Storage for Grid Deferral: The Case of Israel

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***Abstract*—To meet its target of 30% renewable energy integration by 2030, Israel must considerably develop its transmission grid. One idea that may reduce the costs of grid development is to use energy storage for grid deferral, that is, to locally store and time shift energy that cannot be transmitted due to grid congestion. For Israel this function would be most beneficial at noon when the grid is expected to be most congested due to high shares of solar energy. To study this idea, in this paper we estimate the required storage capacity as a function of renewable energy generation and grid capacity in Israel, and use the results to calculate the current required storage costs, which is then compared to the expected costs of grid development. We also analyze the added value of storage for generation capacity replacement, and show the conditions under which value stacking can increase the attractiveness of storage for grid deferral. Two main findings are that the storage capacity needed to enable connection of additional PV plants to the existing grid grows non-linearly, and that the use of storage for grid deferral is limited to an addition of 170% over the current PV capacity.**

***Index Terms*—Energy storage, renewable energy, grid deferral**

I. INTRODUCTION

In October 2020, the government of Israel declared a desired electrical energy mix of 30% renewable energy and 70% natural gas by 2030, thus significantly surpassing the objectives declared in the Paris Agreement. Israel is expecting to reach this new renewable energy objective mainly by using solar energy, since the country lacks other renewable energy sources such as wind, hydro, bio-gas, or geothermal.

High shares of solar energy implies three main geographical and economical challenges for Israel: first, Israel is expected to encounter excess solar generation at noon, mainly during the fall and the spring seasons. Being an "electricity island", Israel will need storage systems to absorb this surplus energy [1]. Second, a lack of land reserves limits the potential area for solar plants. The target of 30% renewable energy is equivalent to $\sim$15 000 MW of installed solar capacity, which requires $\sim$150 000 dunams of land. Even with large rooftop and water reservoir installations, the 22 000 km^2 country would need to allocate large areas to meet the required target [2]. Third, large renewable energy installations far from the main cities will require extensive grid development, which implies additional costs and land [3].

One idea that may reduce the costs and the land required for grid development is to use energy storage systems for grid deferral. The main idea is to locally store and time shift energy that cannot be transmitted due to grid congestion. For Israel it would be most beneficial to store excess energy at noon when the grid is expected to be most congested due to high shares of solar energy, and use it at early morning and late afternoon. In addition to relieving the congestion in the grid, these energy storage systems are also expected to be used as generation capacity replacement.

The use of energy storage for grid deferral has been discussed in the recent literature from many angles [4]–[6]. Work [4] proposes an optimal dispatch algorithm for a large scale energy storage system (ESS) in order to optimally generate revenue from relieving transmission congestion. A case study demonstrates that the ESS significantly contributes to congestion relief. In [6] a scheduling method for battery ESS in the distribution network is proposed in order to defer substation expansion. The results demonstrate that the expansion deferral may incur only negligible additional operation costs. Work [5] introduces a method to size an ESS for the purpose of peak shaving, showing that it is possible to defer network reinforcements during the entire ESS lifetime.

Other studies focus on the economic viability of energy storage as a replacement for grid investments [7]–[9]. For instance, both [7] and [9] propose multi-objective optimization based expansion planning models. Study [9] proposes a planning methodology that co-optimizes transmission expansion and ESS integration, taking into account the additional value of postponing or avoiding grid investments. Similarly, study [7] proposes a grid expansion planning model of generation, transmission and grid-scale ESS, which is formulated as a mixed-integer linear program. The IEEE RTS-96 test system with 24 buses is used as a case study, which demonstrates that co-optimization of the three assets can lead to substantial cost savings. It is shown that the cost savings mainly stem from investments deferral, rather than savings in operational costs.

In this paper we analyze the use of storage for grid deferral in the Israeli grid. By focusing on this specific grid, we attempt to highlight the practical value of grid deferral for small isolated power systems, and to provide a practical tool for policy makers. Through simulations we estimate the required storage capacity as a function of renewable energy generation

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and grid capacity, and use the results to calculate the current required storage costs, which we later compare to the expected costs of grid development. We also analyze the added value of storage for generation capacity replacement, and show the conditions under which value stacking can increase the attractiveness of storage for grid deferral.

II. THE ISRAELI ELECTRICITY SECTOR AND CURRENT PLANS TO MEET THE RENEWABLE ENERGY OBJECTIVES

Israel has ambitious renewable energy targets for 2030, considering its special characteristics and current status. In 2020, Israel generated 72 TWh of electricity, only 6% of which from renewable energy. Israel has declared its intention to eliminate coal, by shutting down the oldest coal units and converting the rest of the coal capacity to gas, while increasing the share of renewable energy to 30% by 2030. This goal seems to be challenging for several reasons. First, electricity demand is expected to grow at an annual rate of 2.7%, amounting to a 40% growth over the next decade [10]. This rapid growth is attributed to the 1.9% growth in population, the use of electricity for water desalination, and the possibility of a rapid growth in electric transportation. Second, Israel is an “electricity island”, with no interconnections to neighboring states, and thus must maintain its energy balance at all times by local generation, while maintaining grid stability and reserves. Third, Israel recently reformed its electricity sector structure and established an independent system operator [11]. Hence, the required renewable energy capacity is expected to be developed by the private sector, while Israel’s Electricity Corporation would be responsible for developing the grid.

Another key challenge is that due to the lack of other renewable energy resources, the country plans to achieve its renewable target mainly by solar energy. The 2030 renewable energy target is aiming to connect 15 GW of solar power, which will be equally divided between utility scale plants, water reservoirs installations, and rooftop installations (5 GW each). In addition, Israel is expecting to connect 0.7 GW of wind power, and less than 0.1 MW of biogas.

In Israel, land and water reservoirs that are suitable for utility scale solar plants are typically far from the main cities, and therefore their connection would require grid development. Thus, the Israeli system operator published a preliminary plan for grid development [12] set to enable the connection of future solar capacity at the overall cost of four Billion dollars (Table I). The plan is 2-5 times more extensive than Israel’s current grid development plan, thus raising concerns that it would not be ready in time to achieve the renewable energy targets. In this context, recent statistics published by the Israeli Electricity Authority shows that the average waiting time for high voltage line permits is 9 years [13], i.e. such permits would probably be granted around 2030, not providing sufficient time for building the new power lines prior to 2030.

III. METHODOLOGY

The methodology is based on a high temporal resolution simulation in which we estimate the required storage capacity as a function of renewable energy generation and grid capacity. The grid capacity is also used to estimate the availability of the grid to absorb stored excess energy during off-peak hours. The results are then used to calculate the storage costs, which we later compare to the expected costs of grid development. We also analyze the added value of storage for generation capacity replacement in order to find the conditions under which value stacking can increase the attractiveness of storage for grid deferral.

TABLE I
CURRENT AND FUTURE GRID DEVELOPMENT PLANS.

Plan	400 kVA lines [km]	161 kVA lines [km]	Switching station	Substations
Current development plan	90	560	1	17
Additional plan to meet renewable target	470-720	810-1130	6	96

We focus on three regions in Israel that differ in the cost of grid development that is required for connecting additional solar capacity: Eilat, the Western Negev, and a typical medium voltage distribution grid. For each region the following steps are performed:

1) The average cost of grid development per MW of solar capacity is calculated according to the overall expected grid investment and future solar capacity in each area (see Table II).
2) The storage capacity that is required to connect additional solar capacity to the existing grid is analyzed using an hourly simulation. The simulation uses an estimation of the hourly solar generation in each region according to the irradiation in Israel, and calculates the hourly excess generation given the existing grid capacity. The power and energy capacities of the storage that is needed to absorb the excess generation are calculated according to the hourly excess generation along the year.
3) The availability of the grid for absorbing stored excess energy during off-peak hours is estimated by calculating the number of hours in which there would be no available grid capacity to discharge the stored energy. We assume that renewable capacity can be added to the grid up to the point where 5% of the stored energy cannot be discharged at any hour of the day. This threshold implies a loss of 5% of the income due to energy curtailment.
4) The average cost of grid development is compared to the cost of using storage to enable additional solar capacity. Both grid and storage costs include a maintenance component that would be paid annually. Future costs are discounted at 4% to find the net present value.

The sources and assumptions we used for estimating the costs are detailed next. Grid cost estimates are based on [14], assuming 1 Million \$/km of 161 kVA lines, 0.14 Million \$/km of 22 kVA lines, 2.5 Million \$/km of 400 kVA lines, 20 Million \$ per substation, 120 Million \$ per switching station and 2.5

TABLE II
GRID DEVELOPMENT COSTS IN EACH REGION [14].

Region	Existing PV capacity [MW]	Potential of additional PV capacity [MW]	Total cost of additional grid development [Million $]	Average grid development cost [Million $/MW]
Eilat	190	1260	827	0.7
Western Negev	200	1783	721	0.4
Distribution Grid	36	36	7	0.2

Million $ per transformer added to an existing substation. The Western Negev region represents the average grid development cost in Israel, while in the Eilat region it is 50% higher, and in the distribution grid it is significantly lower. The cost of storage is based on [15], and storage parameters are based on [16], as shown in Table III. Energy losses due to storage efficiency are evaluated according to recent PV tenders at 4.5 $ cent per kWh. Annual energy loss values are discounted by a rate of 4%. Replacement cost of battery rack at the end of life are evaluated according to forecasts of future battery cost [17] and discounted at a rate of 4%.

TABLE III
STORAGE PARAMETERS [16], [17].

Parameter	Value
Depth of discharge [%]	90
Round trip efficiency [%]	87
Lifetime of battery rack [years]	15
Maintenance and degradation cost [% of $/kWh]	2.5
Construction cost at 2023 [$/kWh]	250

A. *The Economic Value of Generation Capacity Replacement*

In addition to the economic value of using storage for grid deferral, the same storage systems can be used to defer investments in generation capacity. As of 2018, the Israeli Electricity Authority estimated a need for additional 4 GW by 2030, to meet growing demand. PV generation, which is rapidly growing, will provide some of the capacity needs during the day, thus the need for additional capacity is expected mainly during the evening. Storage capacity used for absorbing excess PV generation in areas where the grid is already congested can also provide a replacement for additional generation capacity. This stored excess PV energy would be discharged during the evening to supply the peak demand.

We calculate the expected value of storage for generation capacity replacement as follows. Following [18], we assume that 4 kWh of storage can replace 1 kW simple cycle generation capacity. Moreover, based on [19], we assume that the cost of new generation capacity is 854 $/kW, and that annual operation and maintenance costs are 48 $/kW/year. Assuming a weighted average cost of capital (WACC) after tax of 7.5% and 20 years of operation, we find that the value of replacing 1 kW of generation capacity is 213 $/kWh, and that the present value of operations and maintenance (O&M) savings is 120 $/kWh.

IV. RESULTS

In this section we first analyze how additional PV capacity affects both the storage capacity that is required to absorb excess PV generation, and the availability of the existing grid to absorb the stored energy during off-peak hours. Next, we analyze the economic viability of storage for grid deferral in three regions in Israel.

We first demonstrate that the required storage capacity increases at a nonlinear rate as PV capacity is added to the grid. Figure 1 shows excess solar generation during the day for different additions of PV capacity in the Eilat region. The graph shows that for a small percentage of additional PV capacity, the grid will be able to absorb the majority of the energy and congestion will occur only at noon. However, as the percentage of additional PV capacity grows, a larger share of the energy needs to be stored. Thus, the required storage capacity per *additional* PV capacity is a monotonic increasing function. In other words, the more PV we add, the more storage we need per MW of PV. This function is non-linear and approximately concave, as can be seen in Fig. 2, which shows the average storage energy capacity required per MW of additional PV power for different total additional PV capacities. As can be seen, the required storage energy capacity increases at a nonlinear rate as additional PV power is added. Moreover, it seems that for total additions of over 100% the required storage converges to a limit of 4.5 hours per MW.

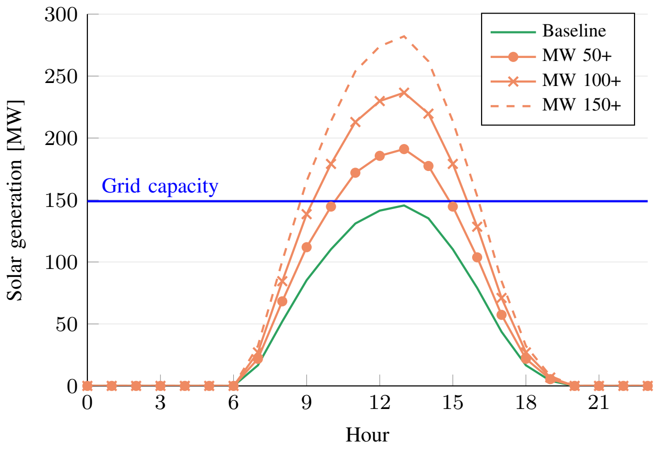

Fig. 1. Example of excess solar generation as a function of additional capacity. 🟩 Generation of current PV capacity; 🟧 Generation of additional PV capacity.

In Fig. 3 we study the availability of the grid for storage discharge. The figure shows the percentage of days with sufficient grid capacity for storage discharge, as a function of additional PV capacity. As can be seen, for a capacity addition of up to 170%, the grid will be available for storage discharge 100% of the days. However, larger capacity additions imply that for a growing percentage of the days there will not be

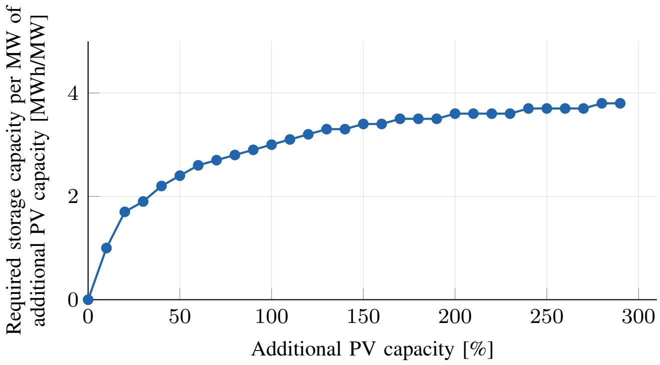

Fig. 2. Average storage capacity required per additional solar capacity.

sufficient grid capacity for storage discharge. Thus, additional PV capacity larger than 170% would require grid development.

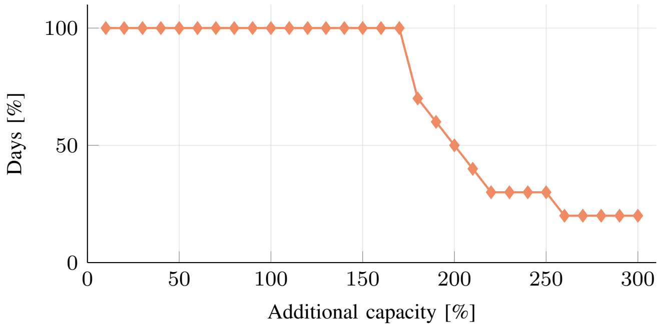

Fig. 3. Grid availability as a function of additional capacity.

Next, we analyze the economic viability of storage for grid deferral in three regions in Israel.

A. Eilat Region

Eilat is a city located in the southern part of Israel in a region that is characterized by availability of land and by an annual generation of 1 900 solar hours. By 2020, 190 MW of PV capacity were connected in this region, and there is a potential for additional 1 260 MW. However, grid congestion at noon disables the connection of additional PV capacity.

Grid development plans for the region include 120 km of 161 kVA lines, 150 km of 400 kVA lines, one switching station and 12 substations. The overall capacity investment and present value of the grid O&M costs are estimated at 827 Million $, with an average cost of 0.7 Million $/MW.

Table IV depicts the cost of storage for a range of additional PV capacity in the Eilat region and for a range of storage prices. The colors indicate the viability of the storage compared to investment in grid development and generation capacity. Green indicates viability of storage compared to grid development; Yellow indicates viability of storage only if, in addition to grid development, capacity replacement can also be monetized; Red indicates non viability of storage compared to investment in grid development plus capacity investment.

Note that the average cost of storage increases as the additional PV capacity increases. More importantly, storage becomes viable for grid deferral at the Eilat region for 10% additional PV capacity. For higher additions of PV capacity storage remains viable either if its cost reduces or if it is compensated for capacity replacement.

TABLE IV
COST OF STORAGE FOR ADDITIONAL PV CAPACITY [M $/MW] IN THE EILAT REGION.

Capacity addition [%]						
300	200	100	50	20	10	Storage cost $/kWh
🟨 0.8	🟨 0.8	🟩 0.6	🟩 0.5	🟩 0.3	🟩 0.2	50
🟨 1.0	🟨 1.0	🟨 0.8	🟩 0.7	🟩 0.4	🟩 0.3	100
🟨 1.3	🟨 1.2	🟨 1.0	🟨 0.8	🟩 0.5	🟩 0.3	150
🟨 1.5	🟨 1.4	🟨 1.2	🟨 1.0	🟩 0.6	🟩 0.4	200
🟨 1.8	🟨 1.6	🟨 1.4	🟨 1.1	🟨 0.7	🟩 0.5	250

🟩 Viable for grid deferral 🟨 Viable for grid deferral and capacity
🟥 Not viable

B. Western Negev region

The Western Negev is attractive for utility scale PV plants due to availability of land and its proximity to consumption areas. However, following the installation of 200 MW PV in this region, grid congestion disables additional PV connections.

Future grid development plans for this region include 150 km of 161 MVA lines, 50 km of 400 MVA lines, 16 substations and one switching station. The average cost for grid development in this region is estimated at 0.4 Million $/MW.

Table V depicts the cost of storage for a range of PV capacity additions at the Western Negev region and for a range of storage prices. Note that due to a cheaper cost of grid development in this region, storage is viable for grid deferral only for small PV capacity additions and only if the cost of storage drops to 200 $/kWh. However, in this case too, capacity replacement makes storage viable for grid deferral for PV capacity additions up to 170% even at the current level of storage prices.

TABLE V
COST OF STORAGE FOR PV CAPACITY ADDITION [M $/MW] IN THE WESTERN NEGEV REGION.

Capacity addition [%]						
300	200	100	50	20	10	Storage cost $/kWh
🟨 0.8	🟨 0.8	🟨 0.6	🟨 0.5	🟩 0.3	🟩 0.2	50
🟨 1.0	🟨 1.0	🟨 0.8	🟨 0.7	🟩 0.4	🟩 0.3	100
🟨 1.3	🟨 1.2	🟨 1.0	🟨 0.8	🟨 0.5	🟩 0.3	150
🟨 1.5	🟨 1.4	🟨 1.2	🟨 1.0	🟨 0.6	🟩 0.4	200
🟥 1.8	🟨 1.6	🟨 1.4	🟨 1.1	🟨 0.7	🟨 0.5	250

🟩 Viable for grid deferral 🟨 Viable for grid deferral and capacity
🟥 Not viable

C. Distribution Grid

The majority of solar capacity in Israel is expected to be connected to the distribution grid. This is due to limited availability of land which implies small scale PV plants and extensive use of rooftops.

The cost of additional PV capacity in the distribution grid results from upgrade of medium voltage lines and substation transformers. The last is due to the current limitation of the overall capacity that can be connected to a single transformer to 36 MW. The average upgrade cost of an additional transformer and ∼10 km of 22 MVA lines is ∼0.2 Million $/MW.

Table VI depicts the viability of storage in deferring this investment. Distribution grid development is substantially cheaper compared to the cost of developing the transmission grid to enable the connection of additional PV capacity. Therefore, as can be seen, storage is only viable if compensated for capacity replacement.

TABLE VI
COST OF STORAGE FOR PV CAPACITY ADDITION [M $/MW] IN THE WESTERN NEGEV REGION.

Capacity addition [%]							
300	200	100	50	20	10		
0.8	0.8	0.6	0.5	0.3	0.2	50	Storage cost $/kWh
1.0	1.0	0.8	0.7	0.4	0.3	100	
1.3	1.2	1.0	0.8	0.5	0.3	150	
1.5	1.4	1.2	1.0	0.6	0.4	200	
1.8	1.6	1.4	1.1	0.7	0.5	250	

🟩 Viable for grid deferral 🟨 Viable for grid deferral and capacity
🟥 Not viable

V. CONCLUSIONS

Demanding renewable energy targets, ambitious grid development plans, and declining storage prices may make the use of storage for grid deferral a practical solution in Israel. This paper analyzes this idea in simulation, focusing on three regions in Israel in which the grid is already congested at noon due to existing PV generation. Our simulation results demonstrate two main phenomena. First, the results show that as PV is added to the grid, the required storage capacity per additional PV capacity grows. Moreover, this relationship is non-linear and seems to converge at some point to a limit of 4.5 hours per MW (see Fig. 2). Second, the results show that the use of storage for grid deferral in Israel is limited to 170% of the current PV capacity. This is because connecting additional PV capacity beyond the 170% threshold implies that during a large share of the year the energy could not be fully discharged from the storage due to grid congestion.

We also analyze the economic viability of storage for grid deferral in three regions in Israel. One main conclusion is that in areas with high grid development cost (>0.7 Million $/MW) it is already viable to use storage for grid deferral for additional PV capacity of up to 10%, assuming storage cost of 250 $/kW. For higher additional PV capacity, grid deferral with storage would be viable if the cost of storage drops to 200 $/KWh and below, or if the value of using storage for generation capacity replacement is monetized. In areas where grid development is significantly cheaper, such as the Negev or a typical distribution network, the use of storage for grid deferral seems to be economically viable only when the value of storage for generation capacity replacement is monetized. It should be noted that grid deferral is by no means enough in order to meet the Israeli renewable energy goals of 2030, and some investments in grid development seems unavoidable.

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