ECONOMICAL STUDY ON LOAD SHAVING BY PV IMPLEMENTATION FOR BULK CUSTOMERS IN RIYADH

2021 6th International Conference on Renewable Energy: Generation and Applications (ICREGA) | 978-1-7281-8301-5/20/$31.00 ©2021 IEEE | DOI: 10.1109/ICREGA50506.2021.9388227

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***Abstract*—This paper presents an economical study of the effect of demand-side management (DSM) by implementing a PV system on bulk customers on all elements of the electricity sector including their impact on grid operations and planning in the Kingdom of Saudi Arabia. Demand Side Management is assumed to be applied in Riyadh, as a case study, using the concept of load shaving by photovoltaic system implementation for bulk customers as a segment to manage the demand during peak period. The Time of Use (ToU) tariff model is developed and incorporated in this study. Then an economical study is carried out to calculate the money-saving by Saudi Electricity Company as the impact of load shaving at peak period. Moreover, the paper considers the economic impact of the load reduction influences on the long-term forecast and hence the investment in the conventional generation power plants. Finally, the study determines how much is the saving of electricity bills for bulk customers due to PV implantation including the expected payback period to support the usefulness of adopting DSM for the electricity sector in KSA.**

Keywords—generation ramps, generation flexibility, frequency control, PV economic model, load shaving by PV.

I. INTRODUCTION

Saudi Arabia announced ambitious targets in terms of Renewable Energy integration for the next 5 years with a 27 GW target [1]. Renewables are noticeable to the system and have an impact on operations nature. In order to integrate renewables generation in the activities of Saudi Electricity Company (SEC), a set of new functions have to be introduced on top of the current operation & control value chain. One of the most important aspects of real-time operation is the coverage of peak demand during peak hours, leading to the operation of high-cost production units [2],[3].

Increasing variable renewable energy resources with low/zero fuel costs are potentially leading to challenges in providing incentives for investment in long-term flexible resources. In order to achieve the target of renewable generation in KSA within the next five years, an approach can be taken to encourage the customers to implement PV on their side, which will help to reduce customers demand and also take advantage of the excess energy spilled to SEC network when the RE generation is higher than the demand. By this approach, the surplus energy of customers will be utilized and it will be financially beneficial to the customers as it will be seen in the last section of the paper.

Most of the researches in the energy field started to take dynamic tariffs seriously. It is a research trend in the world to achieve optimum dynamic tariff, which can be used as an encouraging tool to apply demand-side management (DSM) using PV for load shaving on the bulk customer side[4],[5]. The main goal of researches for DSM with the dynamic tariff is to accomplish a flat load profile with minimum average load, which leads to a minimum cost of generation and reduction of the customers' bills. The bulk customers are the preferable party to apply the load-shaving technique to take advantage of their financial ability and a large sunny area, which can produce a high amount of generation using PV systems.

In this study, a dynamic tariff is developed based on the load profile in KSA. The economic visibility of implementing a PV system for bulk customers in Riyadh is analyzed with a consideration of dynamic tariff application. The study drives some financial conclusions for the economic model of the electricity sector in KSA.

The rest of the paper is organized as follows. Section II explores the load and generation profiles in KSA. Section III drives the energy profile of the bulk customers in which the DSM with the PV shaving technique is implemented. Section IV explains how the ToU model is derived from the case study. Section V shows the details of the designed PV system. Section VI shows the result of applying the PV shaving technique using bulk customers on the Riyadh load profile. Finally, Section VII summarizes all the economical parameter outcomes of the case study.

II. LOAD & GENERATION PROFILE

The load profile is very important to analyze customer behavior and helps in choosing the optimum model of the dynamic tariff. In this paper, the load profile has been collected through SEC [6] for the 2nd of September 2018 as a model day of the study case. Figure 1 shows the Riyadh load profile for the selected day of the case study:

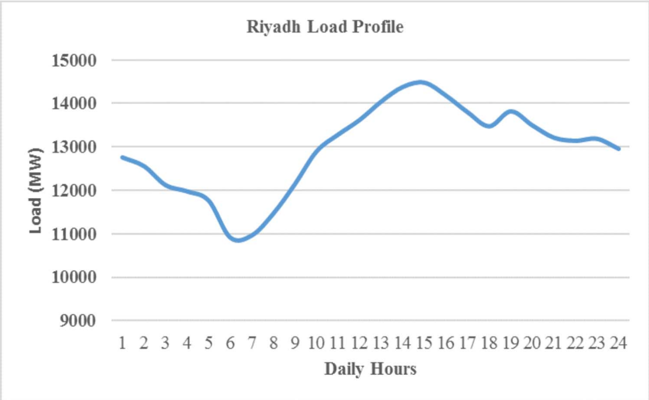

Fig. 1. Riyadh load profile at KSA peak day 2018 [6]

As shown in Fig. 1, the load profile consists of three regions, peak, off-peak, and shoulder. One of the most important objectives in the study is to reduce the load during peak hours due to its high cost using the DSM by PV shaving technique for bulk customers. The total energy of each power plant, which was running at the peak day, has been collected through SEC [6]. An aggregation of energy for the SEC online generation for each hour in the peak day has led to a generation profile shown in Fig. 2:

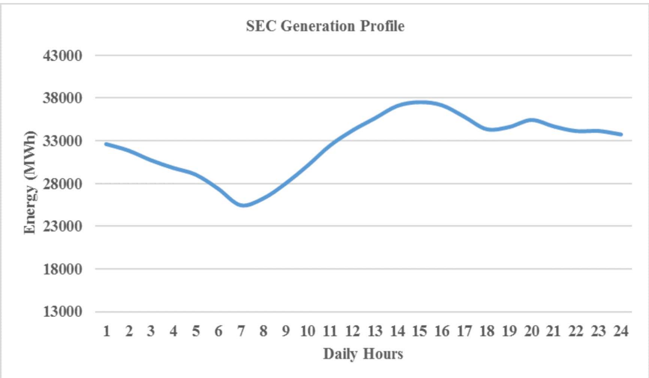

Fig. 2. SEC generation profile of the peak day [6]

III. Model of Bulk Customer Energy Profile and DSM Technique

DSM is one of the most famous methods to regulate electricity consumption. DSM plays a high role in controlling the peak demand by several techniques so that the peak load can be reduced and, hence achieving the lowest cost possible for the electricity sector[7]. The generation of electricity in Saudi Arabia is only by using conventional power plants which makes it very costly to follow the peak demand. Using DSM will be efficient in reducing the cost of electricity generation, which will be reflected in a reduction of expenses for Saudi Electricity Company (SEC).

A case study on the Riyadh load profile has been carried out using the most important technique of DSM, which is load shaving using PV system implementation. The load shaving technique depends on installing a PV system on the bulk customers' side to generate power. Part of the customer consumption will be covered by PV generation, which will lead to lowering the peak load on the customers' side. There might be a possibility that PV generation exceeds customer consumption, which will lead to an injection of the surplus energy to the SEC grid. Injection of energy to SEC network will lead to an earning of money for the customer, which will be explained more in the last section of the paper. The bulk customers are the preferable party to apply the load shaving technique because they are financially strong and they have large unshadowed areas that are suitable to be covered by PV modules. Hayat Mall has been adopted as a model bulk customer for the study. The analysis was implemented on the Hayat Mall, then based on the results, an assumption was carried out for all other bulk customers.

Hayat Mall energy for the second of September 2018 has been collected through the SEC meter reading which was equal to 34567 KWh [6]. Due to the unavailability of Hayat Mall hourly consumption data, an assumption has been carried out to determine the hourly consumption profile at the peak day shown in Fig. 3:

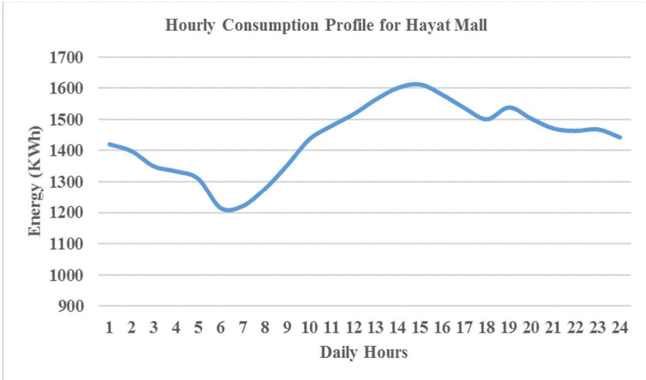

Fig. 3. Hourly consumption profile at the peak day for Hayat Mall [6]

It can be seen that the pattern of the the consumption profile in Fig.1 and Fig.3 are identical due to the assumption of hourly consumption for Hayat Mall which was based on analyzing main parameters that affect load behavior in Riyadh which is air conditions; so the hourly load profile has been assumed to have an equivalent load pattern as Riyadh load pattern [6].

IV. Time Use of System Tariff

The main desire of time use of system (ToU) tariff is to encourage the bulk customer to reduce their peak load using DSM represented by PV implementation for the benefit of electricity bill cost reduction. ToU is a type of tariff model, which depends on blocks of tariff for specific times (Peak, Off-Peak, and Shoulder) [5]. Therefore it is suitable for the case study load model shown in Fig.1. ToU is a tariff price scheme that is already applied to large domestic customers in the US and Canada [5]. Figure 4 shows an example of ToU in summer and winter[5]:

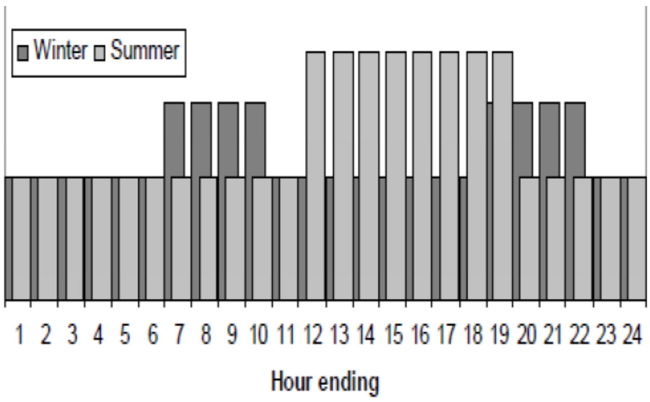

Fig. 4. Example of summer and winter ToU Schedule [5]

Electricity & Cogeneration Regulatory Authority (ECRA) is leading the restructuring of the electricity sector in Saudi Arabia. One of the major objectives is to implement a ToU tariff. ECRA has conducted a study to determine the blocks of tariff depending on the historic load profile. The result for September is used in this paper as the ToU model, which can be seen in Table I [8]:

TABLE I. ToU TARIFF MODEL

ToU Time Blocks	Load Category
11:00 – 20:00	Peak
01:00 – 03:00	Shoulder
09:00 – 10:00	
21:00 – 24:00	
04:00 – 08:00	Off-Peak

The final step to complete the ToU model is to determine the tariff of each block of the ToU tariff model. Table II shows the expected percentages of different tariff about the current applied tariff which was collected through the National Control Center department at SEC[6]:

TABLE II. ToU TARIFF MODEL PRICE

Load Category Block	Tariff
Peak	125% (38 Halala /KWh)
Shoulder	100% (30 Halala /KWh)
Off-Peak	85% (23 Halala /KWh)

V. PV SYSTEM DESIGN FOR HYATT MALL

Installing a PV system in bulk customers' side has several benefits to SEC such as voltage support, improved power quality, loss reduction, and improved utility system reliability. A PV system is designed for an exemplar bulk customer. The design of PV systems for bulk customers can be made accordingly. Hayat Mall is considered as the location model of the study with a design of a grid-connected PV system. Integrating the PV system for Hayat Mall will result in either covering part of its load, covering its total load, or covering total load with a spill to the SEC network. A schematic diagram of a grid-connected PV is shown in Fig.5 [9]:

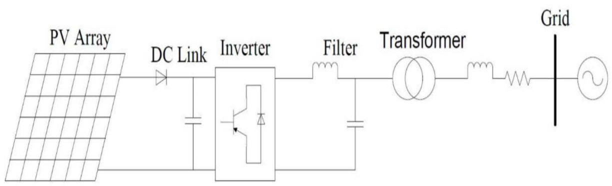

Fig. 5. Schematic diagram of a grid-connected PV system[9]

Hayat Mall is a shopping mall (24°44'36.1"N, 46°40'45.8"E) located in Riyadh, Saudi Arabia. A simulation of PV system design has been carried out through the Helioscope website with a consideration of all potential areas to install a PV system on the rooftop of the mall. Five locations areas of parking in addition to the rooftop have been considered in the design. On the peak day, the simulation results show the energy production of the PV system for each area as detailed in Table III:

TABLE III. PV SYSTEM OUTPUT FOR HAYAT MALL AS EXPECTED BY HELIOSCOPE

Location of design	Area (m2)	Output (MWh)
Rooftop	68665	17
Parking Areas (five locations)	42596	29
Total	111261	46

The Simulation has been run assuming the utilization of Trina Solar, TSM-PD14 (320W) panel module. SMA Sunny Tripower 25000TL-30 with a rated power of 24.1 kW inverters is used for the designed PV system. Table IV shows the number of components of the designed PV system for Hayat Mall:

TABLE IV. LIST OF COMPONENTS FOR THE DESIGNED PV SYSTEM

Location of design	Number of PV Panels	Number of inverters
Rooftop	21089	225
Parking Areas (five locations)	12348	132
Total	33437	357

The output energy of the designed PV system on the peak day reaches 45.98 MWh with hourly generation profile shown in Fig. 6:

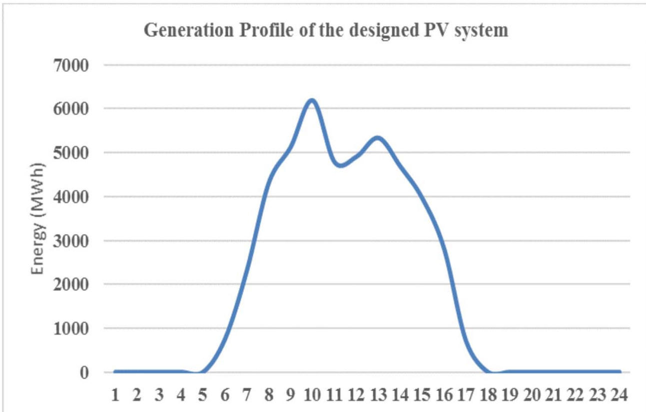

Fig. 6. Hourly generation profile of the designed PV system for Hayat Mall.

VI. RESULTS OF LOAD SHAVING TECHNIQUE

In this section, the output of the designed PV system is analyzed and a load of Hayat Mall was studied to address the effect of DSM using the load shaving technique. The daily energy consumption of Hayat Mal as seen previously for the peak day is equal to 34567 KWh while the output of the designed PV system is 45997 KWh .In Table V and Table VI the concumpion energy is represented by negative sign while generation energy is represented by positive sign .The hourly result of implementing the PV system on Hayat Mall comparing to its load profile is shown in Table V:

TABLE V. HOURLY ANALYSIS OF INTEGRATED PV SYSTEM FOR HAYAT MALL WITH SEC NETWORK

Time	PV System Output (KWh)	Hayat Mall Consumption (KWh)	The Net Energy of The PV Integrated System With SEC Network (KWh)	Percentage of PV system shaving (%)
01:00	0	-1420	-1420	0
02:00	0	-1397	-1397	0
03:00	0	-1349	-1349	0
04:00	0	-1333	-1333	0
05:00	0	-1309	-1309	0
06:00	756	-1215	-458	62
07:00	2326	-1220	1106	191
08:00	4322	-1277	3045	339
09:00	5141	-1352	3789	380
10:00	6200	-1435	4765	432
11:00	4791	-1478	3312	324
12:00	4916	-1516	3400	324
13:00	5344	-1563	3781	342
14:00	4693	-1600	3093	293
15:00	3969	-1611	2358	246
16:00	2814	-1578	1236	178
17:00	705	-1535	-831	46
18:00	0	-1499	-1499	0
19:00	0	-1537	-1537	0
20:00	0	-1501	-1501	0
21:00	0	-1470	-1470	0
22:00	0	-1462	-1462	0
23:00	0	-1467	-1467	0
24:00	0	-1442	-1442	0

The hourly result of the integrated PV system shows that the consumption of Hayat Mall is mostly covered by the production of a PV system for specific hours with a majority of spill the production of the PV system to SEC network. The remaining considered bulk customers' energy profile as per ECRA reports is representing 35% of Riyadh load profile[6]. Using hourly load profiles of the bulk customers and applying the assumption of implementing a similar PV system design of Hayat Mall using the percentage of PV shaving, the expected shaving by integrating PV system for all bulk can be seen in Table VI:

TABLE VI. LOAD SHAVING BY IMPLEMENTING PV SYSTEM FOR BULK CUSTOMERS.

Time	Bulk Customer Load Profile in Riyadh (MW)	Expected of PV system production for Bulk Customers (MW)	Riyadh Load (MW)	Riyadh Load Profile Affected by PV shaving of Bulk Customers (MW)
01:00	-4465	0	-12756	-12756
02:00	-4394	0	-12555	-12555
03:00	-4242	0	-12121	-12121
04:00	-4192	0	-11977	-11977
05:00	-4117	0	-11763	-11763
06:00	-3820	2379	-10915	-8536
07:00	-3838	7315	-10966	-3651
08:00	-4015	13591	-11471	2120
09:00	-4252	16169	-12148	4021
10:00	-4514	19498	-12896	6602
11:00	-4649	15066	-13282	1784
12:00	-4767	15461	-13620	1841
13:00	-4915	16805	-14042	2763
14:00	-5032	14760	-14376	384
15:00	-5066	12481	-14473	-1992
16:00	-4961	8849	-14175	-5326
17:00	4828	2216	-13794	-11578
18:00	-4715	0	-13472	-13472
19:00	-4835	0	-13814	-13814
20:00	-4722	0	-13491	-13491
21:00	-4623	0	-13209	-13209
22:00	-4599	0	-13139	-13139
23:00	-4614	0	-13184	-13184
24:00	-4534	0	-12953	-12953

The following graph shows the power of PV generation of the bulk customers compared with Riyadh load profile:

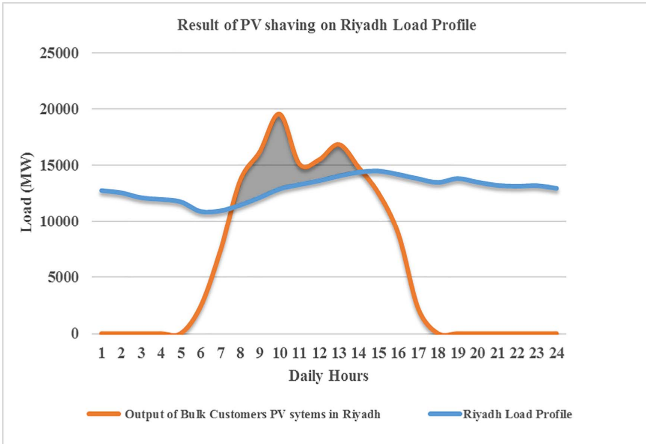

Fig. 7. Result of Load shaving using PV installation for Riyadh Bulk Customers on Riyadh load profile

The shaded area in Fig.7 shows that for some hours the PV generation is higher than Riyadh load demand. Since KSA has an interconnected electrical system, the excess of generation due to PV implementation can be interchanged to other areas outside Riyadh to balance the system. Moreover, Fig.7 Shows that due to second load peak occurrence at night when the PV production is no longer available, the effect on the long-term forecast is slightly weak with a reduction for the peak equal to 659 MW capacity.

VII. ECONOMIC STUDY OF USING DSM AND TOU

Economic analysis was carried out in this paper for the designed PV system so that the expense of the PV system is reflected on the hourly saving of the peak day with an estimation of the payback period of installing a PV system for a bulk customer. The price of the PV modules and inverters collected through manufacturing websites [10],[11]. Using the cost analysis of the designed PV system in [12], the percentage of the cost for the installation and labor from the capital cost of PV panels and inverters assumed to be 18% and 21% respectively. Table VII shows the detailed cost of the designed PV system for Hyatt Mal

TABLE VII. TOTAL COST OF THE DESIGNED PV SYSTEM FOR HAYAT MALL.

	Number of Components	Price per Module (SAR)	Total (SAR)
Modules	33,437	169	5,650,853
Inverters	357	11,343	4,049,451
Sub Total			9,700,304
Installation (Rails, clamps, fittings, etc.). **Electrical Equipments** (Wire, connectors, breakers, etc.)	-	-	1,746,055
Labor	-	-	2,037,064
Sub Total			3,783,119
Total			13,483,423

Considering 25 years of the lifetime of the PV system, the hourly price for the designed PV system through the year is equal to 61.5 SAR per hour. Combining the result that has been expressed previously on the paper (the load shaving using PV system, implementing ToU tariff and the cost of the designed PV system), hourly and daily saving of Hayat Mall has been calculated as seen in Table VIII:

TABLE VIII. HOURLY COST SAVING FOR HAYAT MALL BY IMPLEMENTATION OF PV SYSTEM.

Time	PV System Hourly Cost (SAR)	Hayat Mall Bill Cost (With Out PV System Implementation) (SAR)	Hayat Mall Expected Bill Cost (With Integrated PV System) (SAR)	Expected Hourly Cost Saving For Hayat Mall (SAR)
01:00	-61.5	-426	-483	-61.5
02:00	-61.5	-419	-477	-61.5
03:00	-61.5	-405	-462	-61.5
04:00	-61.5	-300	-357	-61.5
05:00	-61.5	-295	-352	-61.5
06:00	-61.5	-273	-161	109
07:00	-61.5	-275	191	462
08:00	-61.5	-287	628	911
09:00	-61.5	-406	1079	1481
10:00	-61.5	-431	1372	1799
11:00	-61.5	-554	1185	1735
12:00	-61.5	-568	1218	1782
13:00	-61.5	-586	1360	1942
14:00	-61.5	-600	1103	1698
15:00	-61.5	-604	827	1427
16:00	-61.5	-592	406	994
17:00	-61.5	-576	-369	203
18:00	-61.5	-562	-620	-61.5
19:00	-61.5	-577	-634	-61.5
20:00	-61.5	-563	-621	-61.5
21:00	-61.5	-441	-499	-61.5
22:00	-61.5	-439	-496	-61.5
23:00	-61.5	-440	-498	-61.5
24:00	-61.5	-432	-490	-61.5
Total	-1380	-11050	2850	13804

The tariff pricing mechanism in this paper for the bill cost reduction is using the net metering model. The net metering model is a more common model in the US which depends on a bi-directional meter with one tariff mechanism for both consumption and production [13]. The feed-in tariff is another metering mechanism that can be used to separate the production and consumption tariff. The feed-in tariff is still not regulated by ECRA which can be used to adjust high-selling tariffs when the PV system is injecting power to SEC network and, hence encouraging bulk customers to implement the PV system. As seen in Table VIII, the expected daily gain for Hayat Mall is 13804 SAR. Since the production of the PV system is almost consistent throughout the year for the Hayat Mall location as seen in Fig. 8.

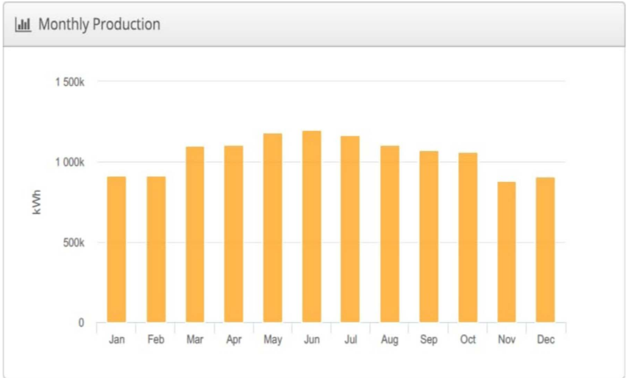

Fig. 8. Monthly Generation Profile of PV System for Hayat Mall by Helioscop

The production of the PV system is assumed constant throughout the year. Considering the peak day profile, which represents the worst-case scenario with the lowest spill to network due to high consumption, the yearly expected saving for Hayat Mall is equal to 5,038,460 SAR per year.

Equation (1) shows the calculation of the payback period for Hayat Mall PV system cost:

$$\text{Payback Period} = \frac{\text{PV System Cost}}{\text{Yearly Expected Gain}} \quad (1)$$

Where:

PV System cost = 13,483,423SAR.

Yearly Expected Gain = 5,038,460 SAR/Year.

Therefore, the expected payback period of installing a PV system for Hayat Mall is 2.7 Years. The study shows a low return back period due to the high payment of spill power to the customer, which is assumed to use the net metering model as explained earlier. Analysis of calculating the gain cost for SEC was carried out in this paper to define a full economic structure due to PV implementation for bulk customers. The first expected gain analyzed in this paper for SEC is by the effect of load shaving of implementing a PV system on bulk customers during the peak period. The capacity of reduction for long-term forecast was calculated previously to be 659 MW. The expected reduction on the hourly peak is almost equivalent to one unit (Jeddah South) which has the highest generation capacity in the Kingdom with a cost of 3,000,000,000 SAR [14]. This amount will be saved by the SEC due to the effect of PV implementation on the Long-Term forecast. The other cost reduction of SEC is due to lowering the hourly production cost of conventional generation and saving the amount of fuel consumption to be sold internationally by the government. Using the production profile mentioned previously with determining the fuel type through the SEC is used to come up with the hourly production cost[4]. The hourly production cost has been calculated using Equation (2):

$$\text{Generation Cost [SAR]} = EG * AVGCost \quad (2)$$

Where:

EG is the Generation Energy [MWH] And AVGCost is the Hourly Average Cost [SAR/MWh].

Table IX shows the expected hourly cost-saving be SEC after PV implementation by bulk customers:

TABLE IX. HOURLY PRODUCTION COST SAVING FOR SEC.

Time	Production Cost of SEC (Without PV System Integration) (SAR)	Production Cost Saving by SEC (With PV System Integration) (SAR)
06:00	-1,136,404	98,669
07:00	-1,040,868	298,983
08:00	-1,079,402	559,214
09:00	-1,154,547	667,469
10:00	-1,268,897	822,148
11:00	-1,388,955	645,178
12:00	-1,480,365	669,362
13:00	-1,553,398	733,019
14:00	-1,633,386	650,578
15:00	-1,665,707	554,379
16:00	-1,645,819	392,174
17:00	-1,575,548	97,526
Total	-16,623,296	6,188,699

It can be seen by the previous table that the daily operation cost reduction for SEC by implementing PV systems for bulk customers is equal to 6,188,699 SAR. By analyzing all the economic analyses for bulk customers and SEC with the reflection of the fuel consumption reduction, ECRA can adjust the spill price and tariff mechanism accordingly to have the optimum gain for all participants in the electrical sector. The general cost parameters for government, SEC, and the customers can lead to choose the optimum gain for all electricity sector parties.

VIII. CONCLUSION

Based on the assumptions made in the study, implementing PV systems for bulk customers in Riyadh is expected to result in an injection of energy to the SEC network with a maximum of 432% of the total energy consumption. The designed PV system for Hyatt Mall as a model of bulk customers is covering a total area of 111,261 m2 and daily energy production of 46 MWh. The result shows a very high potential energy to be produced using PV system implementation for bulk customers in Riyadh, which can support in achieving KSA renewable targets for the coming five years. However, the high-expected energy from PV generation is challenging in terms of frequency response, which need units with a fast ramp rate that can follow the pattern of PV generation and balance the electricity system. The regulator can limit the percentage of PV sharing from customers after studying all operation risks. The economic results show a very acceptable return back period of 2.7 years for bulk customers due to PV system implementation with the applied ToU tariff and net metering model. Also, ECRA can adjust the feed-in tariff to encourage the bulk customers to install PV systems by regulating a high production tariff for the excess of PV generation. The result also shows a huge amount of savings for SEC on the peak day by covering part of the demand by the PV generation rather than using conventional generation with approximately 6 million SAR at the peak day. It also shows a saving of 3 billion SAR for SEC due to the effect of PV generation from bulk customers on long-term load forecasts. Nevertheless, due to the second peak occurrence at night with the unavailability of PV generation, installing energy storage will have a higher effect on long-term forecasts resulting in more savings for SEC. Finally, all economic results show a very ambitious future of the case study in which ECRA can adjust all the economic parameters to ensure full benefits for electricity sector participants (government, SEC, and the customers).

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