planned nearby living room. All four-bed rooms have attached bathroom and access through core of corridor. Overall, architectural planning of four-bed villa features four bedrooms with attached bathrooms, a kitchen with store, a living room, a majlis (guest area) and a maid room with attached bathrooms.

Fig. 5 - Four Bedrooms Villa Plan

Consumption of electricity in four -bed house has calculated through UAE standards prescribed by power generation and distribution companies such as Sharjah electric and water authority (SEWA) [26], Dubai electric & water authority (DEWA) [27] and Federal electric & water authority (FEWA) [28], as shown in Table 18.

Table 18 - Load Calculation for Four-Bed Villa

Source: Improved from [26] [27] [28]

3.3.1 Feasibility of GT-PV system for Four Bed Villa

In context of adapting GT-PV power generation system in four-bed house of Sheikh Zayed Housing program, following tables from 19 to 25 produced to show the various aspect, i.e. PV power generation, consumption, power saving, PV power & panels costing and their payback time.

Table 19 - Total power generation of four-bed villa

House Type	Area available m2	Energy produced / m2 (Watts)	System required area x watts/m2 (kW)	Sun hours/day	Total energy produced System x sun shine hours/day (kW)
Four Bed house	250	150	37.5	5	187.5

Table 20 - Total household power need & load calculation of four-bed villa

House Type	Number of occupants	Power consumption per house/day (kWh)	Power consumption per person/day (kWh)	Power consumption per person/year (kWh)
Four bed	8-9	130	16	7908

Table 21 - Total power produced & saved four-bed villa

House Type	Energy produced/day (kWh)	Energy consumed/day (kWh)	Energy saved/day (kWh)	Energy consumed/year (kWh)	Energy saved /year (kWh)
Four bed house	187.5	129.8	57.5	47,377	20,987

Table 22 - The following table shows the total PV energy consumed & its cost four-bed villa

House Type	No. of Occupants	Energy consumed/year (kWh)	Energy Price @ 0.2 AED/unit (AED)
Four bed house	8-9	47,340	9468

Table 23 - Power sale through net metering four-bed villa

House Type	Energy sold to utility/year (kWh)	Price of energy sold to utility @ 0.2 AED/unit (AED)
Four bed house	15,585	3117

Table 24 - Principal cost PV system four-bed villa

House Type	System required (kW)	Price/ kW (AED as 2019)	Total cost (AED)
Four bed house	37.5	3000	112,500

Table 25 - PV panels payback period & panel deficiency impact four-bed villa

House Type	Price of Power used in house/year (AED)	Price of Power sold to utility /year (AED)	Total amount recovered /year (AED)	Cost of system (AED)	Proposed Payback period	PV Panel deficiency vs 8 years of payback Impact *Solar panels degrade at 0.5%/ Year
Four bed house	9468	3117	12585	112,500	8.9 years	4

4. Discussion

The Two-Bed villa with roof area of 184m^2 generates power of 138 kWh/day. The total electrical load of fixtures and appliances is 94.268 kWh/day. The electrical load is 3 water heaters, 6 air conditioners, sockets and lights. 2 water heaters are installed in bathroom 1, bathroom 2 and 1 heater serving the kitchen and maid's bathroom (each working for 2hrs/day) which consume 9 kWh/day of electrical energy. However, 6 air-conditioners (each working for 12hrs/day) are installed in the living room, majlis, kitchen, bedroom 1, bedroom 2 and maid's room consume 72 kWh/day of electrical energy, whereas, the sockets consume 3.8 kWh/day and lights consume 9.468 kWh/day. However, total PV power saving is 43.732 kWh/day electrical energy. This power can be sold through Net Metering for 3,000AED/year. Since the initial cost of the PV panel system is the main limitation for its implementation. Therefore, the GT-PV system provides the opportunity to recover the initial cost in efficient manner. In two-bed villa, the principal cost of the PV system is 82,800 AED and it will be recovered in 8 years on price 10065 AED/Year, breakup as 6,876 AED spent on power consumption and 3,189 AED earned on power sale to net grid. The discussion concerning two-bed vial is summarized in Tables 2-8, shown in section 3.1.1.

Three-Bed villa with roof area of 230m^2 generates power of 172.5 kWh/day. The total electrical load of fixtures and appliances is 112 kWh/day. The electrical load is 4 water heaters, 7 air conditioners, sockets and lights. 3 water heaters are installed in bathroom 1, bathroom 2, bathroom 3 and 1 heater serving the kitchen (each working for 2hrs) which in total consume 12 kWh/day of electrical energy. However, 7 air-conditioners (each working for 12hrs/day) installed in the living room, majlis, kitchen, bedroom 1, bedroom 2, bedroom 3 and maid's room consume 84 kWh/day of electricity, whereas the sockets and lights consume 4.6 kWh/day and 10.69 kWh/day electricity respectively. However, total per day PV power saving is 60.5 kWh/day. This power can be sold through Net Metering for 5511 AED/year. In three-bed villa, the principal cost of the PV system is 103500 AED and its payback time is 7.5 years on price 13,635 AED/Year , breakup as; 8,124 AED spent on power consumption and 5,511 AED earned on power sale to net grid. The discussion concerning three-bed villa is summarized in Tables 10-16, shown in section 3.2.1.

The Four-Bed villa with roof area 250m^2 generates 187 kWh/day power. The total electrical load of fixtures and appliances is 130 kWh/day. The electrical load is 5 water heaters, 8 air conditioners, sockets and lights. 4 water heaters are installed in bathroom 1, bathroom 2, bathroom 3, bedroom 4 and 1 heater serving the kitchen (each working for 2hrs) which in total consume 15 kWh/day of electrical energy. However, 8 air-conditioners (each working for 12hrs/day) installed in the living room, majlis, kitchen, bedroom 1, bedroom 2, bedroom 3, bedroom 4 and maid's room consume 96 kWh/day electricity, whereas, the sockets consume 6.4 kWh/day and the lights consume 12.348 kWh/day of electrical energy. However, total PV power saving is 57.5 kWh/day, this additional power can be sold through Net Metering for 15584 AED/year. In four-bed villa, the principal cost of the PV system is 112,500 AED and its payback time is 8.9 years on price 12,585 AED/Year, break up as, 9468AED spent on power consumption and 3,117 AED earned on power sale to net grid. The discussion concerning four-bed villa is summarized in Tables 18-24, shown in section 3.3.1.

5. Conclusions

UAE and other GCC countries have realized that they can no longer be dependent on oil resources alone for economic prosperity and future power needs over the long term and hence have moved towards economic diversification. Since GCC, countries are shifting towards renewable resources for energy generation to preserve their oil wealth. Therefore, encouraging the individuals, mass housing developers to adapt sustainable and renewable energy mix in new developments.

This study concludes that in coming decades, the electrical industry could be excessively affected by renewable technology. however, RE would not be an only way to solve the global energy need, a sustainable combination (retrofitting) of innovative technologies in existing structures might provide an enduring approach to electricity generation.

GT-PV is a sustainable and renewable energy system, analysis and discussion in sections 3 & 4 respectively specifies that the adaptation of GT-PV in existing housing would bring substantial reduction in national energy usage, thus stimulate sustainable environment. The main limitation to the adaptation of this system is its principal cost but results of this study indicates that this cost will be payback within 7.5 to 8.5 years for 2 ,3 and 4 bed villas, in this regard this principal cost could be termed as the investment cost.

Two-Bed villa with roof area of 184m^2 generates power of 138 kWh/day of which the total electrical load of fixtures and appliances is 94.268 kWh/day. However, total PV power saving is 43.6 kWh/day electrical energy which is then sold through Net Metering for 3,000AED/year. The principal cost of the PV system is 82,800 AED whereas, its payback time is 8 years on price 9,881 AED/Year and efficiency of PV panels' will depreciate only 4%.

In case of three-bed villa, roof area of 230m^2 generates power of 172 kWh/day. Whereas, the total electrical load of fixtures and appliances is 112 kWh/day. While, the total PV power saving is 60.5 kWh/day which can be sold through Net Metering for 5511 AED/year. In three-bed villa, the principal cost of the PV system is 103,500 AED and its payback time is 7.5 years on price 13,683.5 AED/Year, and efficiency of PV panels' will depreciate only 3.5% only.

Four-Bed villa with roof area 250m^2 generates 187.5 kWh/day power. The total electrical load of fixtures and appliances is 130 kWh/day which can be sold through Net Metering for 3117 AED/year. In four-bed villa, the principal cost of the PV system is 112500 AED and its payback time is 8.9 years on price 12,585 AED/Year and efficiency of PV panels' will depreciate only 4% only.

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