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Identification of the Optimal Electrical Interconnection Point for Exporting Solar Energy to the Southern European Countries

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ABSTRACT

With a growing demand for electric power, interconnecting national grids is crucial for ensuring stability and creating economic benefits through energy export1. This paper evaluates the transmission lines of the Libyan Electrical Network to determine their capacity to accommodate additional power for export the electrical energy to the Southern Europe Countries. The study simulates the injection of power from new photovoltaic (PV) stations in Ghadames, Asdaada, Hoon, and Bani Walid, and then analyses the grid's stability when this power is withdrawn from two potential coastal interconnection points, Al-Garaboly and Al-Khoms. Using NEPLAN software, network performance was assessed under normal (N) and contingency (N-1) conditions across three scenarios, which are: the existing Libyan grid scenario, and changing the existing ratio of Current Transformer (CT) scenario, the final scenario is integration of new 400 kV lines currently under construction. The results indicate that Al-Khoms is a more robust interconnection land point than Al-Garabuli. The most effective strategy for increasing export capacity involves activating the new 400 kV lines, which allowed for a maximum stable export of 1430 MW from Al-Khoms Station and 660 MW from Al- Garaboly Station under N-1 conditions. The evaluation of the transmission network is a fundamental aspect in selecting the optimal connection land point. However, several other considerations influence the final decision regarding the connection, such as the route of the submarine cable. These considerations include environmental studies that account for sensitive areas such as coral reefs and ecological impacts, in addition to oil concessions and military sites etc. It is essential to consider these factors to determine the best electrical connection point.

Keywords: HVDC, Grid Interconnection, Libyan Power Grid, Power System Analysis.

تحديد نقطة الربط الكهربائي المثلى لتصدير الطاقة الشمسية لدول جنوب أوروبا

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ملخـــــص البحـــــث

مع الطلب المتزايد على الطاقة الكهربائية، أصبح من الملح الحديث عن أهمية الربط البيني بين شبكات الدول لضمان الاستقرار العام وخلق نوع من الاتزان، بالإضافة إلى الفوائد الاقتصادية لتصدير الفائض من الطاقة. تعرض هذه الورقة دراسة لتقييم خطوط نقل الشبكة الكهربائية الليبية لتحديد افضل نقطة ربط لتصدير الطاقة الكهربائية لدول جنوب أوروبا وذلك عند حقن قدرة إضافية من محطات طاقة

شمسية في مناطق مثل غدامس والسدادة وهون وبني وليد، ومن ثم دراسة وضع شبكة النقل الكهربائية عند سحب هذه القدرة من محطتي القره بوللي والخمس. تم رصد نتائج عناصر الشبكة من حيث التحميل الزائد للحالتين الطبيعية (N) والطوارئ (N−1). وقد تمت دراسة سيناريوهات مختلفة، منها تغيير نسبة محولات التيار (CTs) وإدخال خطوط نقل جديدة بجهد 400 ك.ف (قيد الإنشاء). وقد كانت أفضل النتائج عند إدخال خطوط 400 ك.ف، حيث بلغت أقصى قدرة يمكن تصديرها من محطة القره بوللي 660 ميجاوات، بينما وصلت في محطة الخمس إلى 1430 ميجاوات في حالة الطوارئ (N−1). تمت هذه الدراسة باستخدام برنامج NEPLAN المتخصص في تحليل شبكات القدرة الكهربائية. يعتبر تقييم شبكة النقل عنصرًا أساسيًا في اختيار أفضل نقطة ربط. ومع ذلك، توجد اعتبارات أخرى تؤثر على القرار النهائي بشأن الربط، مثل مسار الكابل تحت سطح البحر. تشمل هذه الاعتبارات الدراسات البيئية التي تأخذ في الاعتبار المواقع الحساسة مثل الأحواض المرجانية، والأثر البيئي، بالإضافة إلى الامتيازات النفطية والمواقع العسكرية. يجب أن تؤخذ هذه العوامل معا بعين الاعتبار لتحديد أفضل نقطة ربط كهربائي.

الكلمات الدالة: نقل الجهد العالي المستمر، الربط الكهربائي، الشبكة الكهربائية الليبية، تحليل أنظمة القدرة.

1. INTRODUCTION

1.1 Background and Context

The global demand for energy continues to escalate due to population growth and economic development, rendering the stability and efficiency of national power grids a pressing concern. The Libyan National Electricity Grid, primarily reliant on 220 kV and 400 kV transmission lines, faces the dual challenge of meeting increasing domestic energy demands while seeking opportunities for integration with neighbouring electrical systems.

1.2 Strategic Importance of Interconnection

Strategically located along the southern coast of the Mediterranean, Libya serves as a critical nexus between Africa and Southern Europe. The country possesses abundant fossil fuel reserves and significant renewable energy potential, particularly in solar energy. Establishing electrical interconnections with Southern European nations offers Libya a unique opportunity to leverage its surplus renewable energy resources, which far exceed domestic consumption requirements.

Such interconnections can enhance the stability of the overall electrical grid, ensuring a secure power supply while facilitating Libya's integration into the global energy market. This initiative is likely to attract foreign investment in renewable energy projects within Libya, thereby fostering economic growth and increasing national revenues through energy exports.

Recent proposals for a power link between Libya and Southern European countries, introduced in 2021[1], highlight the urgency of developing these interconnections. The economic viability and commercial returns of such projects, combined with their technical benefits in terms of network stability and national energy security, underscore the importance of this initiative.

Libya's geographic advantages, characterized by extensive solar radiation and favourable climatic conditions, further support the viability of solar energy generation. The country is situated within the solar belt, experiencing an average solar radiation of approximately 2500 kilowatts/hour/square meter annually, with over 3,500 hours of sunlight each year, particularly concentrated in its southeaster and western regions.

This study aims to evaluate the capacity of the Libyan electrical network to accommodate additional power injections from renewable sources and to identify optimal interconnection points for enhancing energy exports to Europe.

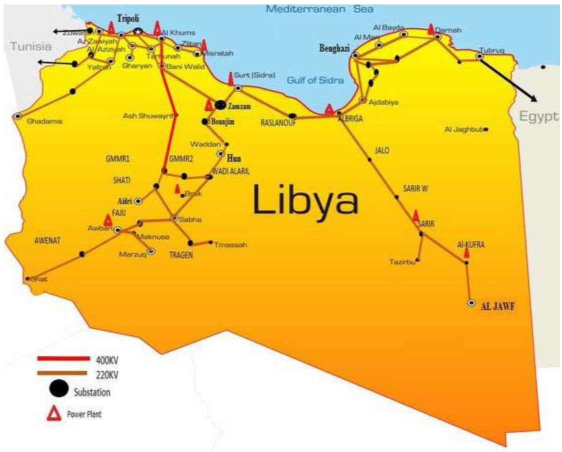
2. LITERATURE REVIEW

The development of energy interconnections in the Middle East has been a subject of significant research, notably discussed by Zhang et al. (2017). Their comprehensive review highlights the economic and technical benefits associated with such projects, emphasizing the potential for enhanced energy security and efficiency through regional collaboration. This context is particularly relevant to Libya, given its strategic position as a connector between Africa and Southern Europe [2].

In the realm of transmission technologies, Kim et al. (2019) explored High Voltage Direct Current (HVDC) systems and their applications in improving power systems. Their findings indicate that HVDC can significantly enhance the efficiency and reliability of electricity transmission over long distances, presenting a viable option for interconnecting Libya with European energy markets [3].

The future of renewable energy in Libya has also garnered attention, as examined by Al-Farasi (2020). This study focuses on the country's abundant solar and wind resources, outlining the current state of energy production and the opportunities for investment in renewable technologies. The insights provided are crucial for leveraging Libya's renewable potential, particularly in the context of energy interconnections [4].

Addressing the integration of renewable energy sources into the Libyan power grid, Malouq, and Mrehel (2022) determined the best location of the PV system in Libyan electrical grid, in which the best performance of the network will be achieved, taking into account the voltage level, line loading, network Losses, short circuit level, voltage stability, as well as harmonic analysis. And facilitate the increase of penetration levels of PV systems in the electric network [5].



A recent assessment by Mrehel et al. (2021) evaluated the performance of the Libyan power grid under various operational scenarios, in the presence of the large-scale PV systems identifying critical bottlenecks and vulnerabilities. The findings underscore the importance of making operational adjustments and enhancing infrastructure to improve grid stability, which is essential for analysing potential interconnection points [6].

Finally, Mrehel and Ghambirlou (2021) investigate the effects of HVDC Link on small signal stability and inter area oscillation for multi machines two area system and use the intelligent technique Genetic Algorithm to tune the Power system Stabilizer to find the optimum gain value to improve the system stability [7].

3. MATERIALS AND METHODS

The study was conducted using NEPLAN, a power system analysis software used for simulating and optimizing electrical networks [8]. The model represents the Libyan Electrical Grid, comprising 1265 elements, with parameters and references provided by the General Electricity Company of Libya (GECOL). The analysis adhered to standard voltage limits (95%-105%) and a 100% element loading reference.

The methodology involved simulating the injection of active power from several new photovoltaic (PV) stations; the specific locations and power injection values for these stations are detailed in Table 1. This injected power was subsequently withdrawn from two potential coastal interconnection points: Al-Garaboly and Al-Khoms. The grid's performance was evaluated based on network element loading and contingency analysis. The investigation centres on quantifying the maximum export capacity of the network without violating the operational limits of its components under both normal (N) and single-contingency (N-1) conditions. Accordingly, the primary objective is to determine the maximum transferable active power at the proposed interconnection points for each of these operational states.

Table 1. Sizes and locations of the PV systems in the Libyan Grid.

#	The region	The injected power (MW)
1	Ghadames	200
2	Asdaada	500
3	Hoon	300
4	Samno	500
5	Ben-Waleed	250
6	Raslanof	500
7	Ojla	250

It should be noted that for each scenario, a preliminary contingency analysis was performed on the base network prior to simulating power injection. This initial step was crucial for identifying and documenting any inherent overloading issues within the grid. This allowed for a clear distinction between pre-existing network vulnerabilities and those directly caused by the power injection. Consequently, elements found to be overloaded during this baseline analysis were considered an intrinsic characteristic of the grid and were not reported as new violations in the subsequent results.

The main scenarios were investigated are:

1. ***Scenario 1: Existing Network:*** Analysis of the current grid with existing Current Transformer Ratio (CTR) of (800:1 A).
2. ***Scenario 2: Modified CTs:*** Replacing the existing Current Transformer Ratio (CTR) from (800:1 A) to be (1100:1 A) to increase the current-carrying capacity of the 220 Kv Transmission lines.
3. ***Scenario 3: Integration of New 400 kV Lines*****:** The model was updated to include several 400 kV transmission lines and transformers that are currently under construction to assess their impact on grid transfer capability.

4. RESULTS AND DISCUSSION

The performance of the two potential interconnection land points, Al-Garabuli and Al-Khoms, varied significantly across the three scenarios.

Scenario 1 (Existing Network):

In Scenario 1, the preliminary contingency analysis conducted on the base network prior to any power injection revealed that 11 transmission lines were already overloaded, as detailed in Table.2. This condition is considered an inherent vulnerability of the main grid. Therefore, these lines are not classified as newly overloaded elements in the subsequent injection tests, as the issue pre-dates the simulation.

Under normal (N) conditions, the maximum power withdrawal was 690 MW at Al-Garaboly and 2046 MW at Al-Khoms. However, under contingency (N-1) conditions, the stable export capacity dropped significantly to 275 MW for Al-Garaboly and 880 MW for Al-Khoms, highlighting severe limitations in the existing infrastructure.

Table2. Loaded elements for the existing Libyan electrical network

Normal Network (N)	Emergency network (N-1)	(N-1)/ violation %
No over loaded elements	JANZOR2-B2-SDHMD2-B2	196.85
	JANZOR2-B1-SDHMD2-B1	196.85
	MSRST-MSR220-A	101.63
	MSRST-MSR220-B	101.61
	ALJALA-SIDHAMID	140.07
	L1230836120	120.93
	SDH-NAT220-A	120.67
	SHK-RWA220-B	107.75
	SHK-RWA220-A	107.75
	ZWA-HRSH220-A	105.14
	ZWA-HRSH220-B	105.35
	TR2-RWAYS400-220 transformer	108

Scenario 2 (Modified CTs):

Adjusting the CTs ratio proved to be a highly effective operational measure. This change enhanced the base network's resilience, reducing the number of overloaded lines from 11 to 6 during the initial N-1 contingency analysis (performed prior to power injection) as detailed in Table 3. Consequently, the potential export capacity increased significantly. At Al-Garaboly, the stable N-1 capacity rose to 660 MW, while at Al-Khoms, it increased to 1430 MW. This demonstrates that operational adjustments can yield substantial improvements in grid performance.

Table 3. Loaded elements for the existing Libyan electrical network.

(N)	(N-1)	(N-1)/ violation %
No over loaded elements	JANZOR2-B2-SDHMD2-B2	176.15
	JANZOR2-B1-SDHMD2-B1	176.15
	MSRST-MSR220-A	109.82
	MSRST-MSR220-B	109.82
	SDH-NAT220-A	101.8
	ALJALA-SIDHAMID	101.87
	TR2-RWAYS400-220	108%

Scenario 3 (New 400 kV Lines):

The integration of planned 400 kV lines yielded the best results. This infrastructure upgrade eliminated the chronic overload on the TR2-RWAYS400-220 transformer, which was a persistent issue in the other scenarios. In this scenario, the stable N-1 export capacity was 660 MW for Al-Garaboly and 1430 MW for Al-Khoms. Although the maximum capacity for Al-Khoms did not increase from Scenario 2, the overall grid stability was greatly enhanced, and key bottlenecks were resolved. The results consistently show that Al-Khoms is superior interconnection point, capable of handling more than double the power of Al-Garaboly under contingency conditions. The study identified several critical overloaded elements that act as bottlenecks, particularly the JANZOR2-SDHMD2, MSRST-MSR220, SDH-NAT220, and ALJALA-SIDHAMID cables.

5. Tables and Comparsion

Table 4. Results ccomparison between scenario1 and scenario 2 in Base network.

Scenario 1		**Scenario 2**	
N Condition	**N-1 Condition**	**N Condition**	**N-1 Condition**
No over loaded elements	Jan2-B2-Sdh2-B2	No over loaded elements	Jan2-B2-Sdh2-B2
	Jan2-B1-Sdh2-B1		Jan2-B1-Sdh2-B1
	Mis-Mis220-A		Msrst-Msr220-A
	Msrst-Msr220-B		Msrst-Msr220-B
	Aljala-Sidhamid		Sdh-Nat220-A
	Sdh-Nat220-A		
	Shk-Rwa-B		
	Shk-Rwa-A		
	Zwa-Hrsh-A		

Table 5. Results comparison between case1 and case 2 for GARABOLY.

Existing CTS		**Modified CTs**	
(N)	**(N-1)**	**(N)**	**(N-1)**
690MW	**275 MW**	**1100MW**	**660MW**
No overloaded Lines	Rws-Brg-2 Rws-Brg-1 Trs-Hdb-B Trs-Hdb-A Homp-Homwt-A Homp-Homwt-B	No overloaded Lines	TRS-HDB-A TRS-HDB-B

Table 6. shows the comparison between Scenario-1 and Scenario-2 for ALKHOMS.

Existing CTS		**Modified CTs**	
(N)	**(N-1)**	**(N)**	**(N-1)**
2046MW	**880 MW**	**2300MW**	**1430MW**
No overloaded Lines	RWS-BRG-(2) RWS-BRG-(1) TRS-HDB220-B TRS-HDB220-A	No overloaded Lines	TRS-HDB220-A TRS-HDB220-B

Table 2. shows the comparison between Garaboly and AL-khoms results.

GARABOLY:		**ALKHOMS**	
(N)	**(N-1)**	**(N)**	**(N-1)**
1100MW	660MW	2300MW	1430MW
No overloaded Lines	TRS-HDB220-A TRS-HDB220-B	No overloaded Lines	TRS-HDB220-A TRS-HDB220-B

Figure 1 shows an example of 500 MW (active power) being injected through the Sdada busbar

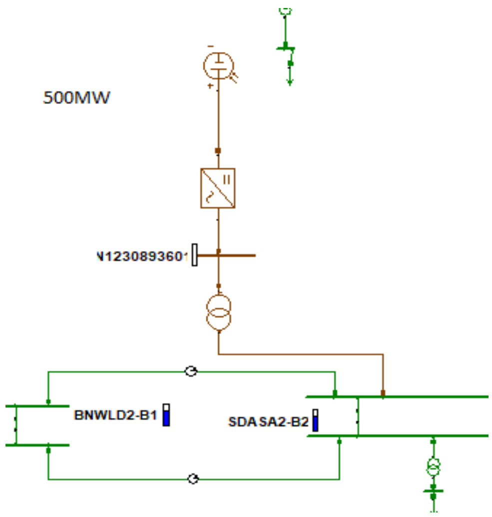


Fig 1. Power injection from a PV station at the Asdada busbar.

Additionally, to provide an example of AC power generation in the national power grid, Figure 2 presents the Tobruk power station as a sample of a traditional power grid

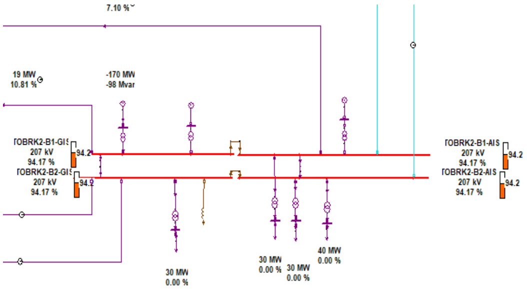


Fig2. A traditional AC power generation source: The Tobruk power station.

6. CONCLUSIONS

This study successfully evaluated the Libyan power grid's capacity for exporting electricity via two potential interconnection points, Al-Garaboly and Al-Khoms, through NEPLAN simulations. The findings confirm that while operational changes like modifying CT ratios can significantly increase power transfer capacity, the most robust and stable solution is the integration of planned 400 kV transmission lines. The analysis definitively identifies Al-Khoms as the more suitable interconnection point, achieving a maximum stable export capacity of 1430 MW under N-1 contingency conditions, compared to 660 MW at Al-Garaboly. The study also highlights persistent overloading on specific cables within the Tripoli and Misrata regions, such as JANZOR2-B1-SDHMD2-B1 and MSRST-MSR220-A, which must be addressed through future upgrades to fully realize the grid's export potential.

7. ACKNOWLEDGMENT

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