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Assessment of Implementing Jordan's Renewable Energy Plan on the Electricity Grid

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Abstract

In the present work, the technical and economic impacts of integrating large scale renewable energy projects of wind and PV systems to the transmission grid in Jordan up to the year 2025 has been investigated. The current grid transmission system of Jordan's electricity network has been modeled and used. Large renewable energy systems of PV and Wind proposed by the master energy plan in Jordan have been introduced to the grid. The Digital Simulation and Electrical Network Calculation (DIGSILENT) program (i.e., power analysis program) and the Wien Automatic System Planning Model (WASP) software were used to evaluate both the technical and economic impacts. It is found that until 2018 Jordan's transmission grid will face minor overloads, while, most of transmission lines will be overloaded by 2020. The technical and economic aspects of the existence of a special transmission line (Green Corridor) from the generation site in the south to the demand locations in the center is investigated and documented. It is found that this solution is vital to the transmission grid and feasible. Moreover, it revealed that because of the dependence of renewable energy systems the LCOE by 2025 will vary only 25 % (between 100 to 125 USD/MWh) when the price of NG increases 50% (from 8 to 12 $/MMBTU) in spite of the additional cost of the "Green Corridor" of 145 M$ for grid reinforcement. Also, it is expected that with the target renewable energy projects and new conventional power plants the LCOE in 2025 will be 43 % less than that in 2014.

Keywords: *Transmission Grid, Grid Impact, Renewable Energy Systems, Green Corridor.*

1. Introduction

Jordan is one of the highest countries in the world in terms of the dependency on the foreign energy sources where is around 97% of the energy needs are imported [1]. Also energy demand in Jordan is growing rapidly due to different reasons such as high growth in population, in addition to hosting high number of refugees from neighboring countries [2]. In order to meet the high demand on electricity and to increase the local resources shares in the energy mix, the government has directed its efforts recently towards encouraging the investment in the renewable energy sector on both large and small scales. The electricity model in Jordan is based on single buyer model where all electricity from all resources is bought by National Electric Power Company (NEPCO) and then it is sold again to the distribution companies and bulk consumers directly through transmission network. The installed generation capacity in Jordan as of 2015 is 3.8 GW, around 2.6 GW through private projects and around 1.2 GW from governmental sector. The highest registered peak load is in 2015 is 3200 MW. The transmission voltages are 400 KV and 132 KV where distribution voltages are 33, 11, and 0.4 KV, the transmission lines length is around 4600 Km circuit and main substation capacity is around 12000 MVA. Furthermore, the Jordanian grid is connected to both Syrian and Egyptian networks through high voltage AC connection on 400 KV level.

The expected renewable energy projects in Jordan come from three main paths (1) direct proposal (2) bidding process, and (3) governmental projects, Jordan has set a target of 10% of the energy mix in 2020 to be produced from renewable energy resources [5]. For this purpose and to secure the supply and to diversify the energy resources in Jordan, several electricity generation projects are committed to be connected to the grid. Table 1 shows the renewable energy projects while Table 2 shows the conventional natural gas fired projects. It should be mentioned that around 70% of the Renewable Energy Systems (RES) are to be erected in the south of Jordan. This will add difficulties to evacuate the produced power to the load center in the middle of Jordan. These challenges include overloading of transmission line, high short circuit current and other challenges that will be discussed and mentioned in the present paper. Furthermore, the development of RES includes small power plants to be connected to the distribution network, the so called "dispersed generation". The effect of this generation is considered negligible for the purpose of the present study.

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Many people have worked in the field of evaluating the impact of renewable energy integration to the electrical systems [6-7]. For example, Paul *et al.* [8] presented a simple approach for comparing the economics of integrating intermittent renewable energy resources by comparing their corresponding Levelized Cost of Energy (LCOE).

The main purpose of the present work is to study the technical and economic impacts of integration large scale renewable energy projects of wind and PV systems connected to the transmission grid in Jordan. Power analysis program Digital Simulation and Electrical Network Calculation Program, DIGSILENT, along with the current system model and proposed renewable projects and WASP (Wien Automatic System Planning Model) were used

2. Analysis

For the present work, the target year is 2025 and the base year is 2016. The database of the Jordanian power system available from NEPCO is used. This database includes data for network representation in both static and dynamic analysis of the Jordanian network, representation of power systems of Egypt and Syria, in addition to the representation of the generation units and the addition of retirement plan for the generation units. This database is revised related to the latest load forecast, generation expansion plan, power exchanges with neighboring countries and new renewable power plants. The following points summarized the main assumptions for the study:

1. All target projects of RES will be integrated to the grid as proposed while the oil shale and Nuclear projects are not.
2. Two stage calculations: stage (a) power flow calculation in sound N-network condition and stage (b) network condition in case of contingency (N-1 condition). Normal (N) Conditions the basic assumptions related with N-criterion of transmission network are: the rating limits of transmission lines should be intended as maximum permanent currents; in normal operating conditions no overload of the transmission network is allowed; no generator will be above its continuous reactive capability. According to the Grid Code the performance requirement for operating voltages under Normal conditions are: 400 kV network, the admissible voltage range is between 380 kV and 420 kV (±5%); 132 kV network, the admissible voltage range is between 118.8 kV and 145.2 kV (±10%). Contingency (N-1) Conditions, N-1 primary criterion is applied to all credible scenarios. The N-1 criterion is considered to be fulfilled, when following the first loss of a circuit or a generation unit no violation of operation limits, overloads, loss of stability and uneconomic operation of generation units or load shedding occurred [9]. In N-1 steady-state conditions the voltages can be expected to deviate outside the above limits by a further +/- 5%.
3. The demand on the generation of the PV is assumed to be 70% of the total installed capacity of the PV projects, and for the wind projects is 80%.
4. The study is based on the assumption not to import power from the neighboring countries in the future. Transfer of power along the interconnections with Egypt and Syria are expected due to power wheeling. The representation of the neighboring countries is necessary for short circuit calculations. Even though it is assumed not to utilize the electrical interconnections but they have a lot of benefits to the Jordanian system like helping in balancing the frequency of the interconnected system and reduce the RE forecast error and share flexibility resources [10-12].
5. The cost of natural gas is based on three different scenarios of 8 $/MMBTU, 10 $/MMBTU, and 12 $/MMBTU in addition to the transportation fees.
6. New generation using conventional system with total efficiency of 49%.
7. Yearly growth of peak load and energy of 5% [5].
8. The tariff of both nuclear and oil shale projects as the latest announced tariffs, 0.10 $/Kwh for nuclear and 0.13 $/Kwh for oil shale.
9. The tariff for the PV projects is 0.148 $/Kwh for 2016 and 2017, 0.0705 $/Kwh thereafter. For the wind projects is 0.117 $/Kwh for 2016 and 2017, 0.1125 $/Kwh thereafter.
10. Discount rate of 7% and 2016 as the base year.

3. Results and Discussion

Loading of several key points in the grid was calculated based on both renewable energy projects and the expansions of the conventional power plants listed in Tables 1 and 2 and their connection on the grid are shown in Fig.1 and Fig. 2. Figure 1 shows the integration of the RES in the southern part while Fig. 2 shows the situation in the northern part of Jordan. From the analysis of the grid with the connection of the renewable projects, several overloading occur in the 132KV line especially in the southern area. Figure 3 shows the loading results up to 2025 in the southern part where most of the expansions and integration of renewable projects will be allocated. It is clear that several overloading in the lines exist due to high penetration of renewable energy beside that they are not in compliance with the N-1 security criterion.

Table 1. Renewable energy projects until 2025

Year	PV (MW)	Wind (MW)	Total (MW)
2016*	475	350	825
2017*	475	500	975
2018	775	500	1275
2019	875	600	1475
2020	975	700	1675
2021	1075	800	1875
2022	1175	900	2075
2023	1275	1000	2275
2024	1375	1100	2475
2025	1475	1200	2675

* Committed projects

Table 2. Proposed conventional generation projects until 2025

Proposed new projects	Proposed connection points	Capacity (MW)	YEAR
New Rehab	REHAB 400/132kv	500	2019
Al Hizam	Al Hizam 132/33	500	2021
New Aqaba	Aqaba 132/33	500	2024
Swaimah	Swaimah S/S	500	2025
Total	---	2000	---

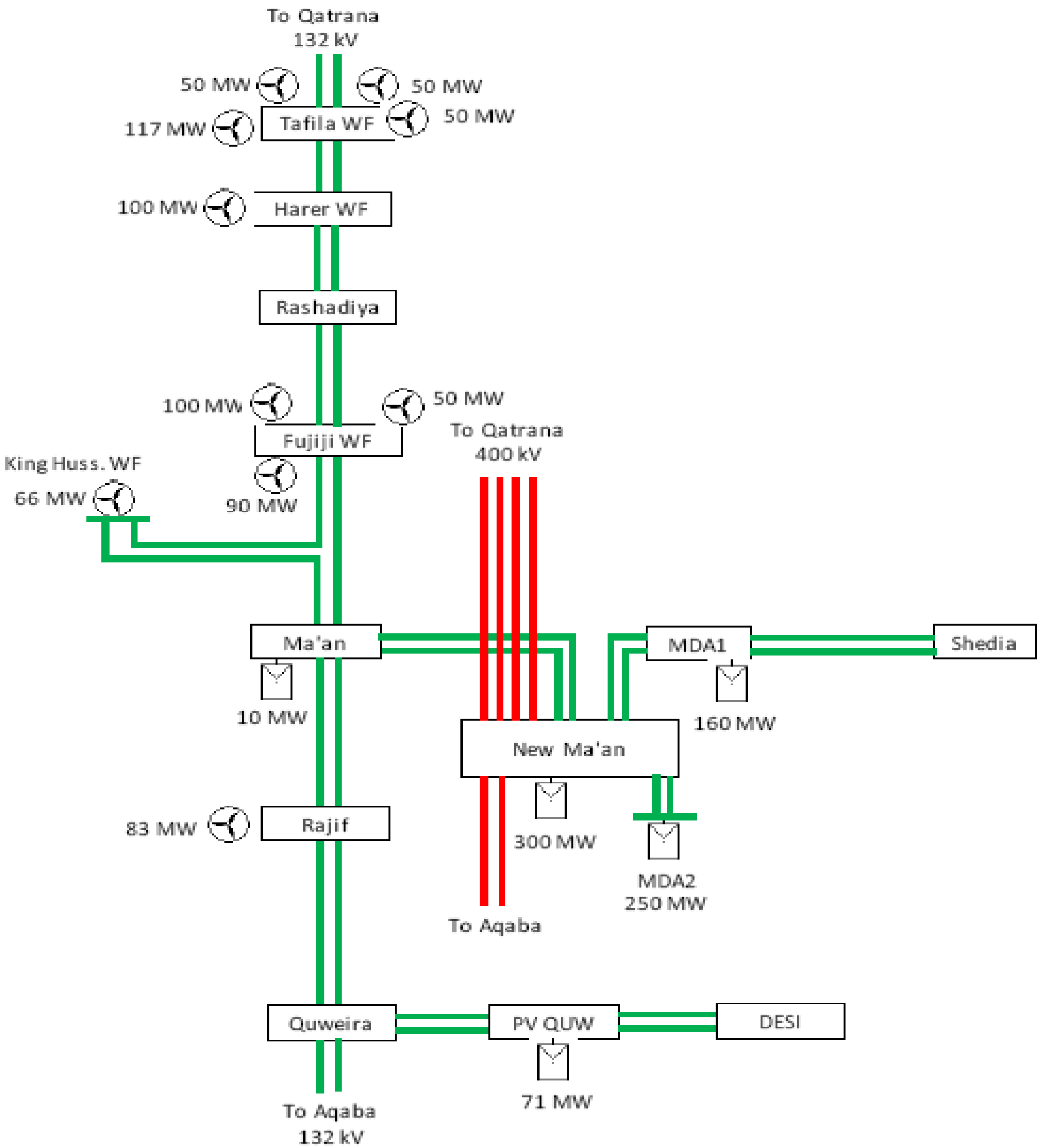


Figure 1. The connection of renewable projects in the southern area in year 2025

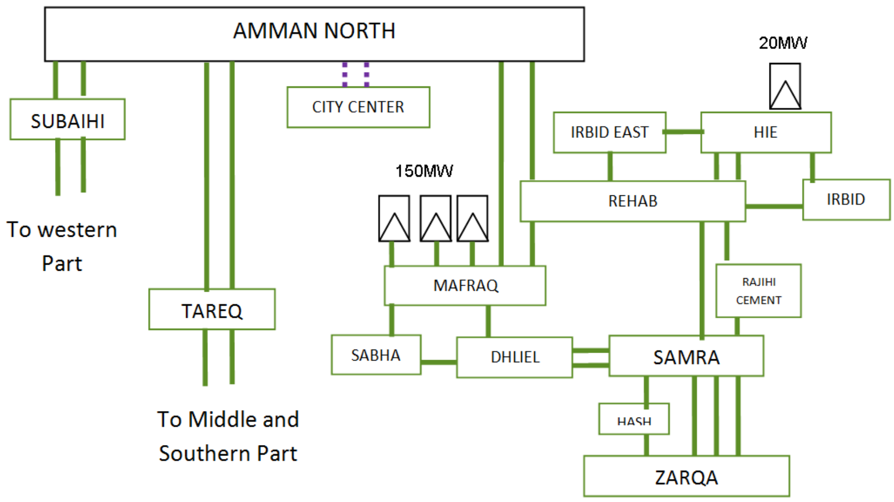


Figure 2. The connection of committed renewable projects in the northern area in year 2025

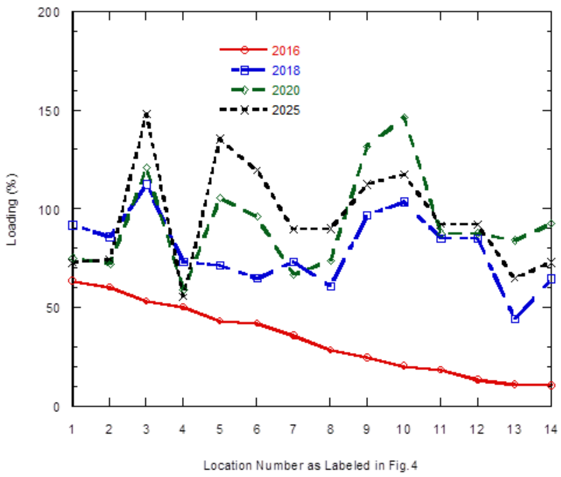
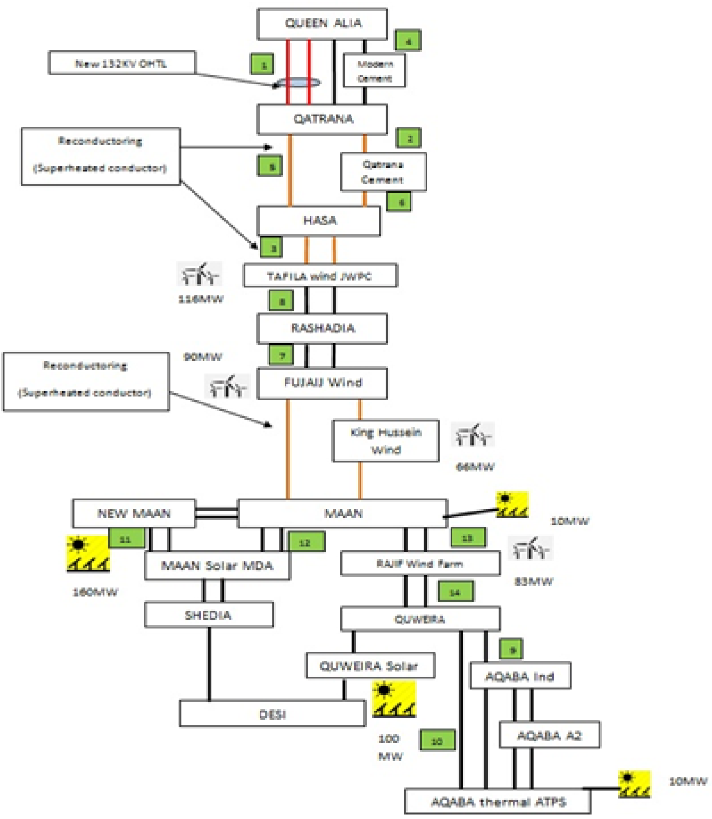


Figure 3. Loading of the 132KV lines in the southern part of Jordan using current grid

To overcome this overloading problems and the presence of bottleneck in the lines from south area to load center, transmission reinforcement is highly needed. It will consist of 400/132/33kV New Ma'an substation with three 400MVA transformers and two circuits 400kV overhead line from New Ma'an to Qatrana with length of 150Km as shown in Fig. 4. The table attached to Fig. 4 shows 14 lines highlighted in that area with names and numbers to be referred to during this work. This reinforcement "Green Corridor" is planned to be constructed starting in 2017. The reinforcements in several 132kV lines will be also considered as part of the green corridor project. It includes replacing the conductors of the lines by superheated conductors which increase the loading limit of the 132 KV Lines to almost double (200%) with current rating of 1500KA compared to the normal existing OHL conductors.

The loading of the 14 selected 132kV lines is studied using DIGSILENT in four target years 2016, 2018, 2020 to 2025, with the presence of the green corridor with year 2016 reflects the current situation. The results shown in Fig. 5 shows the 132 kV grid loading after the constructing the Green Corridor from. The loading results of all 132kV lines in southern area shows that these lines do no experience overloading conditions and, thus, they will be within the thermal rating limits for the next 10 Years.

The reinforcements by Green corridor in the 400kV network are shown in the Fig. 6. The enforcement is needed to accommodate the connection of renewable projects especially in southern area. It includes the New Ma'an 400kV/132Kv substation with three transformers each has capacity of 400MVA and the enforcement in the line (Qatrana- New Ma'an) 400kv with new double circuit also replacing the conductors in 132Kv line.



No	132KV Lines
1	QAIA-QAT X1
2	CMNT-QAT
3	HASA-TAF(1)
4	QAIA-CEMENT
5	QAT-HASA(3)
6	CEMENT -HASA(1)
7	RAS-FUJ
8	RAS-TAF(1)
9	AQI-QUW(1)
10	ATPS-QUW(1)
11	NWMAAN-MDA
12	MDA-MAAN
13	MAAN-RAJIF
14	QWERA-RAJIF

Figure 4. The connection of renewable projects in southern area in 2018 with reinforcement in the 132KV grid

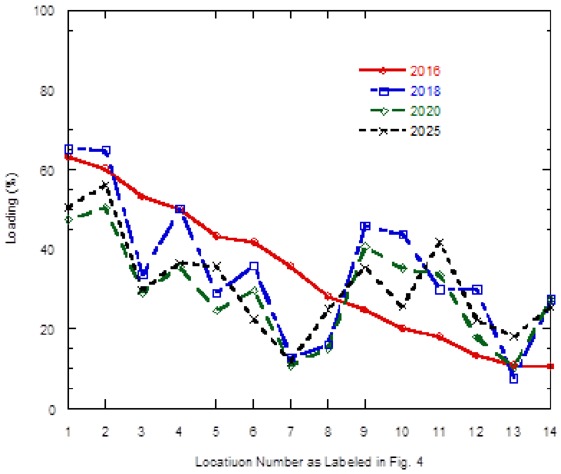


Figure 5. Loading of the 132KV lines in the southern part of Jordan with "Green Corridor"

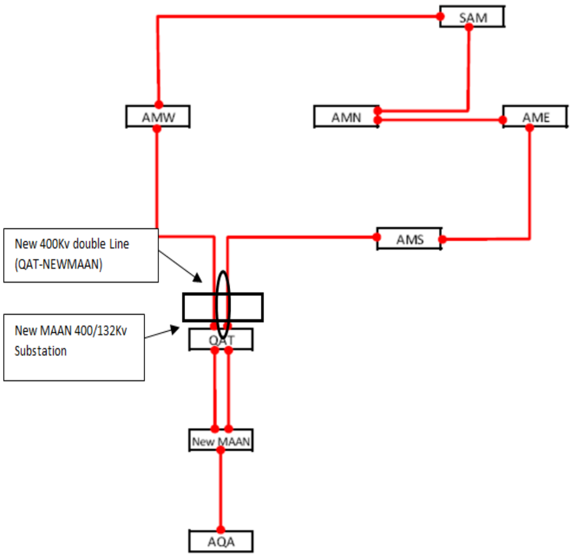


Figure 6. Current Jordanian 400kV grid structure with the reinforcements in the southern part

The lines loading results obtained in DIGSILENT simulation for the 400kV lines with and without the green corridor in the southern part are listed in Table 3. It is clear that this enforcement is needed after 2025.

The sound network condition analysis detected overloading problems in the loading of the following grid components (lines and transformers):

1. 132KV Line ABDOON-AMS.
2. Abdali-HTPS 132KV line
3. Amman South 400/132KV transformers.
4. Amman East 400/132 kV transformer (the third one). These overloading are strictly related to the increase of the demand in the area of Amman.

In addition to that, the presence of overloading in load center substations also should be solved either by expansion, construction of new substation or by transferring load between substations in order to accommodate the huge load growth in that areas, for example, Marqa, Ashrafia, Abdoon, Sahab, etc.

The overloading elements detected after the contingency grid analysis (i.e., N-1 analysis) are highlighted and listed in Table 4. To overcome these overloading problems in the lines and transformers of the grid, recommended transmission network reinforcements and their costs are also given in Table 3. The summation of both transmission reinforcements and generation costs (i.e., total cost) for three scenarios of natural gas prices are calculated and listed in Table 5. For the purpose of better comparison among different technologies of the LCOE is calculated for three scenarios of natural gas prices of 8 \$/MMBTU, 10 \$/MMBTU and 12 \$/MMBTU [13]. It is found that in-spite-of the additional cost of the "Green Corridor" of 145 M\$, the LCOE by 2025 will vary only 25 % (between 100 to 125 USD/MWh) when the price of NG increases 50% (from 8 to 12 \$/MMBTU). This mainly because of the dependence on RES. It is worth mentioning that the cost of generating electricity in Jordan in 2014 is 223 \$/MWh [2]. Thus, with the renewable energy systems and new conventional power plants the LCOE in 2025 will be 43 % less than that in 2014.

Table 3. Comparison of the 400Kv lines loading in the southern part of Jordan with/without green corridor

Year	2016	2018	2020	2025
One line circuit Loading	%	%	%	%
Before Green Corridor				
AQTPS-MAAN X 2	40.80	34.28	28.49	36.20
QAT-MAAN 400 X 2	27.50	35.97	46.78	60.20
After Green corridor	2016	2018	2020	2025
AQTPS-MAAN X 2	40.80	38.00	32.05	57.20
QAT-MAAN(1) 400 X 2	27.50			
QAT-MAAN(1) 400 X4	////	10.98	13.33	21.22

Table 4. Transmission reinforcements needed and their costs until 2025

Network Element	N-1 loading %	Reinforcement Description	Reinforcement cost (k$)
ABDOON-AMS 132KV line	173.8	6.9km/132KVUnderground Cable, double circuit. 2020	1400
Abdali-HTPS 132KV line	115	12.77Km- 132KV overhead, double circuit. 2018	3000
MADABAH-SUWMEH 132KV Line	135.5	20km-132KVoverhead, double circuit.2025	5000
QAIA-MADBA 132KV Line	128.5	19Km- 132KV Reconductering with Superheated conductor.2025	3000
NBAYADER-AMS 132KV Line	126.2	12Km- 132KV overhead, double circuit. 2017	3000
SALT-AMW 132KV Line	122.3	15Km- 132KV Reconductering with Superheated conductor.2017	2200
TAREQ-AMN132(1)	120	5.5Km- 132KV Reconductering with bundle conductor.2020	1000
HASANIND-IRBID 132KV Line	108.3	25Km- 132KV overhead, double circuit.2019	3500
Amman South Transformer	117	Amman South Expansion.2020	7000
Amman East Transformers	110	Amman east Expansion.2018	7000
New Rehab Gen	-	2019	35000
Al Hizam Gen	-	2021	3800
Swaimah Gen	-	2025	2800
HTPS repowering	-	2018	1000
New Aqaba repowering	-	2024	1500
Amman west substation and lines	-	2017	89000
Total Elements cost	-	-	169200
Green corridor cost	-	2017	145000
Total Transmission cost	**-**	**-**	**314200**

Table 5. Overall cost

	Gas Price (8$/MMBTU)		Gas Price (10$/MMBTU)		Gas Price (12$/MMBTU)	
Item	Total discounted cost in M$	Average LCOE (USD/Mwh)	Total discounted cost in M$	Average LCOE (USD/Mwh)	Total discounted cost in M$	Average LCOE (USD/Mwh)
Generation cost	16,669.5	98.59	18,793.7	111.15	20,909.4	123.66
Transmission cost	281.2	1.66	281.2	1.66	281.2	1.66
Total cost	16,950.8	100.25	19,074.9	112.81	21,190.6	125.32

4. Conclusion

In the present work the Jordanian electrical transmission grid modified to reflect the grid situation in each target year up to 2025. Current and proposed generation projects including renewable energy systems are simulated in power system analysis program DIGSILENT. The analysis of the results shows the importance and the need of grid reinforcements in southern area, mainly, the "Green Corridor". The present study showed that such reinforcement is needed to overcome the bottleneck of energy transfer from southern area to load center in north. The analysis is done again but with the green corridor and connection of renewable projects until the target year 2025. As a result more overloaded elements appear in the rest part of Jordanian grid in both normal and contingency cases. These cases are checked and highlighted. Considering the total cost needed for transmission reinforcements and the cost of generation based on three NG prices scenarios, the Levelized cost of energy are calculated, compared and documented. It is found that the LCOE in 2025 will be 43 % less than that in 2014 when the target renewable energy projects and new conventional power plants are delivered.

Remark

It should be noted that part of this paper has been published in GCREEDER 2016 conference**.**

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