Volume 8, Number 3, September 2022
Pages 253-265
ISSN (Print): 2409-9600, ISSN (Online): 2409-9619

Techno-Economic Feasibility Analysis of On-Grid Battery Energy Storage System: Almanara PV Power Plant Case Study

Aouda A Arfoa[1], Eyad Almaita[2*], Saleh Alshkoor[3], Maan Shloul[4]

[1, 2] Department of Power and Mechatronics Engineering, Tafila Technical University, Tafila, Jordan
E-mail: e.maita@ttu.edu.jo
[3] Technical Control Department, Energy and Mineral Regulatory Commission, Jordan
[4] Planning Department, Irbid District Electricity Company, Jordan

Received: June 04, 2022 *Revised: August 11, 2022* *Accepted: August 18, 2022*

***Abstract*—** Battery energy storage systems (BESSs) are considered one of the most developed energy storage system (ESS) technologies because they have different benefits for distribution networks like smoothening the output fluctuations, improving the power quality, peak load shifting, voltage support and delaying the distribution network upgrade. This work involves integrating a BESS into a 33 KV distribution network in Jordan. CYME software is used to assess the impact of BESS at Almanara PV power plant on the 33 KV medium voltage network. The voltage level, power losses, power factor (PF) and voltage step are chosen as performance indicators. For each of these indices, comparisons between the grid performance with and without the BESS are carried out. In addition, the payback period of the BESS is calculated. The obtained results reveal that BESS not only improves the voltage level – with an overall improvement of about 3.03% at both feeders – but also reduces the losses, with an overall reduction in losses of 4.68% at both feeders. BESS is found to decrease the PF with an average of 0.83 at both feeders, while the voltage step doesn't exceed the limits set by the International Electro-technical Commission (IEC). Additionally, the performed economic analysis unveils that the payback period is about 10.98 years.

***Keywords*—** Battery energy storage system; Energy storage system; Techno-economic analysis; Power plant; Payback period.

1. INTRODUCTION

Nowadays, the dominant source of energy in the world is fossil fuel; however, its use is accompanied by several problems. Firstly, this source leads to increasing the greenhouse gases emissions that affect human health. Secondly, the high fluctuation cost of the fossil fuels that specially affects fuel importing countries. According to the energy information agency (EIA), a substantial increase in oil prices will be observed in the next two decades [1]. This increasing demand creates a global demand for distributed generation (DG) technologies and renewable energy sources (RES).

Since 2011, RES have accounted for more than half of all capacity additions in the power sector with more than 140 countries having a target to install a certain percentage of the RES [2]. In Jordan, as an example, the contribution of the RES is approximately 25% from the installed generation capacity. This continuing increasing demand of power transfers to RES in a huge network results in a sophisticated and less secure power system, due to the power output fluctuations and unpredictable amount of RES [3]. This stochastic nature of RES would hamper the grid stability under normal conditions. During extreme weather conditions, RES behavior is completely uncertain. Hence, there is a need to eliminate the adverse effects caused by the RES and make the distribution grid more reliable and stable under normal and

* Corresponding author
Article's DOI: 10.5455/jjee.204-1654330119

resilient conditions [4]. These issues have encouraged researchers to focus on improving power availability and quality along with reliability [5].

To address these challenges, energy storage systems (ESSs) play a leading role in increasing the share of RES and improving the efficiency of the power system. The ESSs offer a continuous support to the power grid in response to load demand variations. This support can be in the form of regulating power system frequency, stabilizing voltage level, upgrading the distribution lines capability and minimizing the fluctuations of RES. ESSs can be also the solution to fix the aging power grid, bridging the gap between the utilities and customer's demand and increasing the use of hybrid and electric cars in transportation sector.

There are various types of ESSs. Fig. 1 shows the classification of the ESSs according to their storage media. It can be divided into three major classes [6-8]:

a) Mechanical ESSs which are classified into pumped hydro energy storage (PHES) [9], compressed air energy storage (CAES) [10] and flywheel energy storage (FES) [11].
b) Chemical ESSs which can be classified into conventional, rechargeable, and flow batteries and hydrogen fuel cells [12].
c) Electrical ESSs which can be also subdivided into super capacitors (SC) [13] and super conducting magnetic energy storage (SMES) [14].

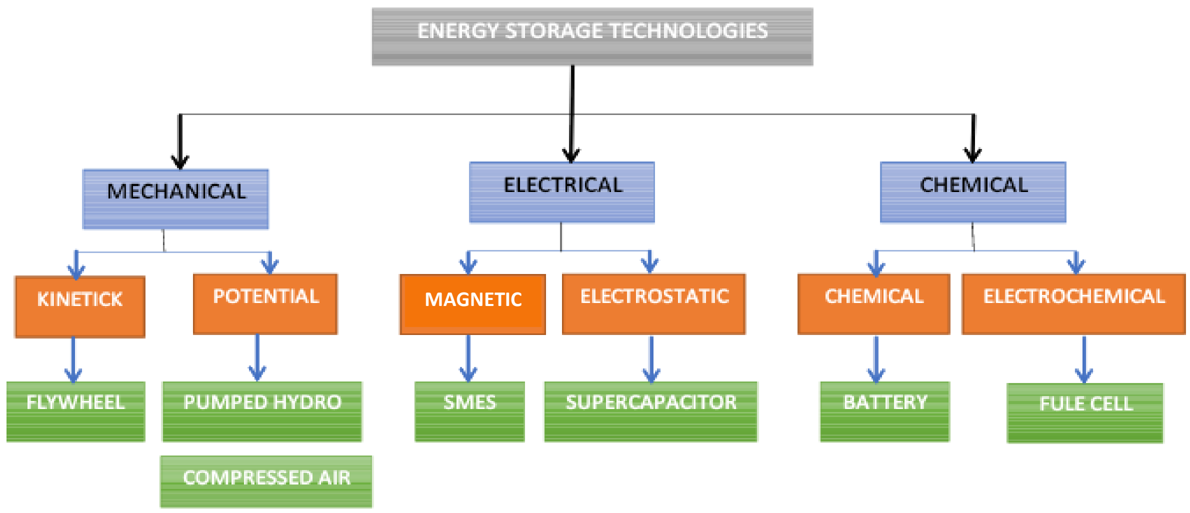

Fig. 1. Classification of ESSs.

With all these types, battery energy storage system (BESS) is one of the most developed ESS technologies in the recent years, due to the rapid increase of installing the RES and the boom of electric vehicles (EV) industry. This is because BESS has several advantages compared to the other ESSs such as: independence from geographic location requirements, fast response and higher efficiency.

The adoption of ESS is a smart way to mitigate the power system issues from large-scale (generation and transmission) networks to small-scale application of distribution and microgrid networks. The applications of ESS can be illustrated in the following: bulk energy services [15-17], transmission services [18], distributions services [19, 20], energy management services [21, 22] and ancillary services [23]. With these benefits, ESS is expected to be a major part of modern electric grids [24]. Fig. 2 summarizes all the applications of ESS.

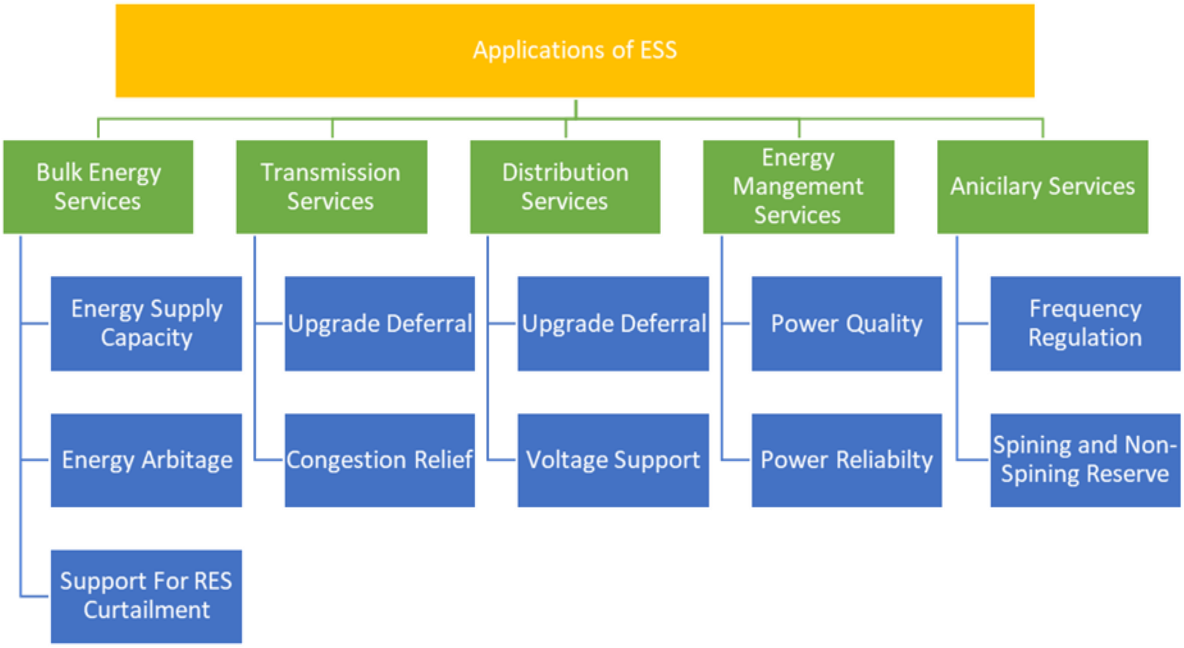

Fig. 2. Applications of the ESS.

One of the applications of the ESS is the voltage support which ensures that the voltage level of specific feeder is controlled within an acceptable range.

BESS can influence power flows along a feeder by acting as generator or load, to regulate the voltage level [25]; so, the distribution companies intend to place the DG, e.g., system near to the distribution load to reduce the power flow, minimize losses and provide stability to the system in terms of avoiding voltage disturbances.

In [26], the authors used the objective function to calculate electricity grid losses while considering limitations of using energy storage devices. Authors in [27] use an optimal method called pattern search (PS) algorithm to reduce the distribution network loss using the MATLAB software. In [28], the simulation results show that the placement approach of the proposed ESSs improves the distribution network performance by improving the voltage profile, line loading minimization and power loss reduction.

Authors in [29] show that the application of the proposed procedure to the defined scenario leads to improve all the terms that are taken into account like network voltages, losses and the cost of imported energy from the external grid.

Authors in [30] present an algorithm for optimal operating of energy storage devices in medium voltage (MV) distribution grids. The proposed algorithm was tested using a CIGRÉ MV test grid. The proposed algorithm showed significant results in loss minimization in the studied MV distribution grid.

Authors in [31] proposed an optimal planning procedure that accounts specifically for the minimization of the network voltage deviations based on the formulation of a mixed-integer linear programing problem.

Authors in [32] proposed the bee colony optimization method to find the optimal placement and capacity of the battery in the radial distribution network for alleviating the voltage rise due to PV sources. One of the simulation results shows that the ESS has different benefits such as energy arbitrage and power quality. The energy arbitrage means purchasing more electricity during off-peak periods, storing that electricity and discharging it during peak periods.

Authors in [33, 34] proposed a method to increase the arbitrage benefits of ESS and reduce the net cash flow, respectively. In the power quality issue, authors in [35] proposed a method to improve distribution network management and its power quality. In [36], authors discussed the optimal implementation of distributed storage resources in a power distribution system or islanded micro grid in conjunction with an intelligent load shedding scheme to minimize the societal costs of blackouts.

This paper aims to find the technical and the economic feasibility study of the battery storage system at Almanara PV power plant. Following the introduction, section 2 is covering the system description and data generation. Section 3 presents the results and discussion. Finally, the conclusions are given in section 4.

2. SYSTEM DESCRIPTION AND DATA GENERATION

2.1. System Description

Our data is obtained from Almanara PV power plant - the first project in Jordan that uses BESS. Almanara PV power plant has been commercially operated since 2015 with 10 MWac capacity. In 2019, the PV plant capacity was expanded by adding 10.982 MWp with 3 MVA and 12 MWh. Thus, BESS made the PV capacity 23 MWp with 18 MVA and limited 13 MWac output at point of common coupling (PCC).

The output power curve is smooth, and the maximum AC threshold values at PCC is 8 MW to Sabha feeder, 4 MW to Alsalhyia and 1 MW to Safawi. Fig. 3 shows the single line diagram of Almanara PV power plant after expansion.

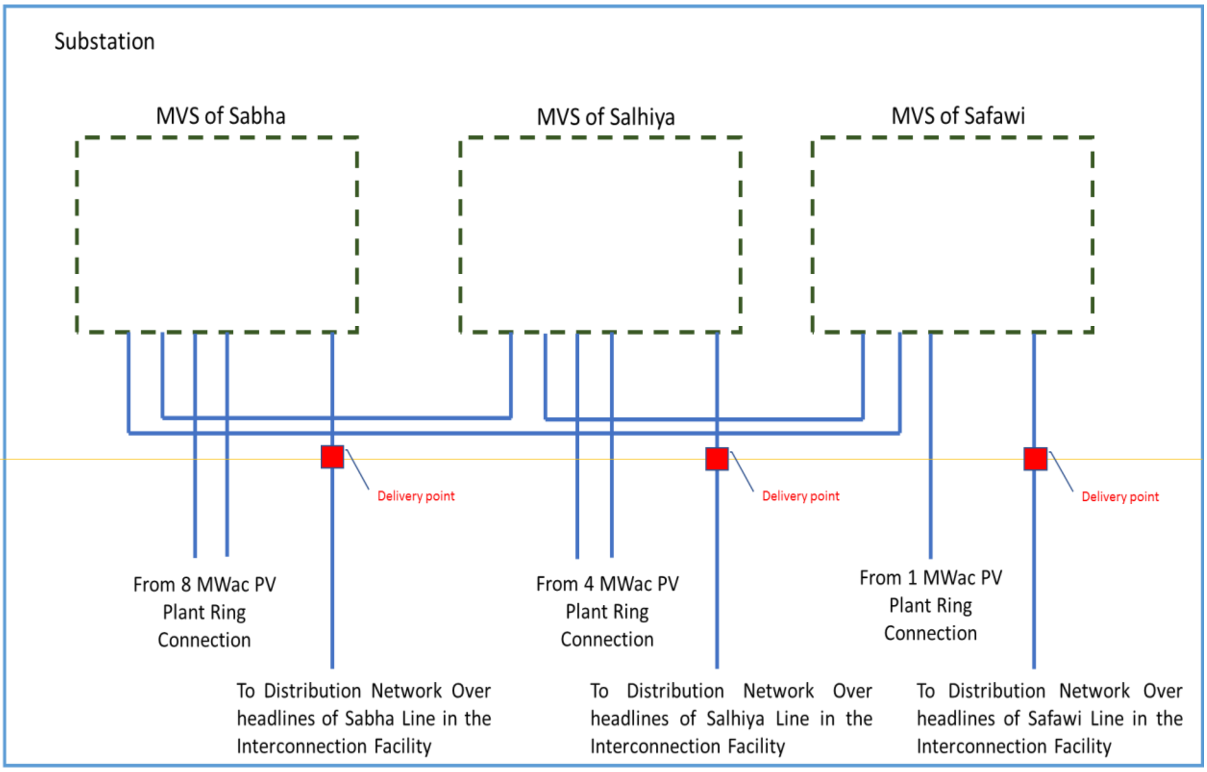

Fig. 3. Single line diagram of Almanara PV plant after expansion.

2.2. Data Generation and Preparation

From the technical point of view, this paper aims to find the effect of four main impacts of the BESS installed at Almanara PV power plant to complete the system impact study. This project contains 12 MWh battery storage system connected to the 33 KV - MVnetwork of Irbid District Electricity Company (IDECO) at both Sabha and Alsalhiah 33 KV feeders, 2 MW connected at Sabha feeder and 1 MW connected at Alsalhiah feeder, with 4 hours discharge periods.

The CYME software [37] was utilized to model and collect the data from BESS. The geographical model of the 33 KV MV feeders in the CYME software is shown in Fig. 4.

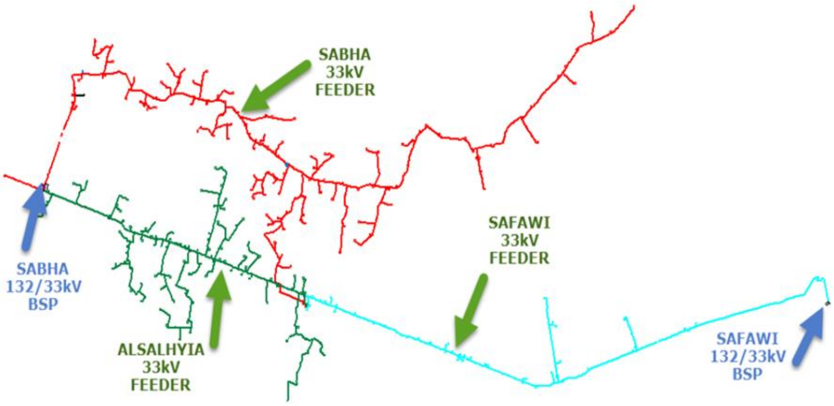

Fig. 4. CYME geographical model of the MV feeders.

The storage system is modeled as an "electronically coupled generator" in the CYME software. Fig. 5 shows how the 132/33 KV Sabha, national electric power company (NEPCO) substation, bulk supply point (BSP) are represented in the CYME software where the storage system is connected at two of BSP 33 KV feeders (Sabha and Alsalhiah).

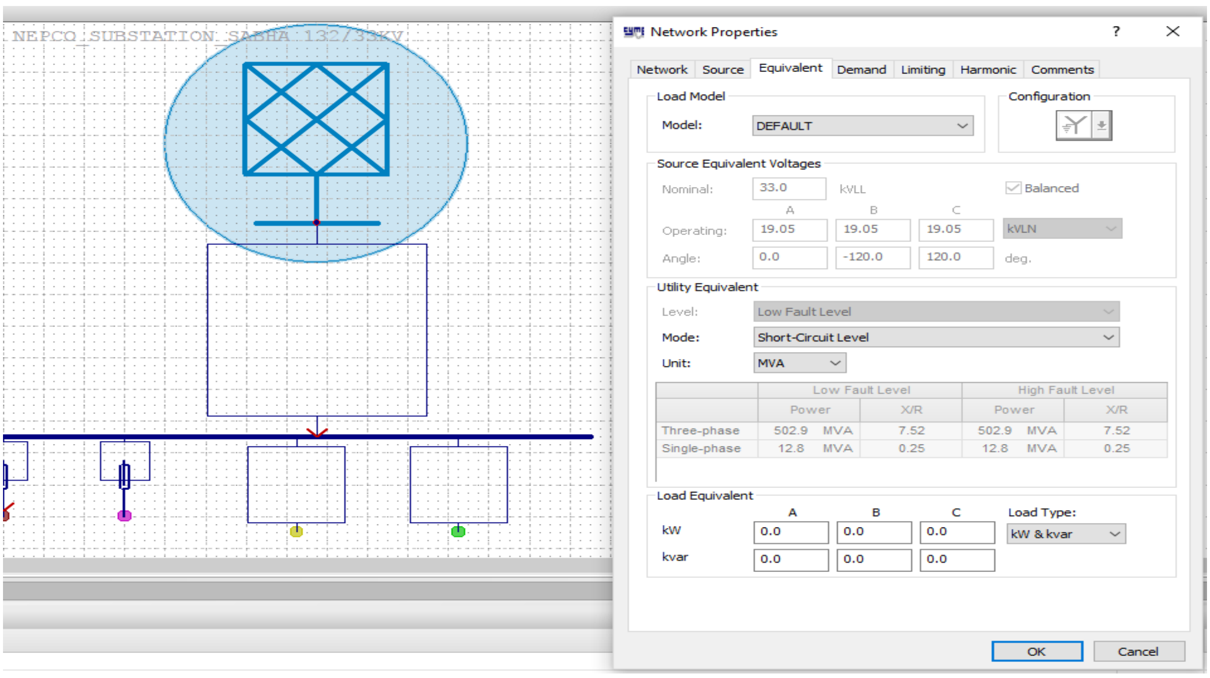

Fig. 5. CYME equivalent model data for Sabha BSP.

For the economic part, the analysis is done for the energy exported from this battery system to the IDECO network before and after the expansion - i.e., before and after BESS connection - based on the real data obtained from both IDECO and Almanara PV power plant to find the benefits of this storage system for a Almanara PV power plant and calculate the payback period.

3. RESULTS AND DISCUSSION

3.1. The Technical Feasibility Study

The system impact study is very important to show the system's compliance with the requirements of the Jordanian code, i.e., the intermittent renewable resource (IRR) distribution connection code (DCC) at MV. The MV distribution network in Jordan is for voltage levels greater than one 1 KV and up to 33 KV. This code (IRR-DCC) establishes the technical connection requirements which IRRs must comply with, and it is complied with other standards such as International Electro technical Commission (IEC) and also with the recommendations of Energy Networks Association (ENA).

3.1.1. Mathematical Model

CYME software is used to find the effect of this storage system on voltage level, losses, power factor (PF) and the voltage step at both feeders by using the power flow analysis tool [37]. This tool is designed to assist in the analysis of static emergencies associated with power flow. With it, the power engineer can create emergency events and single or multiple outage scenarios and compare the results with the base-state network and connection data. The goal of power flow software is to analyze the steady-state performance of a power system under various operating conditions. It is the essential analysis tool for planning, designing and operating any electrical power system.

Power flow studies can provide a number of systematic mathematical approaches for determining complex bus voltages. Through these voltages, it is possible to determine the power flow in the branches and generators distribution and loads under steady state conditions. The power flow analysis in this paper is based on the steady state operation of the power system with and without the presence of the BESS.

It should be noted that, before starting the load flow analysis, the entire network must be designed with all generators, loads and transmission lines. The power grid consists of elements such as transformers, distribution generators, loads, transmission lines, cables and generators.

Suppose we have two buses i and j, the complex power flows in the line from bus i to bus j is given by:

$$S_{ij} = P_{ij} + Q_{ij} = V_i \left(I_{ij}\right)^*$$
$$S_{ij} = V_i \angle \theta i \left[\frac{V_i \angle \theta i - V_j \angle \theta j}{Z_{ij}}\right]^* \quad (1)$$

Active (Pij) and reactive (Qij) powers coming out from the bus i to bus j are given by:

$$P_{ij} = \text{Real}\left[S_{ij}\right]$$
$$= \frac{(Vi)^2 \cos(\theta ij)}{Z_{ij}} - \frac{Vj\,Vi \cos(\theta ij + \theta i - \theta j)}{Z_{ij}} \quad (2)$$

$$Q_{ij} = \text{Imaginary}\left[S_{ij}\right] = \frac{(Vi)^2 \sin(\theta ij)}{Z_{ij}} - \frac{Vj\,Vi \sin(\theta ij + \theta i - \theta j)}{Z_{ij}} \quad (3)$$

For a typical power system that consists of n buses, the net injected power equations in polar formula for each bus can be written as:

$$P_i = \sum_{j=1}^{n} \frac{|Vi||Vj|}{Z_{ij}} \mathrm{Cos}(\theta ij - \delta i + \delta j) \quad (4)$$

$$Q_i = -\sum_{j=1}^{n} \frac{|Vi||Vj|}{Z_{ij}} \mathrm{Sin}(\theta ij - \delta i + \delta j) \quad (5)$$

The solution techniques of distribution network power flow problem are classified into two major reference groups: phase frame approach and sequence frame approach. The forward and backward sweep method, compensation method, implicit Gauss method, modified Newton-Raphson methods or any other miscellaneous power flow methods are different algorithms used under each reference frame [38].

In this work, Newton Raphson method [39, 40], which is the most common method used to solve a power system flow problem, is used to find the voltage drop, losses , etc. This method is a very well-known method that is used to find the power as shown in Eqs. (1) and (2) because it is one of the fastest methods of square convergence with a root.

In order to get the current findings, some assumptions are made. Firstly, the nominal voltage at the BSP (Sabha BSP) - NEPCO Substation 33 KV busbar- is considered to be 1 pu whether BESS was connected (switched on) or disconnected (switched off). Secondly, the value of the PF at the BESS is assumed to be unity.

3.1.2. Effect of BESS on the Voltage Level

Table 1 shows the effect of BESS on the voltage level and the current drawn from the BSP before and after the BESS connected.

Table 1. The effect of BESS on the voltage level at both feeders.

Configuration	Network Id	Current (Max) [A]	Voltage (Min) [kVLL]	Voltage (Max) [kVLL]	Deviation in Voltage (Max) [%]
Storage = ON	Alsalhiah feeder	227.8	30.7	33.0	7.02
Storage = OFF	Alsalhiah feeder	245.3	30.1	33.0	8.78
Storage = ON	Sabha feeder	200.6	30.2	33.0	8.49
Storage = OFF	Sabha feeder	233.5	29.8	33.0	9.76

For the voltage requirements, IEC 60038-2009 code states that the BESS should remain constantly connected to the distribution network with a system voltage of +/10% of the rated voltage for normal and disturbing system. Otherwise, the BESS will trip with different delay times for stability issues.

The results taken at the 33 KV busbars show that the storage system improves the voltage level in both feeders; the minimum voltage level on Sabha improved from 29.8 to 30.2 KV while on Alsalhiah improved from 30.1 to 30.7 KV and complies with the limits set in the code’s requirements. In addition, the current drawn from the BSP was reduced in both feeders; at Sabha feeder it was reduced from 233.5 to 200.6 A, and at Alsalhiah feeder it was reduced from 245.3 to 227.8 A.

3.1.3. Effect of BESS on the Losses at MV Feeders

The losses over the MV feeder were evaluated before and after BESS connection. The importance of this analysis will not impose limits or determine the impacts, but to present the losses percentage change to keep the utility tracing for losses and to take the required mitigation action in case of increase in losses percentage.

The losses are proportional to the square of the current drawn from BSP (MV feeder) where the increase of the current drawn from the BSP will increase the losses.

As shown in Table 2, the storage system reduces the power losses in both feeders. The reduction of the losses at Sabha feeder is about 0.83% (from 5.25% to 4.42%), while on Alsalhiah feeder the reduction is about 0.34% (from 4.36% to 4.02%).

Table 2. The effect of the storage system on the power losses at both feeders.

Configuration	Network Id	Total through Power (Max) [kW]	Total through Power (Max) [kVAR]	Total through Power (Max) [kVA]	Conductor Losses (Max) [kW]	% Of losses
Storage = ON	Alsalhiah feeder	10684	7447	13023	429.85	4.023
Storage = OFF	Alsalhiah feeder	11816	7550	14022	515.11	4. 359
Storage = ON	Sabha feeder	9801	5955	11468	433.16	4. 419
Storage = OFF	Sabha feeder	11829	6176	13344	620.85	5. 249

3.1.4. Effect of BESS on the PF

The active and reactive energy should be analyzed at both feeders. However, the actual energy values are not available for the feeders but only for BSP. Therefore, the PF will be captured from the model and the PF of the BSP will be analyzed to evaluate the impact. Table 3 illustrates the PF at BSP before and after BESS connection.

Table 3. PF before and after BESS connection.

Configuration	Network Id	Total through Power (Max) [kW]	Total through Power (Max) [kvar]	Total through Power (Max) [kVA]	PF
Storage = ON	Alsalhiah feeder	10684	7447	13023	0.8204
Storage = OFF	Alsalhiah feeder	11816	7550	14022	0.84268
Storage = ON	Sabha feeder	9801	5955	11468	0.85464
Storage = OFF	Sabha feeder	11829	6176	13344	0.88643

The intermittent renewable resource (IRR) states that the distribution companies (DISCOs) may require the IRR to operate in power factor control mode where the IRR shall operate to maintain PF anywhere between 0.88 lagging to 0.88 leading, as measured at the PCCs and as requested by the DISCO. So, the BESS operates to maintain power factor anywhere within these limits.

The results show that the BESS reduces the PF at the BSP at both feeders. This reduction is due to exporting active power from BESS towards the BSP. For Sabha feeder, the PF reduces from 0.88643 to 0.85464 while at Alsalhiah feeder reduces from 0.8426 to 0.8204. This reduction that occurs at both feeders is below the limits mentioned in IRR.

3.1.5. The Effect of BESS on the Voltage Step

The voltage step is defined as the percentage of voltage change from the initial voltage because of the BESS unexpected loss or initiation. As stated in the IEC 61000-3 code, the voltage step limit must not exceed 3% of the nominal voltage. The influence of integrating BESS into the grid on the voltage step at the PCC was evaluated and the results are depicted in Fig. 6. It is obvious that the voltage step doesn't exceed the code's limits at both feeders.

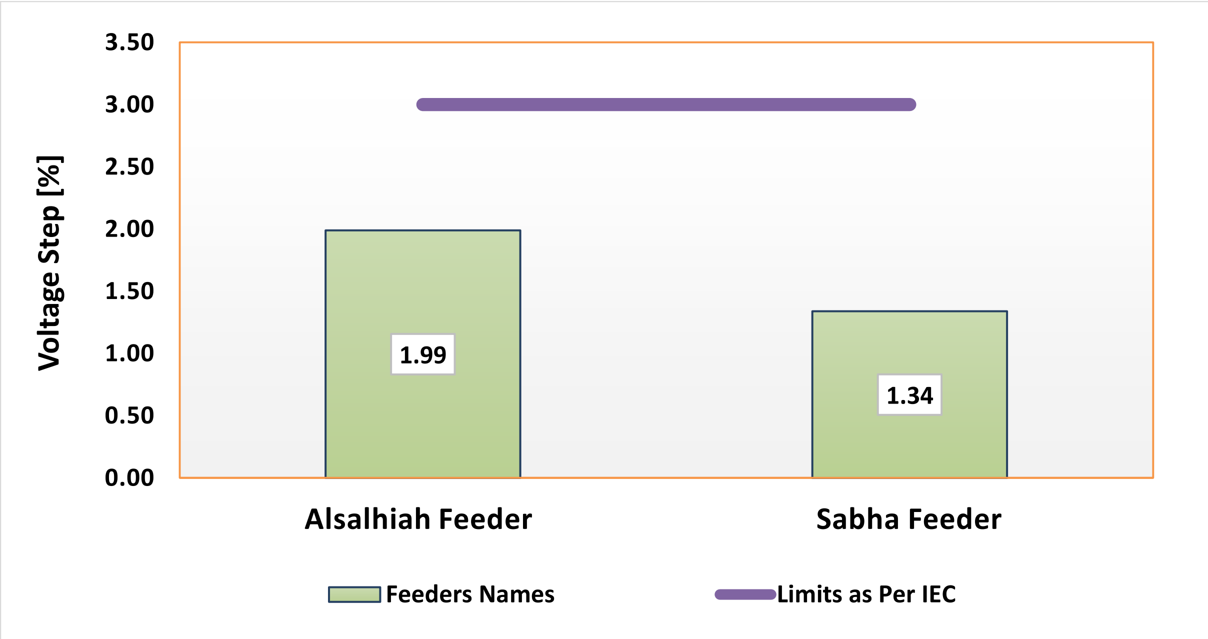

Fig. 6. Voltage step at PCC.

3.2. The Economic Feasibility Analysis

To find the economic benefits of this BESS, a comparison between the energy exported before and after the expansion was made using real data obtained from IDECO and Almanara PV power plant. The results are exhibited in Table 4.

The above table shows that the total energy exported due to the expansion was 19.7229 GWh. 2.732 GWh of this exported energy was from the BESS connected to both feeders. It approximately equals 14% of the total energy added due to the expansion.

Based on the electric tariff of 0.01 Jordanian Dinar (JD)/KWh stated in the contract agreement, the calculation was made. For Almanara PV plant, the cost of energy exported after the expansion became 4853760.1JD/year, while it was 2847243.6 JD/year before the expansion. Additionally, an income of 1972290 JD/year is achieved from the energy exported due to the expansion, and 273220 JDs/year is achieved from the BESS. The cost of the BESS was 3 million JDs including a ten-year of warranty and full maintenance. By using this information, the payback period is calculated as follow:

$$Payback\ Period = \frac{\text{Initial investment}}{\text{Cash flow per year}} \quad (6)$$

which is equal to 10.98 years.

Another important economic benefit of this BESS is related to IDECO. The reduction of losses observed in Table 2 was very important. According to the electric purchase tariff of IDECO in 2020; 0.043 JD/KWh, at both feeders. The summation of saving due to this reduction in the power losses was 398507 KWh/year which is equal to 17135.8 JD/year.

Table 4. Comparison between energy exported before and after the expansion.

Month	Energy exported before expansion [MWh]	Energy exported after expansion [MWh]	The exported energy added due to expansion [MWh]	Energy exported from the battery storage system [MWh]
Jan.	1320	2004	684	108.3
Feb.	1257	2545.4	1288.4	211
Mar.	2005	2924.1	919.1	210.9
Apr.	1913	3772.3	1859.3	255.4
May	1855	4003.4	2148.4	242.5
Jun.	2211	4395.7	2184.7	308.1
Jul.	2308	4491.8	2183.8	315.6
Aug.	2278	4343.4	2065.4	319.8
Sep.	2037	3736	1699	274.4
Oct.	1583	3578.1	1995.1	279.1
Nov.	1165	2592.5	1427.5	123.2
Dec.	1133	2401.2	1268.2	83.9
Total	21065	40787.9	19722.9	2732.2

4. CONCLUSIONS

In this paper, techno-economic feasibility study of the battery storage system at Almanara PV power plant was carried out.

In the technical part, the CYME software was used to find the effect of the storage system at Almanara PV power plant on voltage level, losses, power factor and voltage step. The results showed that the storage system improves the voltage level, reduces the losses and reduces the power factor at both feeders. The reduction in the voltage deviation at Sabha was from 9.76% to 8.49% and at Alsalhiah was from 8.78% to 7.02% and the summation of savings due to this reduction in power losses is 398507 KWh/year which equals 17135.8 JD/year at both feeders. The storage system also reduced the power factor at the BSP to an average of 0.83 at both feeders. The voltage step, in all cases, didn't exceed the limits.

In the economic part, Almanara PV power plant has an income of 273220 JD/year from the BESS with a payback period of 10.98 years.

As a recommendation, the storage system has a positive impact on both IDECO and Almanara PV power plant, so it is recommended to install a storage system at the last feeder of the power plant which is Safawi 33 KV feeder.

Acknowledgement: The authors would like to thank Irbid District Electricity Company (IDECO) for providing data and the CYME software as well as Eng. Hamza Adamat for his support in developing this work.

REFERENCES

[1] M. Sufyan, N. Rahim, M. Aman, C. Tan, S. Raihan, "Sizing and applications of battery energy storage technologies in smart grid system: a review," *Journal of Renewable and Sustainability Energy*, vol. 11, no. 1, 2019.

[2] F. Lucchese, L. Canha, W. Brignol, B. Hammerschmitt, L. Da Silva, C. Martins, "Energy storage systems role in supporting renewable resources: global overview," *2019 54th International Universities Power Engineering Conference*, pp. 1–6, 2019.

[3] P. Diaz, H. El-Khozondar, "Electrical energy storage technologies and the application potential in power system operation: a mini review," *2019 IEEE 7th Palestinian International Conference on Electrical and Computer Engineering*, pp. 1–9, 2019.

[4] V. Venkateswaran, D. Saini, M. Sharma, "Approaches for optimal planning of the energy storage units in distribution network and their impacts on system resiliency — a review," *CSEE Journal of Power and Energy Systems*, vol. 6, no. 4, pp. 816-833, 2020.

[5] F. Mohamad, J. Teh, C. Lai, L. Chen, "Development of energy storage systems for power network reliability: a review," *Energies*, vol. 11, no. 9, 2018.

[6] X. Luo, J. Wang, M. Dooner, J. Clarke, "Overview of current development in electrical energy storage technologies and the application potential in power system operation," *Applied Energy*, vol. 137, pp. 511–536, 2015.

[7] D. Akinyele, R. Rayudu, "Review of energy storage technologies for sustainable power networks," *Sustainable Energy Technologies and Assessments*, vol. 8, pp. 74–91, 2014.

[8] Y. Tahir, M. Nadeem, A. Ahmed, I. Khan, F. Qamar, "A review on hybrid energy storage systems in microgrids," *2020 3rd International Conference on Computing, Mathematics and Engineering Technologies*, pp. 0–6, 2020.

[9] S. Rehman, L. Al-Hadhrami, M. Alam, "Pumped hydro energy storage system: a technological review," *Renewable and Sustainable Energy Reviews*, vol. 44, pp. 586–598, 2015.

[10] G. Venkataramani, P. Parankusam, V. Ramalingam, J. Wang, "A review on compressed air energy storage – a pathway for smart grid and polygeneration," *Renewable and Sustainable Energy Reviews*, vol. 62, pp. 895–907, 2016.

[11] S. Mousavi, F. Faraji, A. Majazi, K. Al-Haddad, "A comprehensive review of flywheel energy storage system technology," *Renewable and Sustainable Energy Reviews*, vol. 67, pp. 477–490, 2017.

[12] M. Ellis, M. Von Spakovsky, D. Nelson, "Fuel cell systems: efficient, flexible energy conversion for the 21st century," *Proceedings of the IEEE,* vol. 89, no. 12, pp. 1808–1817, 2001.

[13] L. Zhang, X. Hu, Z. Wang, F. Sun, D. Dorrell, "A review of supercapacitor modeling, estimation, and applications: a control/management perspective," *Renewable and Sustainable Energy Reviews*, vol. 81, no. June 2016, pp. 1868–1878, 2018.

[14] M. Ali, B. Wu, R. Dougal, "An overview of SMES applications in power and energy systems," *IEEE Transactions of Sustainable Energy*, vol. 1, no. 1, pp. 38–47, 2010.

[15] J. Baker, A. Collinson, "Electrical energy storage at the turn of the Millennium," *Power Engineering Journal*, vol. 13, no. 3, pp. 107–112, 1999.

[16] A. AL Shaqsi, K. Sopian, A. Al-Hinai, "Review of energy storage services, applications, limitations, and benefits," *Energy Reports*, vol. 6, pp. 288–306, 2020.

[17] S. Ould Amrouche, D. Rekioua, T. Rekioua, S. Bacha, "Overview of energy storage in renewable energy systems," *International Journal of Hydrogen Energy*, vol. 41, no. 45, pp. 20914–20927, 2016.

[18] M. Yekini Suberu, M. Wazir Mustafa, N. Bashir, "Energy storage systems for renewable energy power sector integration and mitigation of intermittency," *Renewable and Sustainable Energy Reviews*, vol. 35, pp. 499–514, 2014.
[19] M. Farhadi, O. Mohammed, "Energy storage technologies for high-power applications," *IEEE Transactions on Industry Applications*, vol. 52, no. 3, pp. 1953–1962, 2016.
[20] J. Chow, R. De Mello, K. Cheung, "Electricity market design: An integrated approach to reliability assurance," *Proceedings of the IEEE*, vol. 93, no. 11, pp. 1956–1968, 2005.
[21] J. Barrado, R. Griñó, H. Valderrama-Blavi, "Power-quality improvement of a stand-alone induction generator using a STATCOM with battery energy storage system," *IEEE Transactions on Power Delivery*, vol. 25, no. 4, pp. 2734–2741, 2010.
[22] J. Baroudi, V. Dinavahi, A. Knight, "A review of power converter topologies for wind generators," *Renewable Energy*, vol. 32, no. 14, pp. 2369–2385, 2007.
[23] N. Golubtsova, O. Vasilieva, V. Petrov, F. Filippov, A. Gunin, "Age-related changes of angiomotin and endostatin content in human skin," *Advances in Gerontology*, vol. 6, no. 2, pp. 153–159, 2016.
[24] A. Jamali, N. Nor, T. Ibrahim, "Energy storage systems and their sizing techniques in power system - a review," *2015 IEEE Conference of Energy Conversion*, pp. 215–220, 2015.
[25] J. Bierman, B. Bekker, "Review of control strategies for lithium-ion battery energy storage systems in distribution networks," *2020 International SAUPEC/RobMech/PRASA Conference*, pp. 1–6, 2020.
[26] M. Farrokhifar, "Optimal operation of energy storage devices with RESs to improve efficiency of distribution grids; technical and economical assessment," *International Journal of Electrical Power and Energy Systems,* vol. 74, pp. 153–161, 2016.
[27] P. Lazzeroni, M. Repetto, "Optimal planning of battery systems for power losses reduction in distribution grids," *Electric Power Systems Research*, vol. 167, no. July 2018, pp. 94–112, 2019.
[28] C. Das, O. Bass, G. Kothapalli, T. Mahmoud, D. Habibi, "Optimal placement of distributed energy storage systems in distribution networks using artificial bee colony algorithm," *Applied Energy*, vol. 232, no. July, pp. 212–228, 2018.
[29] S. Dahal, H. Salehfar, "Optimal location and sizing of distributed generators in distribution networks," *2013 North American Power Symposium*, pp. 1-6, 2013.
[30] M. Farrokhifar, S. Grillo, E. Tironi, "Loss minimization in medium voltage distribution grids by optimal management of energy storage devices," *2013 IEEE Grenoble Conference*, no. Mv, pp. 1–5, 2013.
[31] M. Nick, M. Hohmann, R. Cherkaoui, M. Paolone, "On the optimal placement of distributed storage systems for voltage control in active distribution networks," *2012 3rd IEEE PES Innovative Smart Grid Technologies Europe*, pp. 1–6, 2012.
[32] T. Chaiyatham, I. Ngamroo, "Bee colony optimization of battery capacity and placement for mitigation of voltage rise by PV in radial distribution network," *2012 10th International Power and Energy Conference*, pp. 13–18, 2012.
[33] J. Xiao, Z. Zhang, L. Bai, H. Liang, "Determination of the optimal installation site and capacity of battery energy storage system in distribution network integrated with distributed generation," *IET Generation, Transmission and Distribution*, vol. 10, no. 3, pp. 601–607, 2016.
[34] M. Qin, K. Chan, C. Chung, X. Luo, T. Wu, "Optimal planning and operation of energy storage systems in radial networks for wind power integration with reserve support," *IET Generation, Transmission and Distribution*, vol. 10, no. 8, pp. 2019–2025, 2016.
[35] E. Grover-Silva, R. Girard, G. Kariniotakis, "Optimal sizing and placement of distribution grid connected battery systems through an SOCP optimal power flow algorithm," *Applied Energy*, vol. 219, no. August, pp. 385–393, 2018.

[36] J. Gantz, S. Amin, A. Giacomoni, "Optimal mix and placement of energy storage systems in power distribution networks for reduced outage costs," *2012 IEEE Energy Conversion Congress and Exposition*, pp. 2447–2453, 2012.

[37] H. Liu, D. Liu, Q. Liu, "Modeling simulation technology research for distribution network planning," *Energy and Power Engineering*, vol. 05, no. 04, pp. 980–985, 2013.

[38] K. Balamurugan, D. Srinivasan, "Review of power flow studies on distribution network with distributed generation," *2011 IEEE Ninth International Conference on Power Electronics and Drive Systems*, no. December, pp. 411–417, 2011.

[39] A. Eltamaly, A. Elghaffar, A. Ahmed, "Optimum power flow analysis by Newton Raphson," *Ann Fac Eng Hunedoara*, vol. 16, no. 4, pp. 51-58, 2018.

[40] B. Sereeter, C. Vuik, C. Witteveen, "On a comparison of Newton–Raphson solvers for power flow problems," *Journal of Computational and Applied Mathematics*, vol. 360, pp. 157–169, 2019.