

Impact of High Voltage Direct Current Link on Transmission Line in Kurdistan Power System

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ABSTRACT

Kurdistan power system is expanded along years ago. The electrical power is transmitted through long transmission lines. The main problem of transmission lines is active and reactive power losses. It is important to solve this issue, unless, the most of electrical energy will lost over transmission system. In this study, High Voltage Direct Current links/bipolar connection were connected in a power system to reduce the power losses. The 132kV, 50 Hz, 36 buses Kurdistan power system is used as a study case. The load flow analysis was implemented by using ETAP.16 program in which Newton-Raphson method for three cases. The results show that the losses are reduced after inserted HVDC links.

Keywords: Load Flow Analysis (LFA), High Voltage Direct Current (HVDC) Link, active Power, Reactive Power, High Voltage Alternating Current (HVAC), ETAP.

تأثير وصلة التيار المباشر ذات الجهد العالي على خط النقل في نظام كهرباء شمال العراق

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الخلاصة

تم توسيع نظام الطاقة في كردستان منذ سنوات. تنتقل الطاقة الكهربائية عبر خطوط نقل طويلة. تتمثل المشكلة الرئيسية لخطوط النقل في فقد الطاقة النشطة والمتفاعلة. من المهم حل هذه المشكلة، ما لم تفقد معظم الطاقة الكهربائية عبر نظام النقل. في هذه الدراسة، تم توصيل روابط تيار مباشر عالي الجهد (HVDC) اتصال ثنائي القطب في نظام طاقة لتقليل فقد الطاقة. يستخدم نظام كهرباء كردستان 132 كيلو فولت، 50 هرتز، 36 حافلة كحالة دراسة. تم تنفيذ تحليل تدفق الحمل باستخدام برنامج ETAP.16 حيث تم استخدام طريقة نيوتن-رافسون لثلاث حالات. تظهر النتائج أن الخسائر تقل بعد إدراج روابط HVDC.

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Peer review under the responsibility of University of Baghdad.

<https://doi.org/10.31026/j.eng.2022.03.04>

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Article received: 29 /10 /2021

Article accepted: 23 /12/2021

Article published:1/3/2022



Abbreviation

ETAP: Electrical Transient Analyzer Program

HVDC: High Voltage Direct Current

FACTS: Flexible Alternating Current Transmission System

STATCOM: Static Synchronous Compensator

UPFC: Unified Power Flow Controller

SVC: Static Var Compensator

TCPST: Thyristor Control Phase Shifting Transformer

TCSC: Thyristor-Controlled Series Capacitors

QPSO: Quantum Behaved Particle Swarm Optimization

1. INTRODUCTION

Today's power systems are suffered from many issues especially power losses along long transmission lines. HVDC technology has been well-known to transmit power for long distance as a transmission line or submarine cable. It is also used to connect between asynchronous power systems (**Muhammad, 2019**). For that reason HVDC has advantages over three-phase A.C. transmission system, it is play a main role in reducing cost (**Lafta et al., 2018**). The losses in the HVDC transmission system is less than the HVAC transmission system, it is about 75% of the HVAC losses (**Ojwang et al., 2019**).

(**Salama et al., 2014**) has proposed HVDC links for Aswan High Dam/Cairo, when compared to an AC system, power transmission losses have been reduced by around two-thirds. HVDC is the preferable technique for transporting a large amount of power across long distances with minimal loss. HVDC results in excellent voltage profile, lesser conductor, higher efficiency, economical, regulation, no reactive power compensation, reliability and stability than an same sized high HVAC transmission system transmitting (**Halder, 2013**) (**Abass et al., 2021a**), (**Abass et al., 2021b**).

Fig. 1 depicts the fluctuation in transmission costs with distance for both alternating current and direct current transmission. AC is less expensive than DC for distances less than the breakeven distance, but it is more expensive for greater distances. The "breakeven distance" for overhead lines ranges from (400 to 700 km) depending on the per unit line cost, whereas the "breakeven distance" for cable systems ranges between (25-50 km) (**Sood, 2006**).

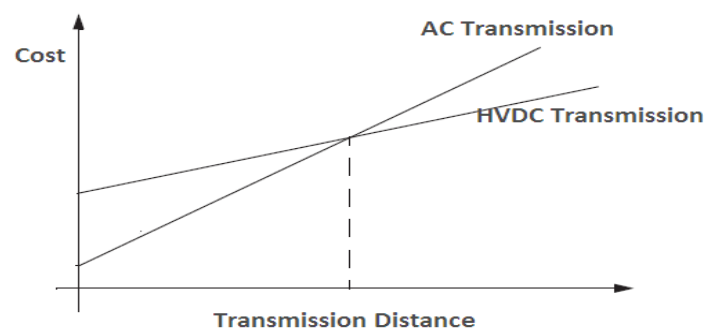


Figure.1 Comparison of AC/DC transmission line cost.



In this paper, HVDC links are inserted in the power system in order to minimize:

- Active power losses.
- Reactive power losses

In this paper, the effect of HVDC link on transmission line losses has been studied by using ETAP.16 software in which Newton-Rapson method is used. The 36-bus Kurdistan Iraq distribution systems are used as a study case.

2. HVDC TRANSMISSION LINES

HVDC transmission line systems have advanced rapidly in the previous five decades due to technological and economic benefits over HVAC transmission line systems. It has been observed that HVDC transmission line systems provide approximately 40% higher efficiency than HVAC transmission line technologies used for large amounts of power transmission over long distances with minimal losses using overhead transmission lines or submarine cable crossings (**Hafeez and Khan, 2019**). This is especially important in an energy landscape characterized by increasing digitalization, carbonization, distributed generation, and help connect green power to the grid, as well as stabilize three-phase power systems. Furthermore, the technique is used to connect several power systems with differing frequencies. In essence, because of the constraints of HVAC, such as reactive power loss, stability, current carrying capacity, operation, and control, HVDC is an interesting technology. The transformer in the HVDC system ramps up the generated AC voltages to the desired level. The converter station receives power from one location in the three-phase alternating current network and rectifies it to direct current (DC), which is then delivered through overhead lines or cables. At the receiving end, an inverter converts the DC voltage back to AC, which is subsequently stepped down to distribution voltage levels at various levels ends (**Li et al., 2019**),(**Abass et al., 2020**).

one of the biggest challenges, a HVDC transmission lines are generally less costly than HVAC and suitable for transmission power for long distances of more than approximately 300 km have been reached (and rated power transmission range is up to 600-800M) then for to be crossing various jurisdictions (cities, counties, states, or even countries (**Halder, 2013**).

This decreases the aesthetic impact as well. Environmental considerations for converter stations in HVDC systems include visual impact, audible sound, electromagnetic compatibility, and the usage of a ground or sea return path in mono-polar applications(**Ahmed et al., 2022**). The HVDC system is very compatible with any environment and can now be integrated into the system without producing any significant environmental difficulties. Underwater cables with cable lengths of up to 1000 kilometers are being planned. As previously stated, long-distance HVDC power transmission technology was introduced in the second half of the twentieth century. The transmission capacity is constantly increasing from early installations that allow less than 100MW of electricity transmission to higher levels (**Alassi et al., 2019**).

The earliest commercial uses of HVDC transmission are generated in order to overcome the technological restrictions on reactive power demand of HVAC cables across long distances, particularly in underwater transmission. Later, HVDC was used for long-distance air lines, and it was discovered that it provides more cost-effective solutions than HVAC technology as transmission distance rises. Furthermore, the cheaper cost structure of HVDC compared to HVAC has played a significant role in the development of HVDC transmission lines over time (**Chen et al., 2015**).



In Iraq, a developing country with a high reliance on foreign energy, HVDC transmission line systems are expected to play a leading role in reducing reliance on foreign energy by ensuring energy efficiency. The infrastructure operations of the HVDC transmission line systems are expected to accelerate. Thus, it is predicted that within the framework of 2020-2024 energy policies, chances for energy accessibility at the national and international levels would be created, which will support and improve sustainability. On HVDC transmission lines, there is typically a fast-acting emergency control system, which is critical for improving dependability, stability, and transmission capacitance (Lafta et al., 2018),(Hussain et al., 2020), (Ismail et al., 2021).

2.1 HVDC Applications

The HVDC system is efficiently used in the following applications(Asplund, 2000), (Kalair et al., 2016):

1. Underground and underwater cable crossings for transmission networks longer than 30 kilometers.
2. The asynchronous connecting of an alternating current system with different frequencies.
3. Power flow control is used to control and stabilize the power system.
4. Long-distance transmission of large amounts of power.

2.2 Advantages of HVDC Systems

Most utility-scale power plants generate alternating current (AC), and most electrical loads are powered by AC. As a result, the large bulk of power transmission lines around the world are of the alternating current variety. However, there are instances when HVDC transmission systems provide several major advantages (Kalair et al., 2016).

- In transmission lines, HVDC uses power electronic technologies. Because there are no mechanical moving components in these devices, there is minimal chance of failure, resulting in exceptionally robust performance and long life under nominal conditions.
- Lowering the price of DC lines because of HVDC can transmit greater power with only two-sets of conductors of a given size rather than three; for example, a typical bipolar HVDC cable-pair for conveying the same amount of active-power costs less than the price of two-parallel 3-separate phases HVAC cables. As a result, they are less complicated, have lower insulation and symmetry requirements, as well as requiring less conductor surface of carried power per unit (Hussain et al., 2021) (Albanna and Hussain, 2020).
- The power flow can be managed rapidly and precisely using the HVDC system, both in terms of power level and direction.
- When compared to HVAC of comparable power, HVDC transmission cables induce a reduction in Corona losses(Ismail et al., 2021).
- It is an obvious fact that direct current transmission is the least harmful to the environment.
- Only one-third of the isolated conductor sets are required as double-circuit AC lines.
- AC grid performance enhancements and firewalling against cascading blackouts.
- Less loss on DC transmission because there is no skin affect results in a more efficient system.
- The connecting of asynchronous grids and grids with varying frequencies.
- It does not contribute to the short circuit current of an alternating current system.
- The availability of a completely controlled power source in either direction.
- Each conductor circuit was operated individually.
- International grid connections for renewables.



- Simpler and more compact transmission towers.
- There is no charge current in steady-state.
- Onshore and offshore grid access.
- Distances are not constrained by stability.
- No need for reactive compensation.

2.3 Disadvantages of HVDC Systems

Some of the disadvantages of HVDC are as follows (Kalair et al., 2016):

- As compared to converter stations utilized in HVAC systems, HVDC converter stations are more expensive and sophisticated.
- As compared to HVAC, the design and operation of multi-terminal HVDC systems are advanced. It is more difficult to disconnect direct current in HVDC transmission cables.
- The presence of high-frequency constituents in DC transmission causes interference in communication systems near the HVDC system. Since rectifier and inverter circuits are used, control systems are complex and require expertise and transmission cables HVDC are costly. It can be set up between two points. There is no way to add to the desired point of the line. Furthermore, there will be a current and voltage harmonics are created on the line, necessitating the use of costly a suitable filter.

2.4 A.C Transmission Line Losses

HVAC systems, on the other hand, have the following restrictions (Albannai, 2019):

- AC systems have lower capital costs but a substantially higher line slope as distance increases. They require compensation along the length, especially at high voltages, because they require what we term VAR (volt-ampere reactive) as opposed to HVDC systems, which have a much greater capital cost, but as the distance rises, the slope of the line becomes flatter. So, where these two lines connect is your breakeven point—this is a function of distance, voltage, and power transmission.
- When opposed to HVDC systems, HVAC systems are more likely to undergo corona effects during adverse weather.
- In contrast to HVDC, inductive and capacitive characteristics are limiting considerations in HVAC systems.
- When compared to HVDC, HVAC has a significant level of interference with communication lines.
- It is not possible to connect two unsynchronized HVAC lines (for example, a 60Hz to a 50Hz line).

3. METHODOLOGY

3.1 HVDC Configurations

The challenge is that two converter stations are required to transmit via HVDC. To begin the transmission process, the AC power must be converted to DC, and once at the intended tie-in location, the DC power must be converted back to AC to be used on the grid. Converter stations are more expensive than VSCs, and the cost of a big HVDC transmission project relies on the voltage, power transfer, and distance. Breakeven studies are typically performed, which include lifecycle cost, and then you arrive at a point where the HVDC system becomes more cost effective (El-Saady et al., 2016), (Raya A. K. Aswad et al., 2020).



The following five HVDC system configurations can be distinguished based on numerous aspects such as reliability, location, the arrangement of the pole and earth return, as well as the capability to transmit bulk power: (1) single-terminal; (2) bipolar; (3) homo-polar; (4) back-to-back; and (5) multi-terminal. **Fig. 2** demonstrates the HVDC component configuration (Kharade and Savagave, 2017).

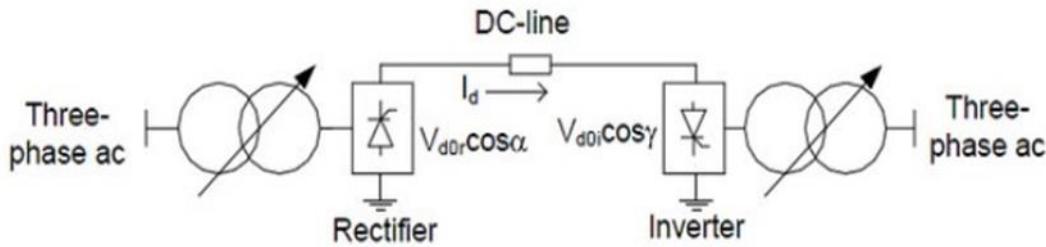


Figure. 2 HVDC link configuration.

4. DESCRIPTION OF KURDISTAN 132KV, 50HZ POWER SYSTEM

The study case which used in this paper is the Kurdistan 132 kV, 50Hz power system. It consists of 36 buses, eight generators and 51 transmission lines. Single line diagram is shown in **Fig 3**. Generation and load demands of system, and transmission line data are illustrated in **Table 1** and **Table 2**.

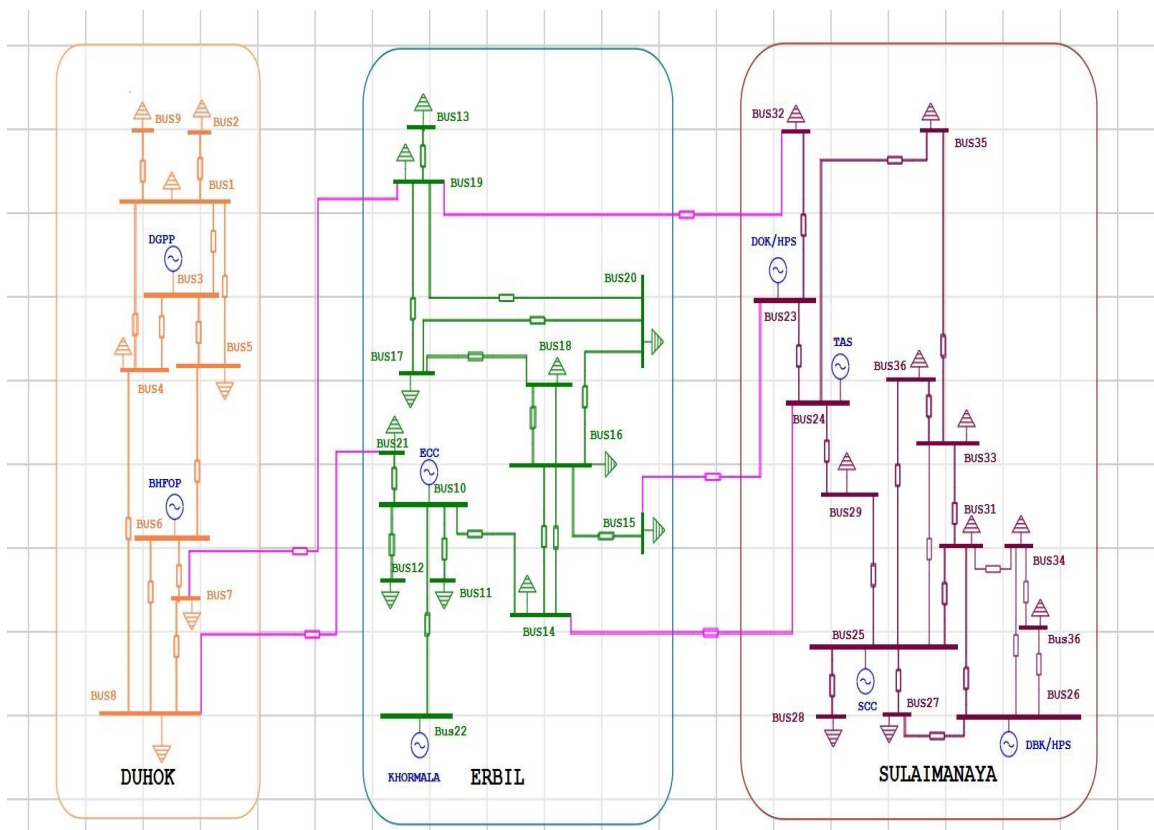


Figure 3. Single line diagram of 132kV, 50Hz Kurdistan power system.

**Table 1.** Generation and load demands of 132kV, 50Hz Kurdistan power system .

Bus.no	Generation		Loads	
	MW	Mvar	MW	Mvar
Bus 1			100	62
Bus 2			50	31
Bus 3	55	34.1		
Bus 4			90	55.8
Bus 5			105	60
Bus 6	140	86.8		
Bus 7			70	43.4
Bus 8			60	37.2
Bus 9			65	40
Bus 10	250	155		
Bus 11	970	601.4		
Bus 12			160	99.2
Bus 13			200	124
Bus 14			100	62
Bus 15			80	49.6
Bus 16			55	34.1
Bus 17			200	124
Bus 18			95	58.9
Bus 19			130	80.6
Bus 20			90	55.8
Bus 21			120	74.4
Bus 22			70	43.4
Bus 23	200	124		
Bus 24	475	294.5		
Bus 25	650	403		
Bus 26	160	99.2		
Bus 27			140	85
Bus 28			50	31
Bus 29			60	37.2
Bus 30			85	50



Bus 31			110	68.2
Bus 32			150	93
Bus 33			130	80.6
Bus 34			90	55.8
Bus 35			60	37.2
Bus 36			145	90

Table 2. Transmission lines parameters for Kurdistan power system (Salih et al., 2022).

Type	Type (Details)	RO (Ω/km)	XO (Ω/km)	R1 (Ω/km)	X1 (Ω/km)	B ($\times 10^{-6}$) (Ω/km)
LARS	Single Circuit- Single Lark Conductor	0.3275	1.231	0.147	0.428	2.66
TEAS	Single circuit- Single Teal Conductor	0.3275	1.218	0.0.097	0.415	2.75
TLAS	Single Circuit- Twin Lark Conductor	0.3065	1.109	0.0725	0.3065	3.7
TTES	Single circuit- Twin Teal Conductor	0.2805	1.113	0.0485	0.301	3.78
LARD	Double Circuit- Single Lark Conductor	0.378	1.28	0.147	0.4	2.87
TEAD	Double circuit- Single Teal Conductor	0.327	1.27	0.097	0.387	2.97
TLAD	Double Circuit- Twin Lark Conductor	0.3065	1.165	0.0735	0.728	4.13
TTED	Double circuit- Twin Teal Conductor	0.2805	1.159	0.0485	0.2725	4.26

5. RESULT AND DISCUSSIONS

In this study, Load flow simulation was implemented for three cases:

Case 1: HVDC link between bus 2 and bus 25

Case 2: HVDC link between bus 8 and bus 26



Case 3: both HVDC link

Although HVDC links are generally utilized to reduce active and reactive power losses in transmission lines in the electrical system. To see the HVDC links effect on the system, the modified 36-bus Kurdistan power system is used as an example. The summary of the test result is shown in **Fig. 4 to Fig. 9**. Both **Fig. 4 and Fig. 5** show the effect of HVDC link on the power losses of transmission lines. Both active and reactive losses are reduced for some transmission lines for case 1. For example the active and reactive losses for line13 reduce by 4.4 MW and 27 MVAR, and for line30 the losses reduced about 31 MW and 19 MVAR. Also it can be notice that the losses for some transmission lined increased for example the losses for line1 increased about 4 MW and 0.5 MVAR or unchanged such as line26, line46, line47, and line48. From the **Fig. 6 and Fig. 7**, it is clear that the losses also reduced for some lines for case 2 but the effect of this link is less than the previous one because the DERBEN power station generates less power than SCC power station. For example the active and reactive losses for line13 reduce by 4.3 MW and 28 MVAR, and for line28 the losses reduced about 9 MW and 28 MVAR. Also it can be notice that the losses for some transmission lined increased for example the losses for line50 increased about 2 MW and 13 MVAR or unchanged such as line21 and line 26. The **Fig. 8 and Fig. 9** demonstrate that transmission line active and reactive power losses reduced much more when both HVDC links inserted at the same time (case 3). For example the active power losses for line13 reduces by 7.15 MW and supply about 1 MVAR, and for line 28 the active power losses reduced about 1MW and supply about 1 MVAR. Also it can be notice that the losses for some transmission lined increased for example the losses for line50 increased about 0.5 MW and 11 MVAR or unchanged such as line21 and line 22. The summary of network power losses and cost are shown in **Table 3**, the average cost for 1MW/hr and the summery of losses is shown in **Fig 10**. In Kurdistan is 32\$ according to KRCC report. Both active and reactive power losses of Kurdistan power system decreased when HVDC links are inserted. The losses decreased about 30 MW and 160 MVAR when HVDC link inserted and decreased about 19 MW and 60 MVAR when second HVDC link inserted. The losses decreased much more when both HVDC links inserted at the same time, they reduced about 35 MW and 163 MVAR. This loss reduction causes a significant decrease in the cost of electricity for Kurdistan power system.

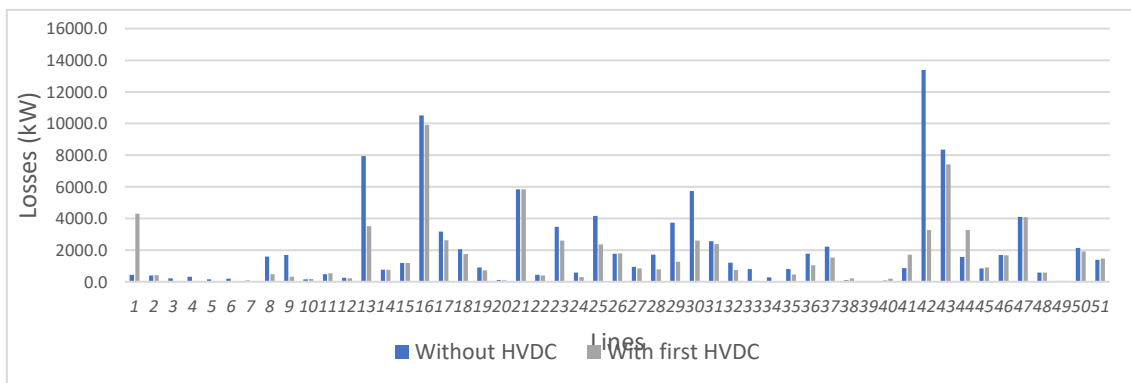


Figure 4. Transmission lines P-losses with/without HVDC link (case 1).

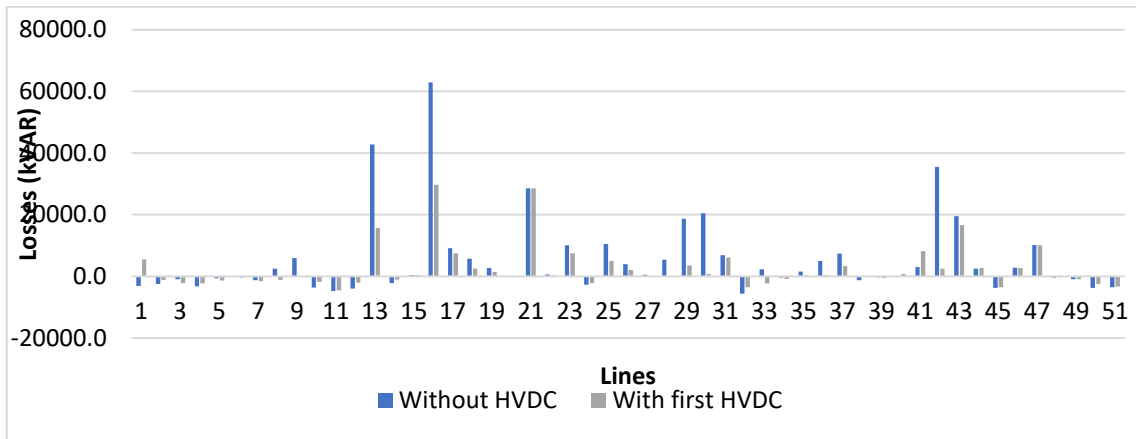


Figure 5. Transmission lines Q-losses with/without HVDC link (case 1).

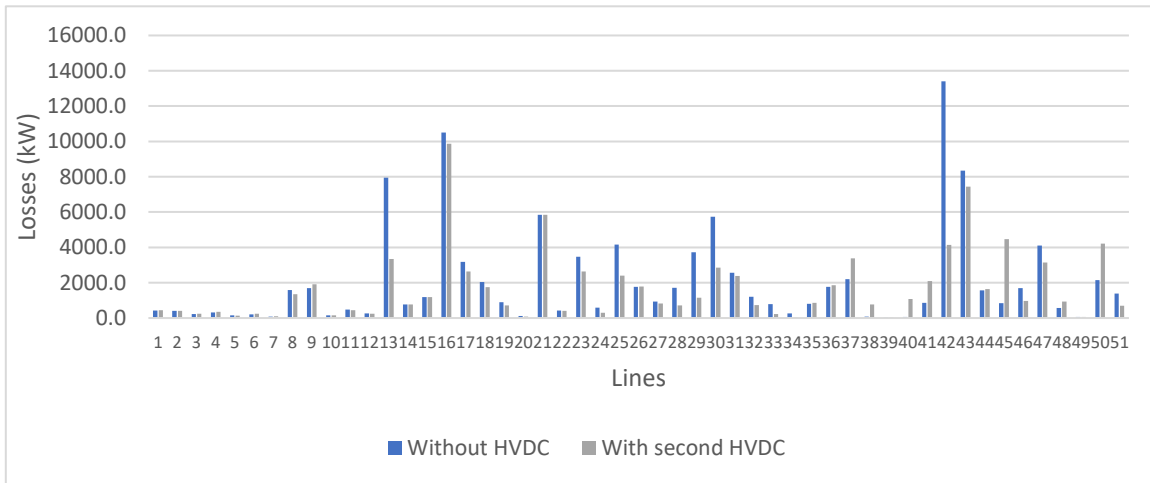


Figure 6. Transmission lines P-losses with/without HVDC link (case 2).

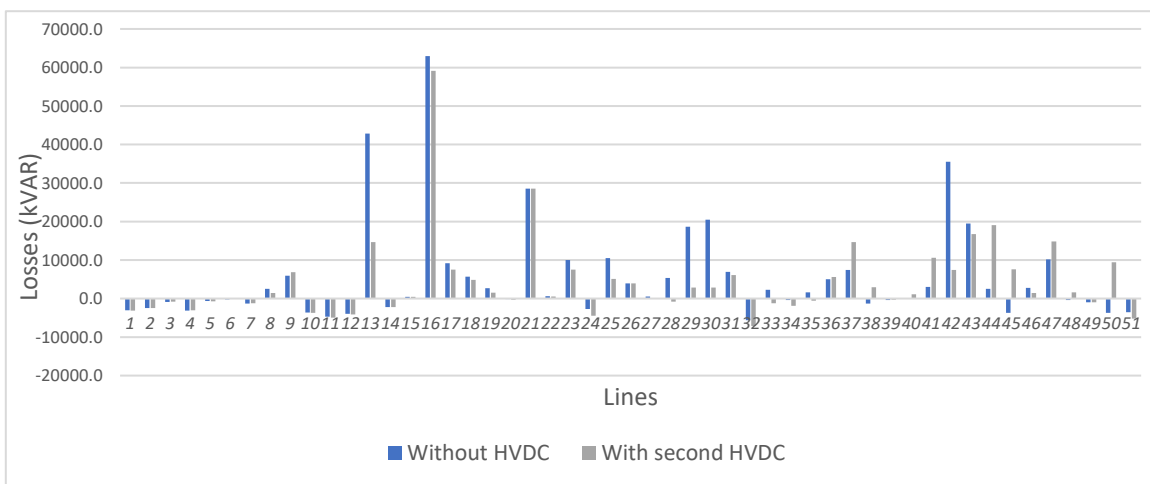


Figure 7. Transmission lines Q-losses with/without HVDC link (case 2).



Table 3. Summary of power losses and cost

HVDC Link	Active losses (MW)	Reactive losses (MVAR)	Cost (\$/year)
Non	105.7495	278.5616	29643699.8
First	75.1	119.149	21052032
Second	86.4638	217.6861	24247680
Both	71.0285	115.742	19902720

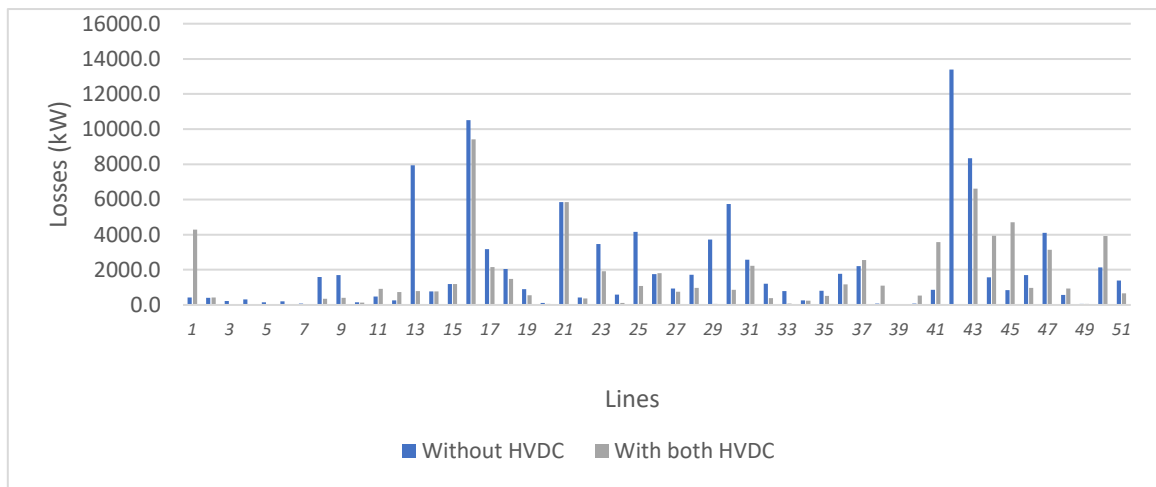


Figure 8. Transmission lines P- losses with/without HVDC links (case 3).

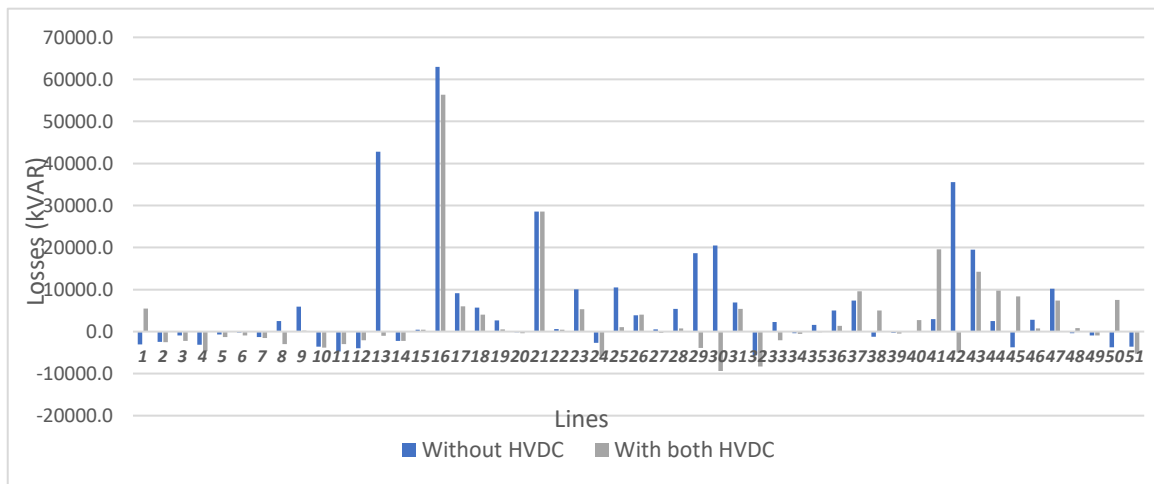


Figure 9. Transmissions lines Q-losses with/without HVDC links (case 3).

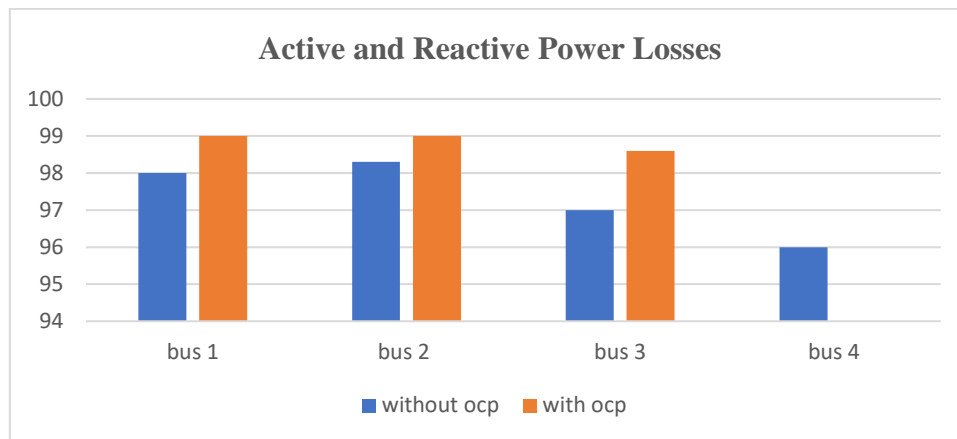


Figure 10. Summary of Active and Reactive Power Losses.

6. CONCLUSION

In this paper, the effect of HVDC link on transmission line losses has been studied by using ETAP.16 software in which Newton-Raphson method is used. The 36 bus Kurdistan Iraq distribution systems are used as a study case. It is obtained that after connecting an HVDC link, both active and reactive power losses for transmission lines are minimized. The load flow showed that the losses are reduced more when both HVDC link are connected. Also, this leads to reduce the cost of losses. The reactive power demand of Erbil load is reduced about 30 Mvar with first link and reduced about 20 MVAR. The overall reactive power demand reduced about 295 MVAR when first HVDC link inserted and reduced about 205 MVA. However the cost is reduces about 9,740,979.8 (\$/year) for case 3.

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