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Stability Improvement of The Iraqi Super Grid (400kV) using High Voltage Direct Current (HVDC) Transmission

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ABSTRACT

This research analyzes the level of the short circuit effect of the Iraqi super network and decides the suitable location for the High Voltage Direct Current (HVDC) connections in order to obtain the best short circuit reduction of the total currents of the buses in the network. The proposed method depends on choosing the transmission lines for Alternating current (AC) system that suffers from high Short Circuit Levels (SCLs) in order to reduce its impact on the transmission system and on the lines adjacent to it and this after replacing the alternating current (AC) line by direct current (DC) line. In this paper, Power System Simulator for Engineering (PSS/E) is used to model two types of HVDC lines in an effective region of Iraqi networks and to perform comparative studies to test the location of Short Circuit Levels (SCLs) between an actual AC and AC/DC case study in a portion of the Iraqi national network. The results proved the effectiveness of this method in eliminating severe faults and unwanted short currents, and the results showed that the bipolar type is better in reducing Short Circuit Levels of the Iraqi network.

Keywords: Iraqi Super Grid, PSS/E, HVDC, Optimize location, AC lines replacement.

تحسين استقرار الشبكة العراقية الفائقة (400 كيلو فولت) باستخدام خطوط النقل ذو الجهد العالي المباشر (HVDC)

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الخلاصة

يحلل هذا البحث مستوى تأثير ماس كهربائي للشبكة العراقية الفائقة ويحدد الموقع المناسب لتوصيلات لمنظومة الضغط العالي لتيار المستمر(HVDC) من أجل الحصول على أفضل تخفيض للدائرة القصيرة للتيارات الكلية للحافلات في الشبكة. تعتمد

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الطريقة المقترحة على اختيار خطوط النقل لمنظومة التيار المتناوب (AC) التي تعاني من مستويات عالية من قصر الدائرة (SCLs) لتقليل تأثيرها على نظام النقل وعلى الخطوط المجاورة له وذلك بعد استبدال الخط التيار التناوب بخط التيار المستمر(DC). في هذا البحث ، يتم استخدام محاكي نظام الطاقة للهندسة (PSS/E) لنمذجة نوعين من خطوط HVDC في منطقة فعالة من الشبكات العراقية ولإجراء دراسات مقارنة لاختبار موقع مستويات الدائرة القصيرة (SCLs) بين دراسة حالة فعلية لمنظومة التيار المتناوب (AC) و AC / DC في جزء من الشبكة الوطنية العراقية. وقد أثبتت النتائج فاعلية هذه الطريقة في إزالة الأعطال الشديدة وتقليل التيارات القصيرة غير المرغوب فيها ، وأظهرت النتائج أن النوع ثنائي القطب أفضل في تقليل SCL للشبكة العراقية.
الكلمات الرئيسية: الشبكة العراقية الفائقة، PSS / E، خطوط النقل ذو الجهد العالي المباشر، تحسين الموقع ، استبدال خطوط التيار المتردد.

1. INTRODUCTION

Development in transmission systems is due to the increasing demand for electric power. As the size and complexity of transmission networks increase, power systems' performance reduces due to short circuit level problems, load flow, power fluctuations, and voltage stability (**Yidong, H. et al., 2013 and Kim, I., 2020.**). High Voltage Direct Current (HVDC) technologies offer some effective schemes to meet these requirements.

The interconnection of power systems offers benefits for power transmission, such as pooling of various energy resources, reducing reserve capacity in the systems, and increasing transmission efficiency. However, if the size of the system is too large, dynamic problems can occur that could risk the reliability and availability of the synchronous operation of the interconnected grids **(Soumyajit, M. et al., 2019**).

Establishing a desired power condition at the given points is best achieved using power controllers such as HVDC. HVDC line is used to transmit large amounts of power over long distances (**Tibin, J. et al., 2018 and Nadhim, Z. et al., 2020**).

Considering application, geographical location, and technology, HVDC transmission systems are categorized into two main topologies, Two-terminal, and multi-terminal HVDC transmission systems. There are only two HVDC converter stations in two terminals, rectifier at sending end and inverter at receiving end. Multi-terminal type is used when the generation location is remote needs to be connected across different geographically isolated regions or different areas within one country (**Das, J. 2018, Zhou, L. et al., 2018 and Hasan, F. et al., 2020**). There are two types of HVDC systems, Current source converters (CSC) and voltage source converters (VSC) (**Ali, M. et al., 2019 and Bin, L. et al., 2019**).

The power transmission capacity of a two-pole HVDC line is the same as that of a single-circuit three-phase HVAC line. Still, there are two conductors in an HVDC, while a three-phase HVAC needs three conductors, so the number of insulators to support the conductors on the tower will also decrease by 1/3. Therefore, HVDC towers are cheaper than HVAC. Direct connection between two AC systems with the same frequency or a new connection within the mesh grid may be impossible due to system instability, two high short circuit levels of undesirable power flow.

An HVDC link controls the flow of power to an AC grid. Thus the load flow can be optimized by means of the HVDC connection to increase transmitted power, reduce losses and improve stability (**Abhimanyu, K. et al., 2019 and Tuaimah, F. M. 2010).** The control approach meets the transmission mechanism during normal operation and carries out satisfactory operations during AC emergencies (**Dohoon, K. et al., 2017**). The general advantage of DC connectors is that short currents of the AC system will not increase.

PSS/E, technological development of the power system, is used due to its ability to update in both numerical analysis methods and component models (**Power Technology International (PTI), 2005 and Khalid S. and Tuaimah, F. M., 2020.**). PSS/E package analyzes the performance of transmission and generation systems in steady-state and dynamic conditions. Power Flow activity needs an iterative method to solve both network conditions and boundary conditions (**Vasudevan,**

R. et al., 2018 and S. Sharif R. and Kasikci, A. 2012). Double AC contingencies analysis of power flow and transient stability can be determined on the system verifying apparatus short circuit capability (**Ting, A. et al., 2017**).

A three-phase fault usually causes the highest current. Thus, it is suitable for carrying out short circuit activity of the 400 kV Iraqi network with a three-phase fault that detects the highest circuit currents. This network can be modeled in power flow programs and transient stability programs such as PSS / E.

In this paper, solutions are presented to reduce the level of faults by using an HVDC line that prevents the transmission of short circuit currents to the 400 kV network in the Baghdad region, which decreases the short circuit currents at the 132 kV network lower.

Section 2 gives a detailed mathematical model for the HVDC system. The HVDC link implementation does not lead to an increase in SCL is covered in Section 3. Section 4 presents details of the Iraqi grid and its problems. Section 5 presents the simulation results for two case studies, while Section 6 concludes the offered results

2. MATHEMATICAL EQUATIONS

Electronic converters are essential, so the details are brief and are explained in the following relevant excerpts depending on Fig.1. (**Das, J. 2018 and Messalti, S. et al., 2012**):

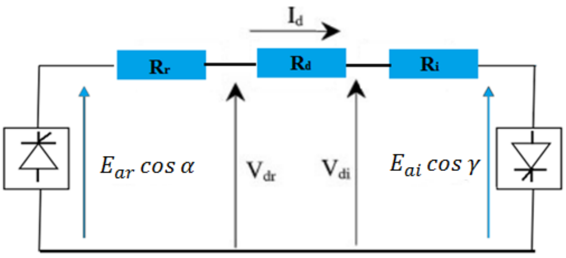

Figure 1. Basic DC transmission circuit **(Messalti, S. et al., 2012).**

In Rectifier side:

$$V_{dr} = N(\frac{3\sqrt{2}}{\pi} E_{ar} \cos\alpha - \frac{3\sqrt{2}\, X_r I_d}{\pi} - 2R_r I_d) \quad (1)$$

$$\mu_r = \cos^{-1}\left(\cos\alpha - \frac{3\sqrt{2}\, X_r I_d}{E_{ar}}\right) - \alpha \quad (2)$$

$$I_{ar} = \frac{\sqrt{6}N}{\pi} I_d \quad (3)$$

In Inverter side:

$$V_{di} = N(\frac{3\sqrt{2}}{\pi} E_{ai} \cos\gamma - \frac{3\sqrt{2}\, X_i I_d}{\pi} - 2R_i I_d) \quad (4)$$

$$\mu_i = \cos^{-1}\left(\cos\gamma - \frac{3\sqrt{2}\, X_i I_d}{E_{ai}}\right) - \gamma \quad (5)$$

$$I_{ai} = \frac{\sqrt{6}N}{\pi} I_d \quad (6)$$

In Transmission line

$$V_{di} = V_{dr} - R_d I_d \quad (7)$$

$$P_d = V_d I_d \tag{8}$$

The power at the Rectifier end

$$P_d = \frac{{V_{dr}}^2}{R_d} - \frac{V_{dr}V_{di}}{R_d} \tag{9}$$

The power at the Inverter end

$$P_d = \frac{{V_{di}}^2}{R_d} + \frac{V_{dr}V_{di}}{R_d} \tag{10}$$

The power at the middle

$$P_{dm} = \frac{V_{dr}V_{di}}{2R_d} \tag{11}$$

The power Losses are

$$P_L = \frac{(V_{dr} - V_{di})^2}{R_d} \tag{12}$$

The voltages V_{di} and V_{dr} are regulated by controlling the following:

- Tap changer on transformers of the rectifier for alternations of 8–10 s.
- The delay angle α of the thyristor for rapid changes of a few milliseconds.

When designing an HVDC system, the power of the AC system is considered by the effective short circuit level of the HVDC system. If the HVDC is planned to replace the present AC line, then flow change in the line will be detected using the present data of the system because the location data of the newly planned HVDC is the same as the replaced AC line (**Donghui, Z. et al.**, **2015 and Powell, L. 2005**).

The case study included two cases, monopole and bipolar types of HVDC transmission lines, and is applied to the Iraqi international network of 400 kV. In this work, it is assumed that a three-phase symmetrical fault occurs with a high fault level for that network which is done by using the PSSE package to identify the high fault levels and their corresponding bus bars.

3. SHORT CIRCUIT CAPACITY (SCC)

Short Circuit Capacitance (SCC) or short circuit level (SCL) in the bus is defined as the product of the magnitude of pre-fault bus voltages and the post-fault current. Another definition of SCC can be formulated as follows:

$$SCC_i = \frac{E_{AC,i}^2}{Z_{th,i}} \tag{13}$$

While AC systems rise in size, short circuit levels go to increase with the associated troubles. Due to the current control essential in DC transmission, the HVDC jumper can be used to join with two power systems without raising the short circuit capacity. And also, the HVDC link does not lead to an increase in short circuit level at the connection buses. This means that circuit breakers will not be necessary to change in existing networks (**Donghui, Z. et al.**, **2015**).,The HVDC systems themself do not add significantly to the short-circuit power of the AC power system.

4. HVDC MODELING FOR THE IRAQI 400 KV NETWORK

The Iraqi electrical national grid consists of a 400KV super grid and 132 kV Ultra High Voltage (UHV) electrical power transmission networks, and it consists of 33 kV and 11 kV system distribution networks. Iraqi electrical power system is divided, from an operation and control point of view (**Planning and Studies Office, 2020**), into four operational subsystems, namely the North region, the Middle region, the Euphrates region, and the South region. Basically, it is noted that: Iraqi national Extra High Voltage grid (EHV) system comprises (46) bus bars. The presented work shows that the peak of generated electrical power in 2020 is 17048.7 MW while the peak load demand is 16646.16 MW.

The Baiji PS and Baiji GPS network is nearly isolated in the northern region due to ISIS violence, while the Erbil GPS, Mosul Dam, and Kirkuk GPS stations are connected. The Middle region contains Haditha Dam; Isolated due to the destruction of ISIS, Diyala GPS, Basmia GPS, Quids GPS, and Kut PS. The Euphrates region has Kherat GPS, Dewaniya GPS, Musayab GPS, Muthanna GPS, and Musayab PS. Finally, the southern region contains Amara GPS, Nassirya PS, Rumela GPS, Hartha PS, Shat Al Basra GPS, Najibia GPS, and Khor Al-Zubair GPS, as shown in **Fig. 2**. In the same Figure, The Baghdad area is marked by rounded red dotted lines, and the red bus bars represent the position of DC lines which will be explained in the next section.

In the Iraqi national network, the Baghdad governorate suffers from excessive loads due to population density. The level of faults is high due to the presence of three stations close to the area, which are Basmaia Gas Power station feed 3000MW in the 400kV grid, Musayab GPS, and Kut Thermal Station, which may cause major faults to the Baghdad region of 400 kV.

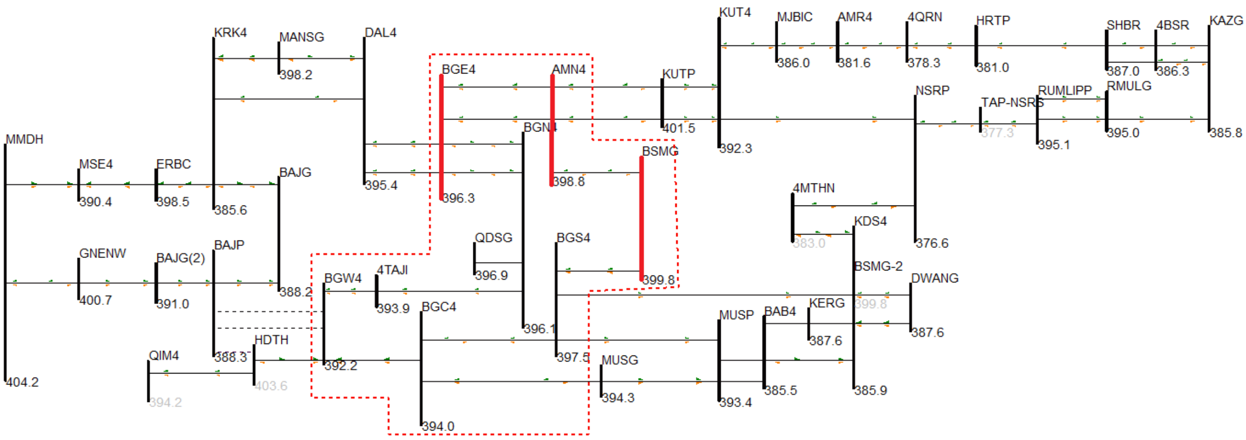

Figure 2. Iraqi (400kv) National Super Grid System.

5. RESULTS AND DISCUSSION

In this work, a three-phase symmetric fault is assumed to occur near bus bars of the Iraqi electrical network (400 kV); the voltage magnitude should not drop below 0.9 per unit (within acceptable limits) at high voltage and extra high voltage networks. In each test system, PSSE has been used to identify the high fault levels and their corresponding connection bus bars with and without the DC line, and then the minimum total losses have been used to find the optimum location. **Table 1.** shows the short circuit level for some stations in the Iraqi 400 kV network.

The monopolar and bipolar are planned and optimized, according to the fault level results, to coordinate generation standards and loads on the AC network with an emphasis on the boundaries of the AC and DC network. It is suitable for comparing fault levels before and after high voltage AC/DC coupling to demonstrate the feasibility of HVDC for reducing short circuit levels in the transient sub-period.

Table 1. The highest (SCL) in Iraqi super Grid.

Bus bar name	Fault level (A)
BSMG	30812.5
BGS4	30812.5
BGN4	29551.6
AMN4	33511.4
KUTP	29958.2
MUSG	28895.1
MUSP	30246.6
BGE4	30401.6
QDSG	25122.9
BAB4	25698

For Monopole DC Network: AC grid is joined to converters, i.e., bus bar Basmaia G (BSMG) connected to a converter1 (in Rectifier side), and bus bar AL-Amine (AMN4) connected to a converte2 (in Inverter side), and DC line connecting between the two AC bus bars and of length 41km with a limit of 1400 MW. It is shown in **Fig. 3**, where the direct current line connecting the Baghdad region and Basmaia region and the AC transmission lines mean disconnection. **Table 2.** shows the SCL for AL-Amine (AMN4) is (33511.4A) and is minimized to (25327.7A) with variance value (8,183.70A) and the BSMG SCL is 30812.5A and is reduced to (18478.5A) with variance value (12,334.0A) when the AC line is replaced by the DC single line; Between AMN4 and BSMG. Also, **Fig. 4** showed how the short circuit levels decreased in bus bars for the Baghdad region and its adjacent stations after applying DC line implementation.

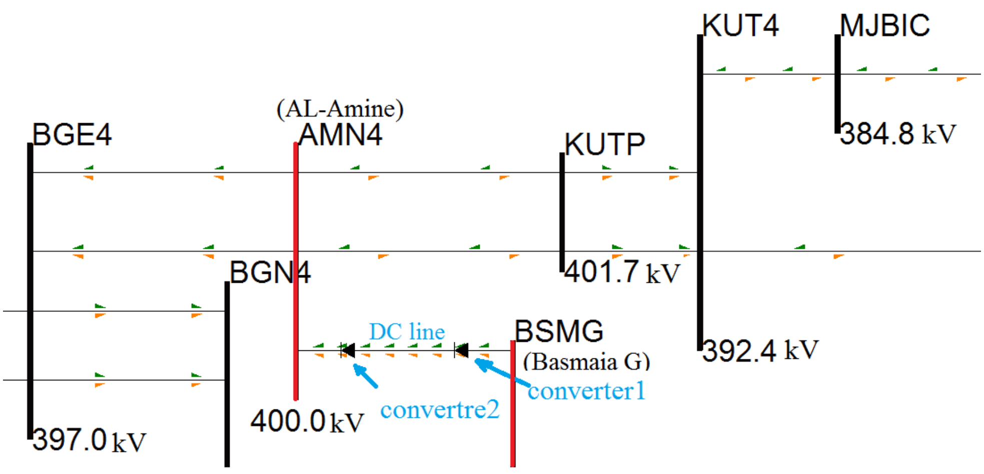

Figure 3. HVDC Link with Baghdad Region for monopolar type.

Table 2. HVDC Effect on SCL of Iraqi Grid for monopolar type between Basmaia and Al-Amine.

NO.	Bus bar name	SCL before HVDC lines (A)	SCL with HVDC lines (A)	variance values of SCL(A)
1	BGC4	19672.1	18727.8	944.30
2	BSMG	30812.5	18478.5	12,334.00
3	BGS4	30812.5	24112.9	6,699.60
4	BGN4	29551.6	26516	3,035.60
5	AMN4	33511.4	25327.7	8,183.70
6	KUTP	29958.2	28305.1	1,653.10
7	MUSG	28895.1	25167.5	3,727.60
8	MUSP	30246.6	28076.9	2,169.70
9	BGE4	30401.6	27246.6	3,155.00
10	BGW4	16220.9	16214.9	6.00
11	QDSG	25122.9	24663.8	459.10

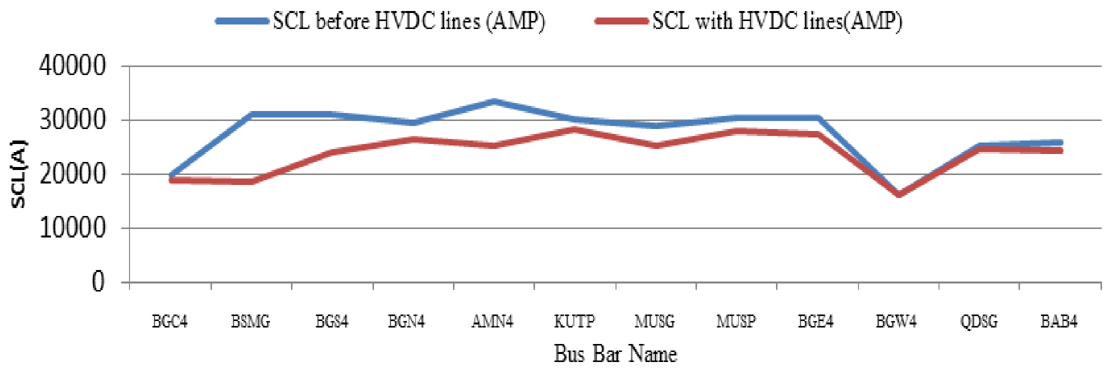

Figure 4. Short circuit levels in Baghdad with and without HVDC monopolar type.

For Bi-pole DC Network: Bi-polar DC converter (two Monopolar) is joined to AC systems, i.e., bus bar (AMN4) connected to a converter1 (in Rectifier side), and bus bar Bagdad East G (BGE4) connected to a converter2 (in Inverter side), and connecting by DC line with a length 40Km of the limit of **1400** MW. It is shown in **Fig. 5**, where the direct current line connecting BGE4 and AMN4 and the AC transmission lines mean disconnection. **Table 3** shows the SCL for BGE4 is (**30401.6**A) and is decreased to (**17405.6**A) with variance value (**12,996.0A**), and the AMN4 SCL is reduced to **(22942A)** with variance value (**10,569.4A**) when the AC line is replaced by the double DC line; Between AMN4 and BGE. Also, **Fig. 6** showed how the short circuit levels decreased in bus bars for the Baghdad region and its adjacent stations after applying DC line implementation.

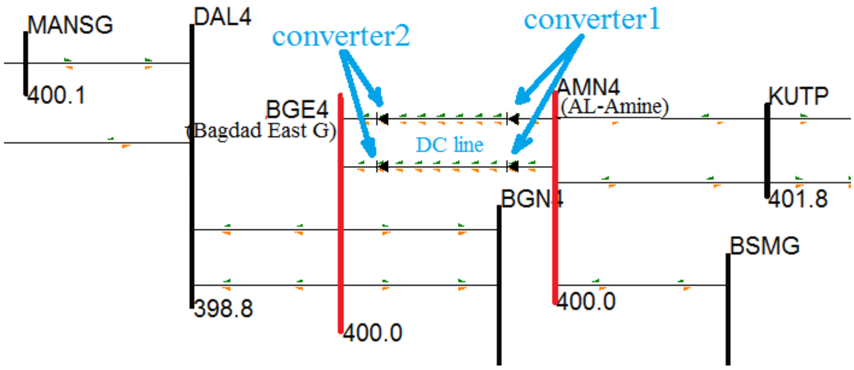

Figure 5. HVDC Link with Baghdad Region for bipolar type.

Table 3. Impact on SCL of Iraqi network before and after HVDC bipolar connection between Baghdad East and Al Amine.

NO.	Bus bar name	SCL before HVDC lines (A)	SCL with HVDC lines (A)	variance values of SCL(A)
1	BGC4	19672.1	19210.5	461.60
2	BSMG	30812.5	26399.5	4,413.00
3	BGS4	30812.5	29834.8	977.70
4	BGN4	29551.6	18394.4	11,157.20
5	AMN4	33511.4	22942	10,569.40
6	KUTP	29958.2	27780.8	2,177.40
7	MUSG	28895.1	26316.1	2,579.00
8	MUSP	30246.6	29555.5	691.10
9	BGE4	30401.6	17405.6	12,996.00
10	BGW4	16220.9	15169.6	1,051.30
11	QDSG	25122.9	17557.3	7,565.60

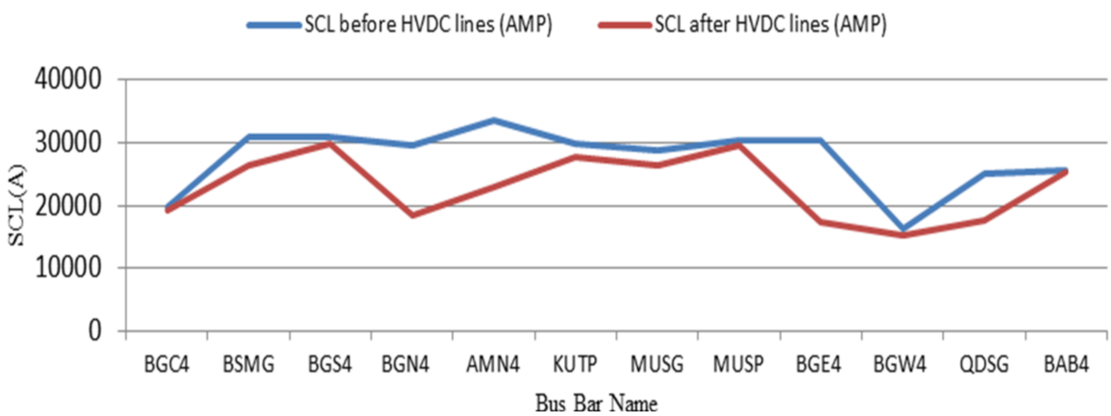

Figure 6. Short circuit levels in Baghdad region with and without HVDC Bipolar type.

6. CONCLUSIONS

The use of the PSSE Tools application facilitates an engineer to realistically engage with a wide range of investigations into electrical power system design and operation. We can summarize this research as follows:

- The use of an HVDC system is necessary in the case of large faults over small distances, where the other benefits are particularly helpful in addressing a problem. Most of the benefits are the elimination of severe faults and the reduction of unwanted short currents.
- It is evident from the previous results that the DC line between 4AMN and BSMG is more effective for reducing SCL in Baghdad region because the high generating capacity of BSMG causes the highest SCL contributions in Baghdad/Rusafa buses; of Iraqi super grid then connecting this bus bar to monopole dc network is more efficient than other bus bars.
- Before HVDC implementation, the highest SCL was in the Baghdad area in AL-Amine (AMN) because the high capacity KUT PS station causes the highest SCL in its transmission line. Then coupling (AMN) with BGE4 by DC bipolar network is more effective than other bus bars.
- Two types of HVDC, monopolar and Bipolar, are applied and studied in the Iraqi national grid, specifically in the Bagdad region. The results are cleared that a bipolar type is better in reducing SCL. This issue is related to the problem from which there is a problem of short currents inflation in stations near Baghdad.
- Finally, it is found that the bipolar affects the SCL of the Iraqi network connecting the bus bar greater than the monopole as shown in the average reduction in SCL of **Fig. 7** for monopole type and **Fig.8** for bipolar type.
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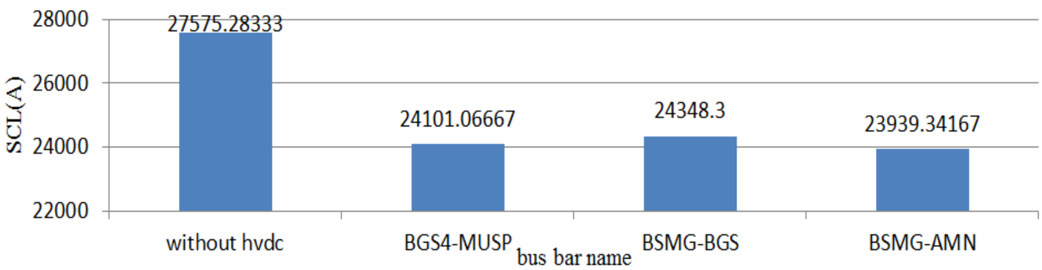

Figure 7. Average SCL reduction for monopolar type in Iraqi super grid (400 kV).

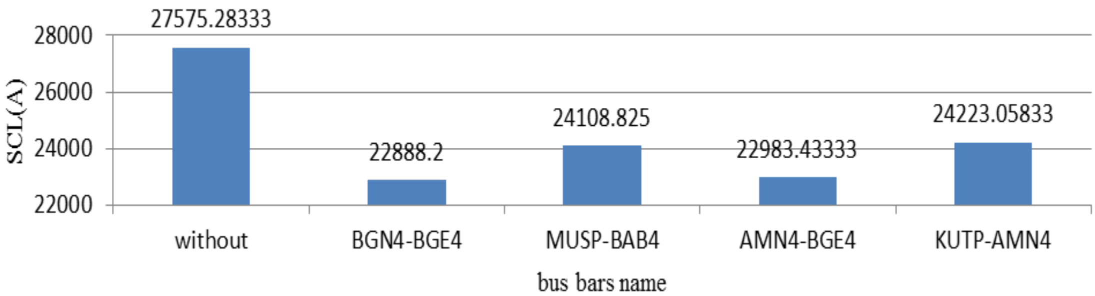

Figure 8. Average SCL reduction for bipolar type in Iraqi super grid (400 kV).

NOMENCLATURE

V_{dr}= Rectifier DC line voltages (V).
V_{di} = Inverter DC line voltages (V).
N = number of converter bridges in series.
α = Delay and extinction angles.
γ = Extinction angles.
E_{ar}= Open circuit line-to-line voltages on the rectifier dc side of converter transformers, (V).
E_{ai}= Open circuit line-to-line voltages on the inverter dc side of converter transformers, (V).
I_d = Transmission DC current, (A).
R_r= Converter transformer in rectifier dc side winding commutating resistances, Ω/phase.
R_i = Converter transformer in inverter dc side winding commutating resistances, Ω/phase.
X_r= Converter transformer in rectifier dc side winding commutating reactance, Ω/phase.
X_i = Converter transformer in inverter dc side winding commutating reactance, Ω/phase.
R_d= Resistance of DC line, Ω/phase.

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