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Power Flow Control of Iraqi International Super Grid with Two-Terminal HVDC Techniques Using PSS/E

Yasar N. Lafta[1*], Nadheer A. Shalash[2], Yaser N. Abd[3] and Ali A. Al- Lami[4]

[1]*Mechatronics Engineering Department, Al-Khawarizmi college of Engineering, University of Baghdad, Baghdad, Iraq*
[2]*Faculty of Engineering of Electrical power techniques, Al-Maamoon University College, Baghdad, Iraq*
[3]*Planning and studies office, Ministry of Electricity, Baghdad, Iraq*
[4]*Planning and studies office, Ministry of Electricity, Baghdad, Iraq*
[1]*yasar@kecbu.uobaghdad.edu.iq*, [2]*eng_n_a_msc@yahoo.com*,
[3]*yasernadhum@yahoo.com*, [4]*allamimalla@gmail.com*

Abstract

The use of HVDC in transmission system is an important technique to improve AC power system performance. PSS/E software is a conventional package used to simulate power system, from which power flow study that involves numerical analysis of power system displays convergence progress. Short circuit activity enables engineer to decide the proper location of HVDC links in order to obtain the best minimization of short circuit currents overall buses in the grid. In this paper PSS/E is used for modelling monopolar and bipolar DC lines in an effective region of Iraqi super grid, in second hand, makes comparative studies to test location for short circuit levels (SCLs) between actual AC and AC/DC case study as part of Iraqi national grid. The finding of this article appears that the addition of DC link leads to power improvement, with the fact that SCL is reduced with bipolar line installation rather than monopolar line.

Keywords: *Baghdad governorate; optimized converters; ac system coupling; ac line replacement*

1. Introduction

Power electronic techniques are used in power system applications presenting excellent performance. Today, the most power devices employed in HVDC are thyristors, and isolated gate bipolar transistor (IGBT) [1].

Conversion in classic HVDC is done by thyristors, whereas conversion in voltage source converters (VSC) is done by transistors (IGBT's).

HVDC transmission that is built in 1954 was the first marketable use for mercury valves linking Gotland and the Swedish mainland [2]. After that line commutated converters (LCC) was the most HVDC technique that is in use [3, 4].

HVDC link controls AC network power flow. Thus load flow can be optimized effectively by HVDC link reducing losses, increasing capacity and improving stability [5]. Control approach is to satisfy dispatch mechanism during normal operation, and to implement satisfactory operations during AC contingencies [6].

DC grid technology is an economic choice having better resolution when compared with AC transmission network, different voltages of DC lines are interconnected using DC/DC converter constructing DC grid [7]. DC grid enriches system flexibility, reliability, and improves redundancy by allocation resources which decrease power losses

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[*] Corresponding Author

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[8]. The general DC links advantage is that short-circuit currents of AC system will not increase.

HVDC is preferred more than 3phase AC transmission system for the reasons that HVDC constructing cost is less; it doesn't need for synchronization between two AC systems, and fast power flow control [9], besides that HVDC limits short circuit currents.

Technology development of power system makes it essential to employ PSS/E due to its ability of updating; in both numerical analysis methods and component models [10].

PSS/E package studies performance of transmission and generation systems in steady-state and dynamic conditions. Power Flow activity requires an iterative method to solve both network condition and boundary conditions [11]. Double AC contingencies analysis of power flow and transient stability can be determined on the system verifying apparatus short circuit capability [12].

HVDC can be modelled in power flow programs and transient stability software such as PSS/E. This software executes IEC 60909 Standard to calculate short-circuit currents. Maximum fault level occurs at generation busbars, due to massive effect on supplying grid.

Typically, 3-phase fault causes the highest current thus it is suitable to execute short-circuit activity for Iraqi 400KV grid with three phase fault which reveals the most high short circuit currents.

2. DC System Concepts

AC load flow provides voltages of ac buses connected to dc system. Line commutated converters are part of all two-terminal dc lines; "Pole control is the core of HVDC control and activates the appropriate controller of the rectifier and inverter station according to the state of AC/DC systems. Then it produces the firing angle for both rectifier and inverter stations" [9].

Rectifier controls the dc current to attain desired power as in eqn. (1):

$$I_d = \frac{Power_{desired}}{Vdc_{Scheduled}} \tag{1}$$

The inverter must typically operates at (γ) higher than minimum to control ac voltage. As angle limits are assumed, power flow solution logic adjust the bridge control angle (α) or (γ), and transformer tap position to control dc voltage and current [13].

The converter DC voltage is given by expressions in terms of rectifier firing delay angle and transmission DC current as in eqn. (2):

$$V_{dr} = N_r\left[\frac{3\sqrt{2}}{\pi}\cos(\alpha_r)E_{ar} - \frac{3}{\pi}\, X_{cr}I_d - 2R_rI_d\right] \tag{2}$$

Where:

V_{dr}= Rectifier DC line voltage;
N_r = Number of rectifier bridges in series;
α_r = Rectifier delay angle;
E_{ar}= Converter Transformer secondary open-circuit voltage;
I_d = Transmission DC current;
R_r= Rectifier transformer secondary commutating resistance in ohms per bridge; and
X_{cr} = Rectifier transformer secondary commutating reactance in ohms per bridge.

Assuming zero-commuting drop initially then:

$$\frac{V_{dr}}{N_r} = \frac{3\sqrt{2}}{\pi}\cos(\alpha)E_{ar}$$

In other side Inverter DC line voltage is given by eqn. (3):

$$V_{di} = N_i[\frac{3\sqrt{2}}{\pi}\cos(\gamma)E_{ai} - \frac{3}{\pi}\ I_d X_{ci} + 2I_d R_i] \quad (3)$$

Where:
V_{di}= Inverter DC line voltage;
N_i = Number of inverter bridges in series;
γ = inverter margin angle.
E_{ai}= Converter Transformer secondary open-circuit voltage;
R_i= Inverter transformer secondary commutating resistance in ohms per bridge; and
X_{ci} = Inverter transformer secondary commutating reactance in ohms per bridge.

AC currents in rectifier or inverter transformer side are given in eqn. (4):

$$I_{ar} = I_{ai} = \frac{\sqrt{6}}{\pi} I_d N_r \quad (4)$$

Where $I_{a(r,i)}$ = AC currents in rectifier or inverter transformer side.

Tap change controller (TCC) maintains rectifier delay angle α within a definite range, usually (12° - 15°). If α margins are violated, then TCC is activated and AC voltage is varied accordingly. TCC at inverter side maintains DC voltage equal to the scheduled value. For safe commutation extinction angle control maintained constant, and DC voltage variation is controlled by tap changer [1].

Voltages of the converters transformer tap (Vdc) is equal to the reference voltage which is assumed; then tap can be determined for every converter transformer. If these taps are in the range of limits, then ac-dc solution can be obtained. However, violation of upper and lower limits of any converter transformer tap causes Vdc to be rescheduled with a repeated procedure.

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 [14].

Case study consists of two cases the first case models a monopole HVDC transmission line where current return path is through earth and the other case model a bi-pole HVDC line.

These cases are applied on Iraqi 400 KV international grid. Three-phase symmetrical short-circuit activity identified the points with high fault level of that grid. Bipolar DC line is modeled in the most high fault level busbar whereas monopolar DC line is modeled in that busbar with fault level less than the highest fault level.

3. Iraqi Super Grid Overview

It is important to introduce an over view of the Iraqi international super grid (400 KV) which represents the case study.

The peak generation is 14500 MW, and peak demand 22052 MW so the shortage is 7552 MW according to the Iraqi power system load after 10/6/2017.

Electrical power system of Iraq is divided into three operational subsystems; from the control point of view; North, Middle, and South regions.

Beside Kurdistan region isolation, north region network is almost isolated because of ISIS violence which contains Mosul Dam, Baiji PS, and Baiji GPS, and Kirkuk GPS station is in service connected with middle region which contains Haditha Dam ;isolated because of ISIS destroy; Basmia GPS, Quids GPS, Kherat GPS, Dewaniya GPS, Kut PS, Musayab PS, and Musayab GPS, and south region contains Amara GPS, Nassirya PS, Rumela GPS, Hartha PS, Shat Al Basra GPS, Najibia GPS and Khor Al-Zubair GPS as shown in Figure 1 [15]. Note that isolation is represented with vertical black lines in that figure.

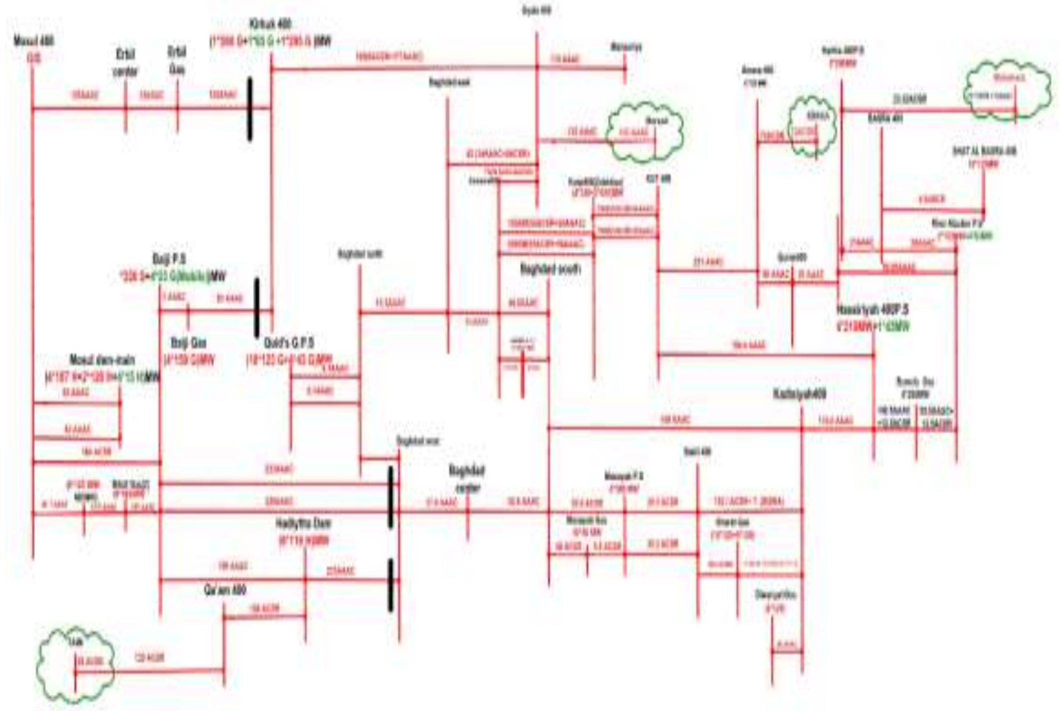


Figure 1. Iraq 400 KV Grid

Fault level of large governorate like Baghdad is high. Mussyab thermal plant infeed the 400 kV grid can deliver high fault infeed into Baghdad ring because the power plant local is close to Baghdad 400 kV ring. Also Kut thermal plant (Zubidya) can bring high short circuit current for its high capacity and its intermediate distance from Baghdad ring.

This paper aims to limit fault level using HVDC link which prevent conveying short circuit currents into the 400 kV network in Baghdad which in turn reduces short circuit currents at the 132 kV network beneath.

Baghdad region 400 KV electrical connections with Musayab and Kut (Zubidya) thermal plants are shown in Figure 2.

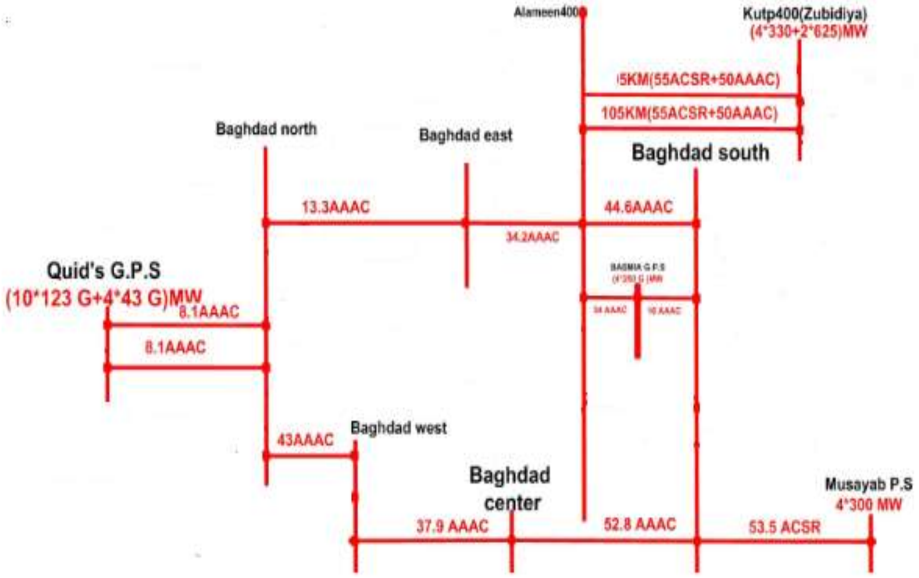


Figure 2. Baghdad Region 400 KV Electrical Connections with Musayab and Kut

4. DC link in PSS/E

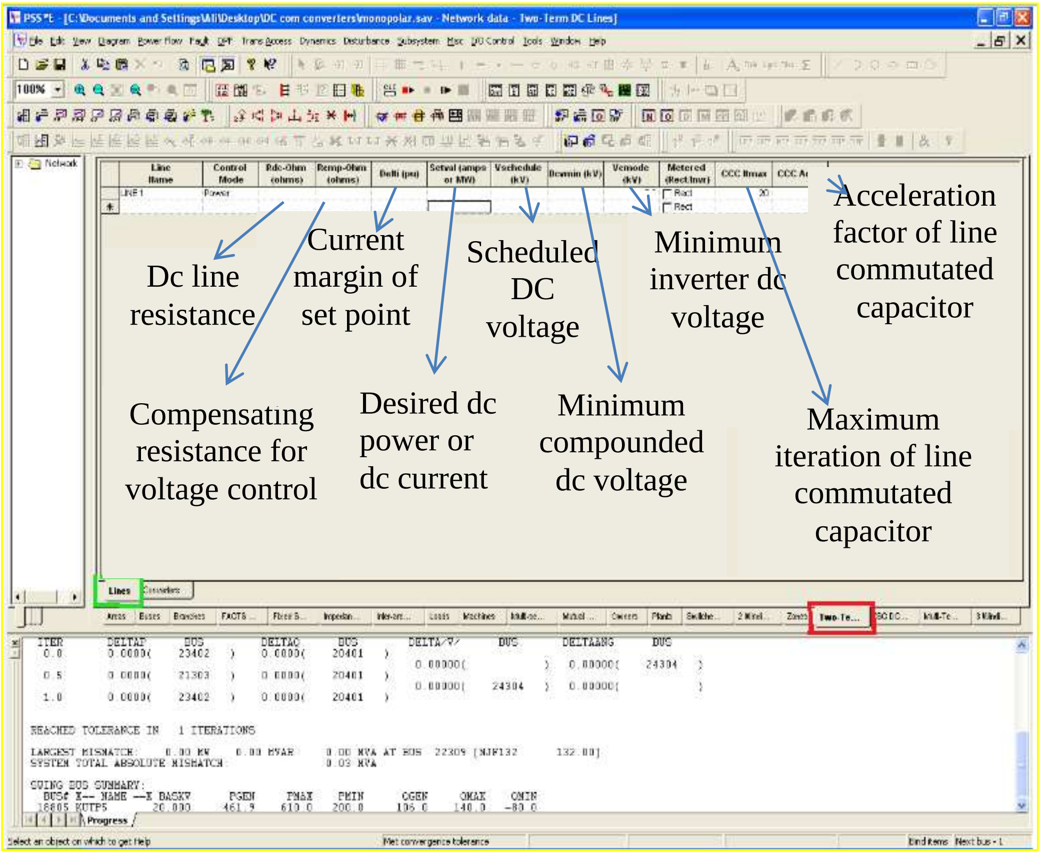
PSS/E treats dc lines as considerable portion that share the power flow solution and their flow is documented in the output and report activities. Line commutated converters are part of every two-terminal dc line. Data of dc line is mostly specified in physical units (kilovolts, amperes, and ohms).

To start entering DC link data in PSSE click on two-terminal dc line icon that is marked with red line in Figure 3 which shows lines of the two-terminal main screen display.

4.1. Line Parameter

Lines; marked with black line; main screen in Figure 3 represents Dc line parameters of the designed HVDC that must be identified with their values.

Desired data of main tabulated parameter is explained in the figure where control mode is either power or current.



Line Name	Control Mode	Rdc-Ohm (ohms)	Rcmp-Ohm (ohms)	Delti (pu)	Setval (amps or MW)	Vschedule (kV)	Dcvmin (kV)	Vcmode (kV)	Metered (Rect.Invr)	CCC Itmax	CCC Ac
LINE 1	Power								☐ Rect	20	
									☐ Rect		

```
ITER      DELTAP     BUS         DELTAQ     BUS          DELTA/V/       BUS          DELTAANG       BUS
 0.0      0.0000(    23402   )   0.0000(    20401   )
                                                     0.00000(                )   0.00000(     24304   )
 0.5      0.0000(    21303   )   0.0000(    20401   )
                                                     0.00000(     24304      )   0.00000(             )
 1.0      0.0000(    23402   )   0.0000(    20401   )

REACHED TOLERANCE IN    1 ITERATIONS

LARGEST MISMATCH:      0.00 MW     0.00 MVAR      0.00 MVA AT BUS  22309 [MJF132      132.00]
SYSTEM TOTAL ABSOLUTE MISMATCH:                   0.03 MVA

SWING BUS SUMMARY:
  BUS# X-- NAME --X BASKV       PGEN     PMAX     PMIN      QGEN     QMAX    QMIN
 18805 KUTPS         20.000     461.9    610.0    200.0     106.0    140.0   -80.0
```

Figure 3. PSS/E Two-Terminal DC Line Parameters Identification

4.2. Converter Parameter

After selecting line raw click on converters icon; marked with yellow line in Figure 4; then converters main screen is displayed and tabulated converters parameters are clarified in Figure 4.

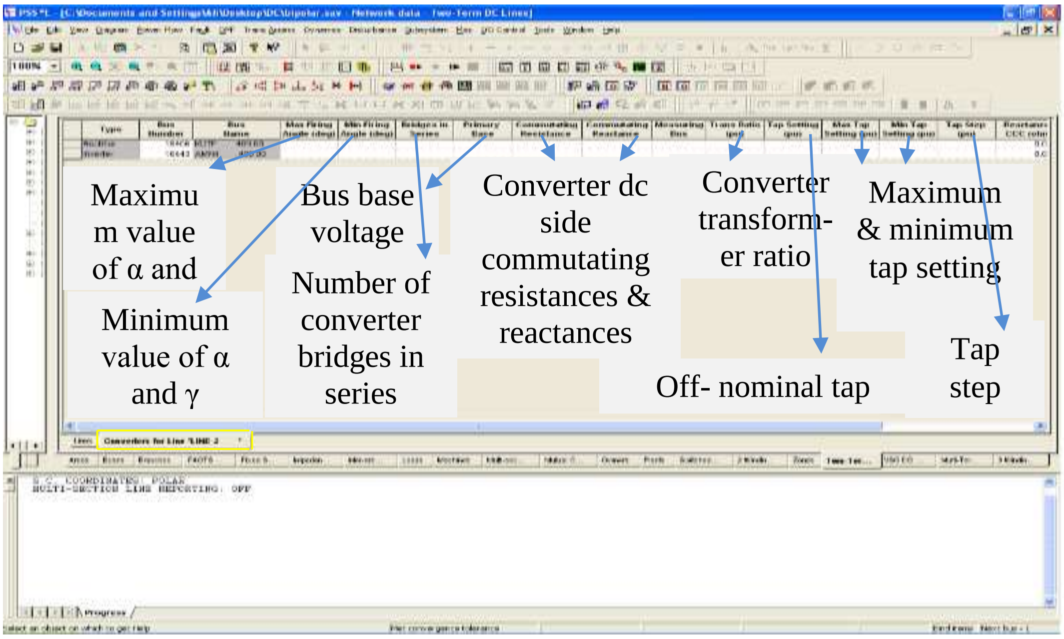


Figure 4. Main Screen of Converters and their Parameter Identification

5. Case Study

Three-phase symmetrical fault is executed using PSSE package to recognize high fault levels and their corresponding busbars. The results were as follows in Table 1.

Table 1. Highest Fault Levels

busbar name and number	Standard Power Supply(MW)	Fault level (AMP)
Alameen 16443	-	31964.9
Baghdad south 16419	-	30707.7
Kut PS 18406	4*330+2*625	30517.8
Musayab PS 20401	4*300	24920.2

According to fault level results monopolar and bipolar converters are scheduled and optimized such that coordinating generation standards and loads on the AC network focusing on both AC and DC network limits.

5.1. Monopole DC Network

AC systems are coupled by converters *i.e.*, busbar 20401 (Musayab PS) is connected to converter C1, also 16419 (Baghdad south) is connected to converter C2, and the DC line links the two AC systems with length 54Km and limit of 600 MW as shown in Figure 5 where busbars out of Baghdad region are represented with circle shape and dotted ac transmission lines means isolation.

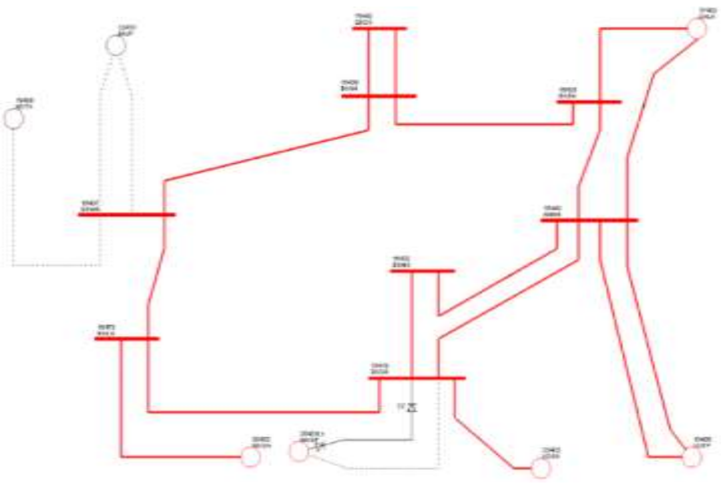


Figure 5. Monopole Connection with Baghdad Ring

Steady state monopolar DC line parameters are shown in Table 2, while converter parameters are shown in Table 3.

Table 2. DC Line Parameters Value of Monopole Model

Parameter	Value
Line Name	
Control Mode	
Rdc (Ohm)	
Rcmp (Ohm)	
Delti(per unit)	
Setval(Mega Watt)	
Vschedule(Kilo volt)	
Dcvmin (Kilo volt)	
Vcmode(Kilo volt)	
CCC Itmax	
CCC Accel	

Table 3. Converter Parameters Value of Monopole Model

Parameter	Rectifier Value	Inverter value
Bus Number		
Bus Name		
Max Firing angle (^{o})		
Min Firing angle (^{o})		
Bridges in series		
Primary Base (Kilo volt)		
Commutating resistance (Ohm)		
Commutating reactance (Ohm)		
Measuring Bus		
Transformer ratio (per unit)		
Tap setting (per unit)		
Max tap setting (per unit)		
Mintap setting (per unit)		
Tap step (per unti)		
Reactance of CCC(Ohm)		

5.2. Bi-pole DC Network

A station of bi-pole converter coupling AC bus with the DC network consists of two converters. Station C1 connected to Kut PS (18406) and C2 to Alameen (16443) are linked by a DC line of length 105Km with limit of 1400 MW as shown in Figure 6.

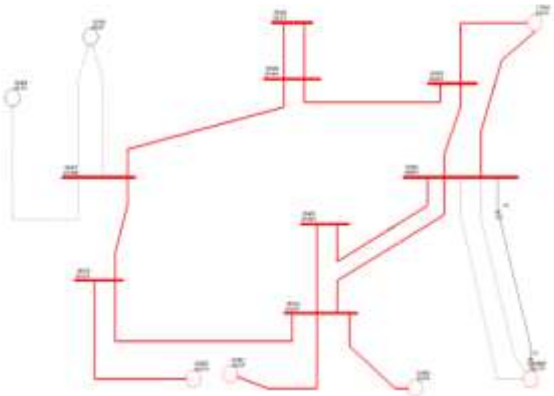


Figure 6. Bipole Connection with Baghdad Ring

Steady state bipolar parameters are shown in Tables 4 and 5.

Table 4. Bipole DC Line Parameters Value

Parameter	Value
Line Name	
Control Mode	
Rdc (Ohm)	
Rcmp (Ohm)	
Delti(per unit)	
Setval(Mega Watt)	
Vschedule(Kilo volt)	
Dcvmin (Kilo volt)	
Vcmode(Kilo volt)	
CCC Itmax	
CCC Accel	

Table 5. Converter Parameters Value of Bipole DC Line

Parameter	Rectifier Value	Inverter value
Bus Number		
Bus Name		
Max Firing angle (°)		
Min Firing angle (°)		
Bridges in series		
Primary Base (Kilo volt)		
Commutating resistance (Ohm)		
Commutating reactance (Ohm)		
Measuring Bus		
Transformer ratio (per unit)		
Tap setting (per unit)		
Max tap setting (per unit)		
Mintap setting (per unit)		
Tap step (per unti)		
Reactance of CCC(Ohm)		

6. Results

It is convenient to compare fault levels before and after high voltage AC/DC coupling to prove the validity of HVDC to limit short circuit levels at sub transient period.

6.1. Monopole Results

Fault levels for all busbars in Baghdad region before and after monopolar HVDC were as follows in Table 6.

Table 6. Baghdad 3 Phase SCL before & after Monopole Installation between MUSP& BGS4

NO.	Busbar name	SCL before monopolar HVDC line installation (AMP)	SCL with monopolar HVDC line (AMP)
1	BSMG	27521.2	24626.3
2	BGW4	17512.7	16988.2
3	**BGS4**	**30707.7**	**25715.9**
4	BGE4	25891.8	24601.35
5	BGN4	23547.5	22634.6
6	QDSG	22368	21580.26
7	AMN	31964.9	29420.5
8	BGC4	18740.1	18009.39
9	**MUSP**	**24920.2**	**18053.4**

It is clear from Table 2 that SCL of Baghdad South (BGS4) is (30707.7A) and reduced to (25715.9 A) with variance of (4991.8 A) when ac line is replaced by mono- polar HVDC line; between BGS4 and MUSP. Likewise MUSP SCL difference of (6866.8 A) is recorded. The chart clarifying the variance stated above shown in Figure 7.

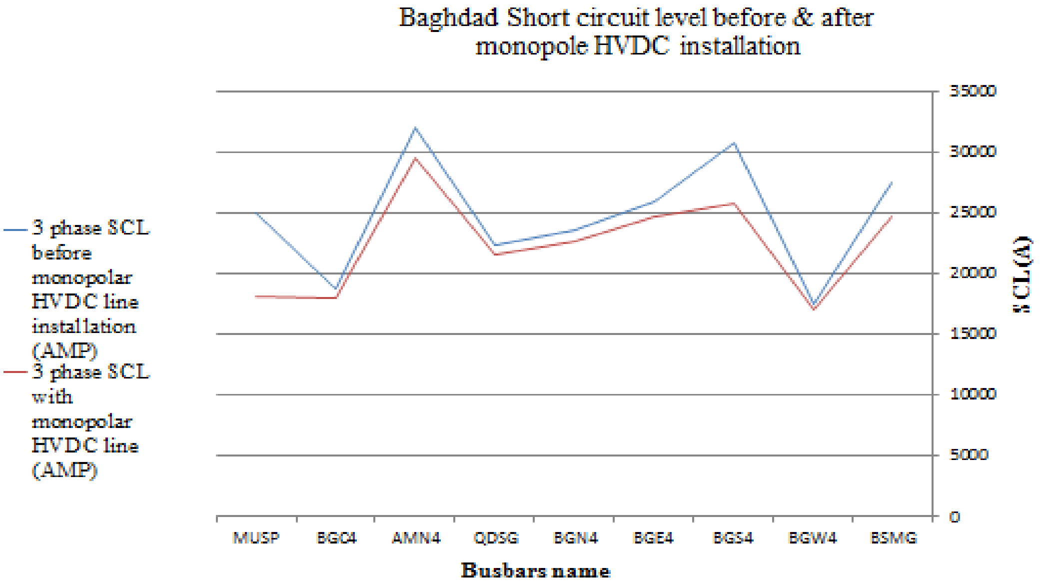


Figure 7. Baghdad Short Circuit Levels with and without Monopole HVDC

6.2. Bipole Results

SCLs in Baghdad region formerly and after bipole HVDC is as shown in Table 7.

Table 7. Baghdad 3 Phase Fault Levels before & after Bipole Construction between KUTP & AMN

NO.	Busbar name	SCL before bipolar HVDC line installation (AMP)	SCL with bipolar HVDC line (AMP)
1	BSMG	27521.2	23626.9
2	BGW4	17512.7	16148.1
3	BGS4	30707.7	26346.6
4	BGE4	25891.8	21543.1
5	BGN4	23547.5	20575.4
6	QDSG	22368	19782.2
7	**AMN**	**31964.9**	**23550.3**
8	BGC4	18740.1	17240.8
9	**KUTP**	**30517.8**	**21855.6**

It is obvious that Alameen SCL is (31964.9 A) and after installing bi- polar HVDC line; between Alameen and KUTP; it is limited to (23550.3A) with difference of (8414.6 A). Similarly, KUTP SCL difference of (8662.2 A) is registered. The graph illustrating the revealed difference is shown in Figure 8.

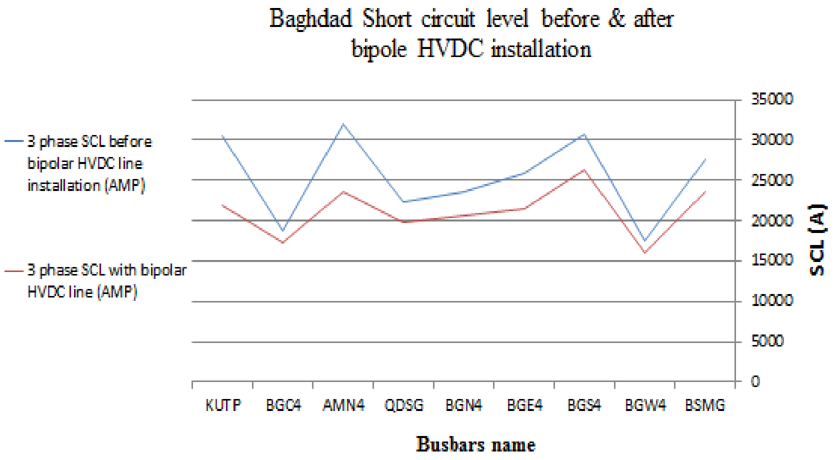


Figure. 8. Baghdad Short Circuit with and without Bipole HVDC

7. Conclusion

Applying PSSE tools with suitable sequence, allow engineer to handle an extensive series of investigations of electric power systems design and operation.

HVDC transmission is used for bulk power transmission with lower losses.

For shorter distances HVDC is necessary where other benefits are useful. Most of the usefulness is to clear severe faults and to limit unacceptable high short-circuit currents.

It is obvious from Table 2 and Table 3 that the bipole line was more effective to limit Baghdad SCL for three reasons:

- The DC cable shown in Figure 6 consists of a forward and a return cable laid in parallel.
- KUT PS station's high capacity causes the highest SCL at its busbar; of the Iraqi super grid out of Baghdad region; then coupling this busbar with the bipole DC network is most effective than other busbars.
- The highest SCL in Baghdad region before HVDC was at Alameen (AMN). This bus bar is linked with Kut PS station using bipole net.

Lastly it is found that bipole affects SCL of the remainder Iraqi grid busbars rather than monopole as shown in Table 8.

Table 8. HVDC Effect on SCL of Iraqi Grid

NO.	Busbar name	SCL before HVDC line (AMP)	SCL with monopole HVDC line (AMP)	SCL with bipole HVDC line (AMP)
1	KRK4	8635.4	8606	8520.7
2	DAL4	17742.5	17153.9	15621.1
3	KUT4	16455.9	16401.5	14561.4
4	KUTP	30517.8	30158.8	23873.4
5	MUSG	22110.7	16802.3	21275.2
6	BAB4	22301.8	18523.7	21664.7
7	GKHER	17549.5	16291.6	17283
8	DWANG	13388	13245.8	13261.3
9	KDS4	19706	19360.9	19398.1
10	NSRP	13642.4	13638.1	13596.7
11	AMR4	9304	9302	9212.9
12	4QRN	9899.7	9899	9857.3
13	HRTP	14435.7	14435.5	14404
14	KAZG	18108.8	18108.7	18080.7
15	RMULG	16610.7	16610.5	16593.3
16	4BSR	15945.7	15945.6	15930.3
17	SHBR	15455.4	15455.3	15441.7
18	4NJB	4833.5	4833.5	4832.9

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