The 1st Regional Conference of Eng. Sci. NUCEJ Spatial ISSUE vol.11,No.3, 2008 pp 396-409

Study the performance of High Voltage Direct Current Transmission using MATLAB

Dr. Jameel K. Abed Al-Jashami
Technical College/Baghdad

Abstract

Some of the electric networks adjacent countries are linked to either the alternating current lines or to direct current lines, that is really depends upon the geographic distance of the linking points and the amount of the used current. In view of rapid and huge increasing of electric power consumption and to shorten the value of losses inside transferring operation besides the electric system steady. Accordingly and due to all we have mentioned the direct current transmission has been established in high voltage for long distance. These lines can be used when the linking points are far- off, and when the frequency for the two required systems are different. Therefore transformation stations are being used at both ending sides to transfer from alternating to direct current and vice-versa. Also a (HVDC) system can be constructed according to stages in proportion with the voltage development and the load requirement. There is always the need to maintain the transformation voltage at ultimate possible value in order to have a high efficiency operation. In this paper the transmission line was represented by using MATLAB program for two different lengths (300,600) Km & different firing angles then comparison is held between **these two lengths according to** efficiency & economical view**.**

1.Introduction

The first DC link was set up in 1954 between the Sweden and the Got land Island. This was a monopole, 100Kv, 20MW, cable system taking use of sea return. In 1961 an under water link was set up between England and France. This was a bipolar 100Kv, 160MW,cable system. Since then more and more high voltage DC systems have been setup. The earlier DC schemes used mercury arc converters .Since 1972 all new HVDC schemes are using thyristors, Table (1) shows some HVDC systems in the world. [1]

The use of an HVDC link in an AC system requires converter stations at each end of the line. The main equipments in a converter station are transformers and thyristor valves.

At the sending end the thyristor converter acts as rectifiers to convert AC in to DC which is transmitted over the line. At the receiving end the thyristor converter acts as inverters to convert DC into AC which is utilized at the receiving end. Each converter can function as rectifier or inverter and thus power can be transmitted in either direction. Since 2000 in Denmark a recent development been the insulated gate bipolar transistor (IGBT) which a development of the mosfet in which removal of current from the gate switches off the through current, there by allowing power to be switched on or off throughout an a.c cycle. The main types of HVDC scheme are distinguished by their DC circuit unipolar, Bipolar links, Back to Back converter.[2]

Table (1) some HVDC system in world. [3]

No.	System	Rated voltage (Kv)	Rated power (Mw)	Length (Km)		Total Km	Years
				OH line	Cable		
1	Gotland (sweden)	100-150	20-30	0	96	96	1954/70
2	USSR	±400	720	470	0	470	1965
3	Southafrica	±266	960	1414	0	1414	1975
4	Delhi	±500	1500	810	0	810	1991
5	Konte Germany -Denmark	400	600	0	170	170	1996
6	Mouticella Texas- Texas	162	600	0	0	0	1998
7	VisbyNas Sweden- Sweden	80	50	0	70	70	1999
8	Thailand - Malaysia	300	300	110	0	110	2002
9	Basslink Australia - Australia	400	600	71.8	298.3	370	2005
10	Norned Norway - Netherland	450	700	0	580	580	2010

Table (2) system using IGBTs.[3]							
No.	Name	Station 1	Station 2	Length Of cable Km	Voltage Kv	Trans. Power Mw	year
1	Tjaereborg	Tjaere- Denemark	Tjaere- Denemark	4.3	9	7.2	2000
2	Direct link	Mullum Australia	Bungalora Australia	59	80	180	2000
3	Cross sound Cable	Newhaven	Shoreham Long Island	40	150	330	2002
4	Troll	Norway	Norway	70	60	8.4	2005

2.merites of DC transmission:-

2.1 Technical advantage:

1. *System stability*: an AC system must remain in synchronism. To maintain stability under transient condition, the length of a 50Hz or 60Hz uncompensated AC line must be less than about 500Km. If series compensation is us`ed, the length can be somewhat longer than this value.
2. *Lesser corona loss and Radio interference:* the corona loss and radio interference especially during bad weather, are lower for DC line as compared to that in an AC line of the same conductor diameter and voltage.
3. The AC system interconnected by a DC line can be controlled independently. They can be completely independent as regarding frequency.
4. *Short circuit current*: the inter connection of two AC systems by an AC line increases the short circuit current in the system sometimes this necessitates the replacement of the existing circuit breakers by the ones that have rating.
5. On the other hand, the contribution of a DC line to the short circuit current is only up to the rated current of the DC line.

The power transmitted between two AC systems with sending and receiving end voltages approximately is given by

$$P = \frac{V_R V_S}{X} \sin \delta \qquad (1)$$

Where δ is the displacement angle between V_S and V_R. In practice δ is limited to about 30^o under steady state to give the margin of 60^o .The power transmitted over an AC link is one half of the theoretical maximum this limitation is not associated with DC links.[4]

2.2 Economic advantages:

DC lines and cables are cheaper than that of AC lines and cables; however the DC line terminal equipment are considerably more expensive than AC line terminal equipments. This is because of the high cost of converters for the DC line. Fig. (1) Shows a comparison between the total cost of

DC and AC transmission. It is seen that for distances above the break-even distance, the total cost of DC transmission is less than the total cost of ac transmission. The DC curve is not as steep as the AC curve because of considerably lower line costs per Km Mediate reactive power compensation has to be taken into account. [5]. The break- even distance is generally different for different projects. For overhead lines the break-even distance generally lies in the rang of 600 – 900Km. For submarine cables the break-even distance lies in the rang of 25 to 50 Km and for under ground cables it lies in the rang of 50 to 100 Km. A. The towers of DC lines are also simpler cheaper and narrower as compared to the towers of AC lines. Fig. (2) Shows the typical transmission line structure. [6**]**

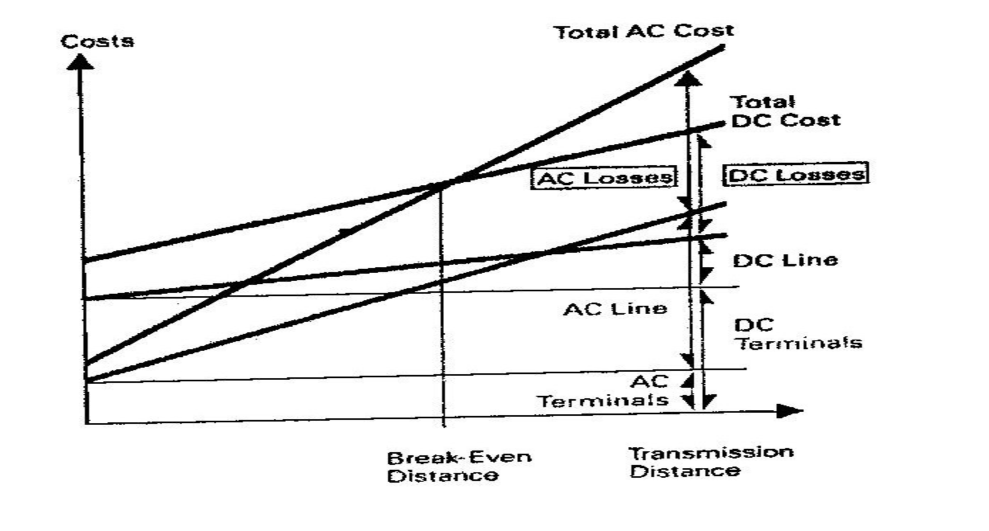


Fig.(1) Comparison between total of cost DC & AC transmission with distance

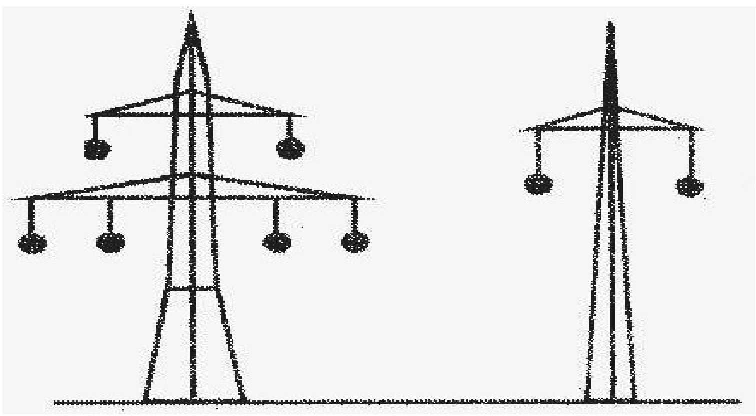


Fig. (2) Typical transmission line structures

3. Construction of DC power stations

3.1- Converter transformer

The converter transformer transforms the ac voltage to a suitable value for feeding the converter. In addition it serves the following functions:

a) Short circuit currents are controlled by suitable impedance valve of these transformers.
b) The reactance of the converter transformer helps in higher order harmonic suppression.
c) By suitable star-star and star- delta connections the required 30^o phase- shift for 12 pulse operation is achieved and reduce filter size with lower cost and this phase shift is produced between the lower and upper 6 pulse bridge of the converter.

3.2- <u>DC reactor</u>

A DC reactor is connected in series with each pole of a converter station. Its inductance lies in the range of 0.4 to 1 H. It serves the following purposes:

a) It decreases harmonic voltage and current in the line.
b) It decreases the incidence of commutation failures in the inverter during dips in the alternating voltage.
c) It smoothens the ripple in the direct current which occurs on the line.
d) It limits the current in the rectifier when a short circuit occurs on the line. The value of inductance of the reactor should be such that a resonance of the dc circuit does occur at power frequency.

3.3- Harmonic filter

The filter arrangement on the AC side of an HVDC converter station has two main duties:

a) To absorbs harmonic currents generated by HVDC converter and thus to reduce the impact of harmonics on the connected A.C SYSTEMS, like A.C voltage distortion and telephone interference.
b) To supply reactive power for compensating the demand of the converter station. Each filter branch can have one to three tuning frequencies.

The amplitude of harmonics decrease with increasing order of harmonics. It is necessary use filters to reduce the harmonic voltage and currents. The DC filters serve only to reduce harmonics on the DC side which must also be limited before entering the line, the reactor is sufficient to limit the magnitude of the harmonics on the side. A non – sinusoidal wave is of the referred to as a complex wave and can be expressed mathematically as equation (2). [7]

$$\mathbf{v = V_O + V_1 Sin(\omega t + \varphi_1) + V_2\, Sin(2\,\omega t + \varphi_2) + \ldots\ldots + V_n Sin(n\omega t + \varphi_n)} \quad (2)$$

Where v is the instantaneous value at any time, Vn is the maximum value of the n^{th} harmonic, φ defines there lattice angular reference and Vo is the mean value .Figure (3)shows typical layout of HVDC station . In 12-pulse valve group operation the orders of the harmonics are 12^{th} and 24^{th} in the DC side expressed as in equation (3) and 11^{th}, 13^{th}, 23^{th}, 25^{th} on the AC side expressed in equation (4).

for

D.C side Degree of harmonics = number of pulses×(n) (3)

And for

A.C side Degree of harmonics = number of pulses× n ±1 (4)

Where (n) is inter equal 1,2,3 ………etc.

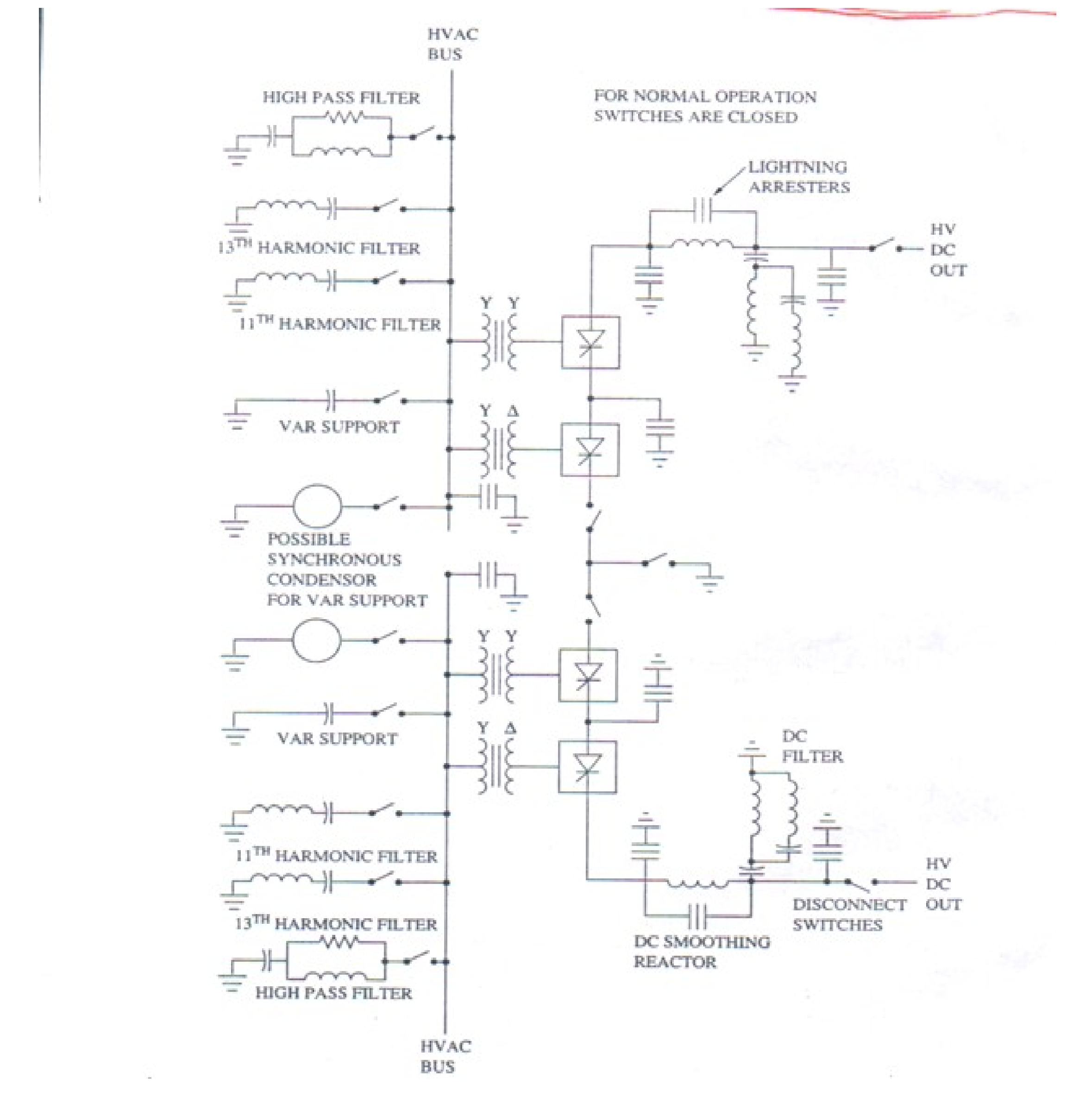


Fig.3 HVDC station Electrical Layout

4 .Mathematical analysis of the bridge circuit

A three-phase arrangement will be described, but most of the analysis will be for n phases so that results are readily adaptable for any system. With no gate control, conduction will take place between the cathode and the anode of highest potential. Hence the output voltage wave is the thick line and the current output is continuous. For six phases the output voltage (V_{dc} represented in equation (5) :

$$V_{dc} = \frac{V_m \sin(\pi/6)}{\pi/6} = \frac{3\sqrt{2}V}{\pi} = \frac{3}{\pi}V_m = 0.995V_m \qquad (5)$$

A positive signal applied to a gate situated between anode and cathode controls. The instant at which conduction commences, and once conduction has occurred the gate exercises no further control. In the voltage waveforms shown in Fig (4) the conduction in the valves has been delayed by an angle α by suitably delaying the application of positive voltage to the gates considering n phases and ignoring the commutation the new direct output voltage with a delay angle of α is:

$$V_{dc}^{/} = V_{dc}\cos\alpha \qquad (6)$$

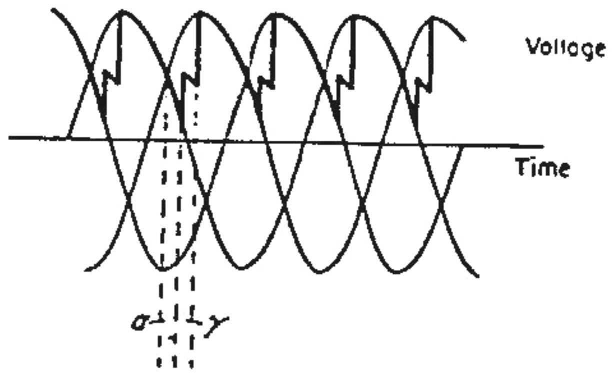


Fig.(4) Waveforms of rectifier with instant of firing delayed by an Angle α by means of gate control.

During the commutation process when two valves conducting simultaneously, the two corresponding secondary phases of the supply transformer are short circuited and if the voltage drop across the valves is neglected the following applies, when two phases of the transformer each of leakage inductance L henries are effectively short-circuited, the short circuit current (Is) is governed by the following equation (in case of six phases):

$$\therefore I_{dc} = \frac{\pi V_{dc}}{6X}\left[\cos\alpha - \cos(\alpha+\gamma)\right] \qquad 7$$

5. System Simulation of simple HVDC 12- pulse transmission

Fig. (5) Shows the 12- pulse HVDC transmission system, this model converter system characteristics with corresponding firing angle. This system consist of AC source system 500KV, 5000 MVA and AC reactor represented the resistance 26Ω connected in parallel with inductance 48H. The AC filter harmonics 600 Mvar designed in four stages, two stages 150 Mvar tuned filter and two stages of 150 Mvar high pass filter used to extract the unwanted harmonics from transformer winding current to give approximately sinusoidal source current. The12- pulse bridge transformer $\mathbf{Y-\Delta, Y-Y}$, 1200MVA, 500/ 200Kv, the reactance of the converter transformer helps in harmonic suppression, the transformer is connected to rectifier 12- pulse thyristor. The triggering of all thyristors must be done simultaneously, in this model the firing angle equal (15^o , 20^o) according to changes in the value of transmission line distance 300, 600Km. The DC reactor 0.5H is used to reduce the ripple in direct current occurs on the line. The function of the inverter in the receiving end is to convert the DC input into AC output, and rejecte the unwanted harmonics by the save DC reactor in the sending end to obtain approximately sinusoidal signal to avoid the network pollutes by harmonics.[9]

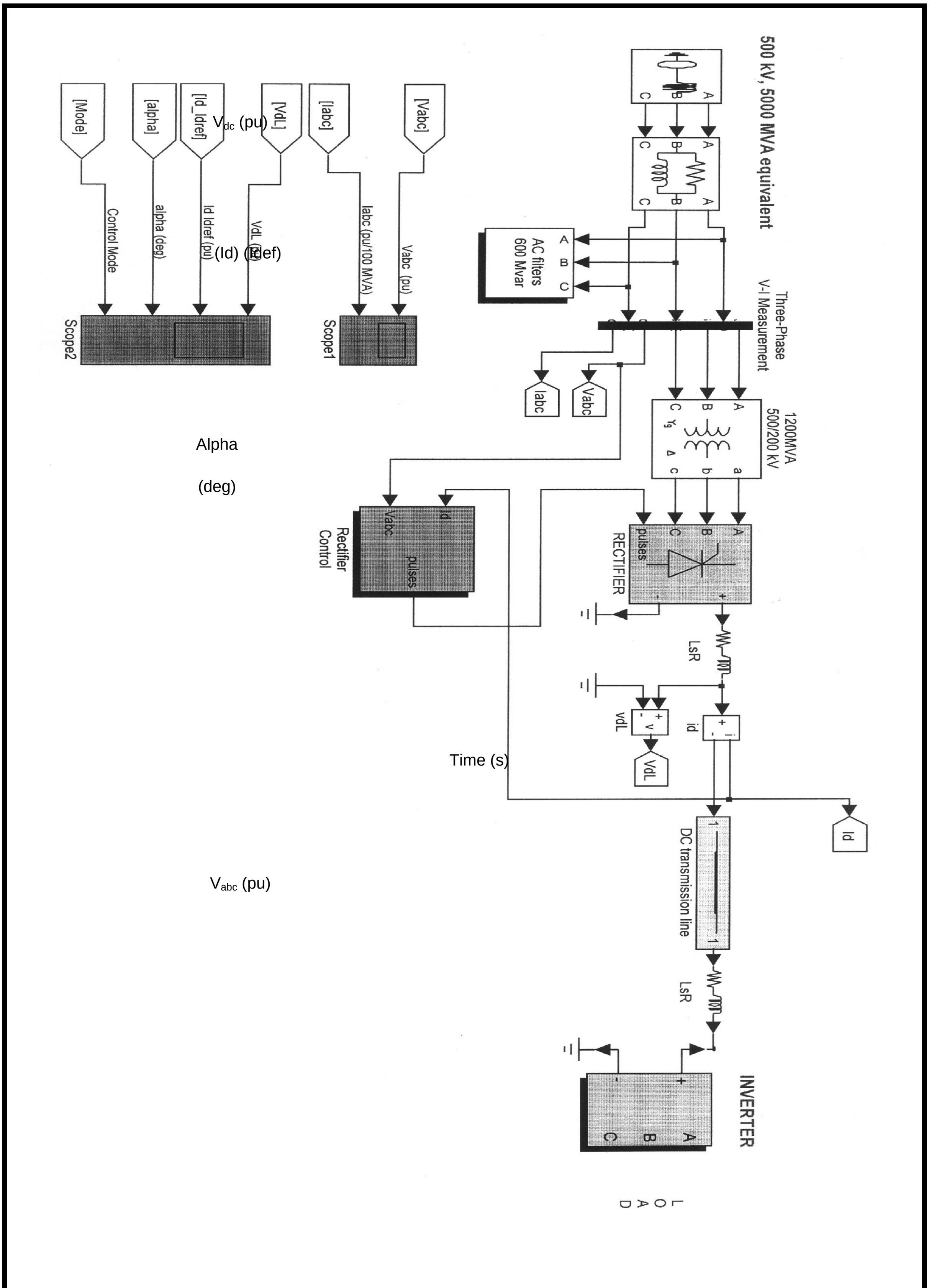
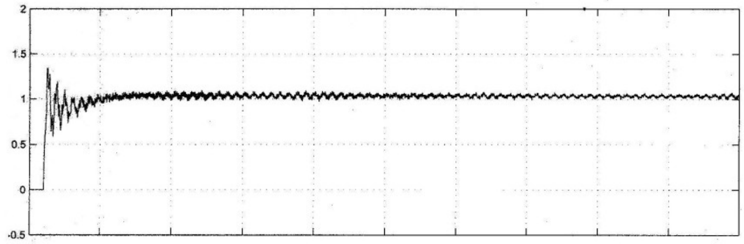


Fig. (5) Simple HVDC 12-pulse transmission system

Case 1

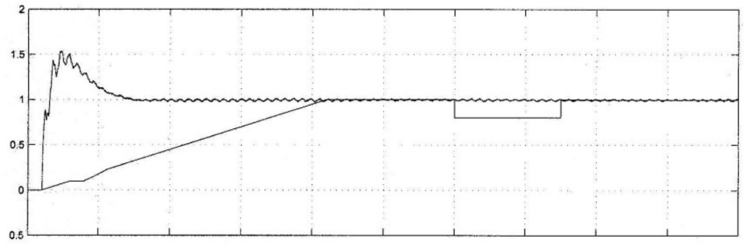
L=300 Km

V_{dc} (pu)

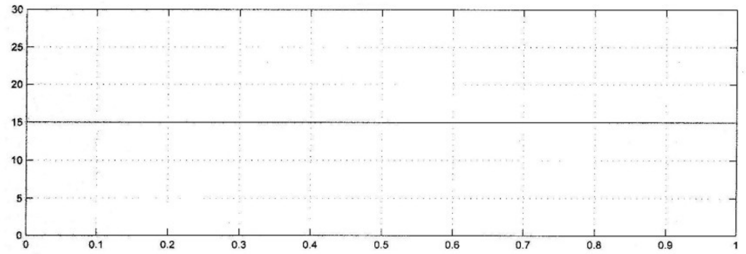


I_{dc} (Idef)

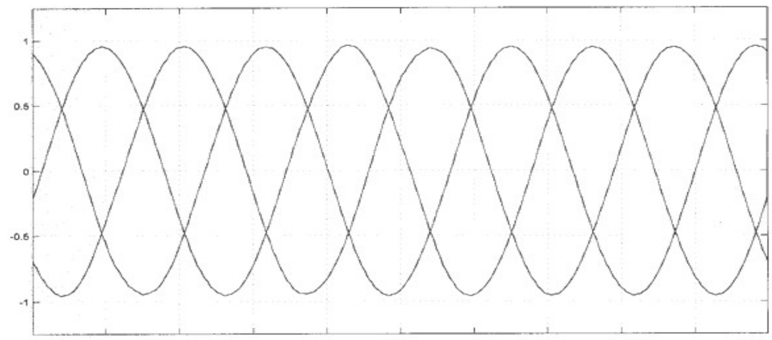
(pu)



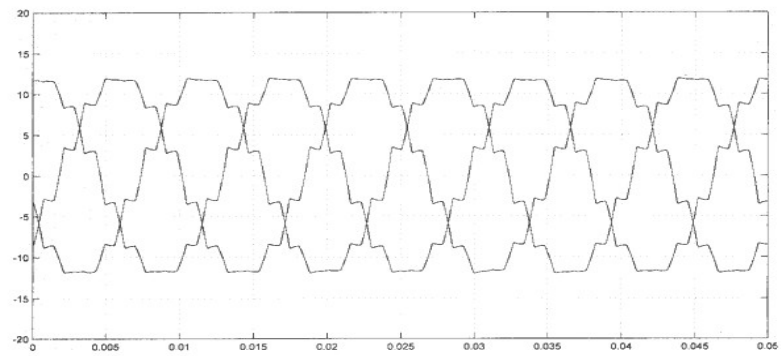
Alpha (deg)



V_{abc} (pu)



I_{abc} (pu)



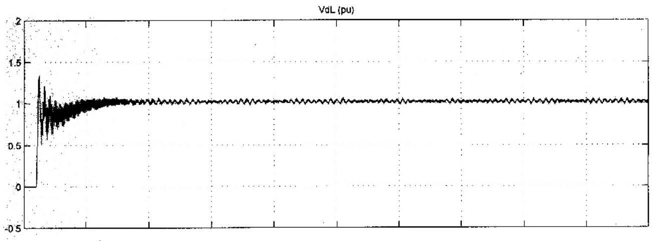
Scope 1-2

Case 2

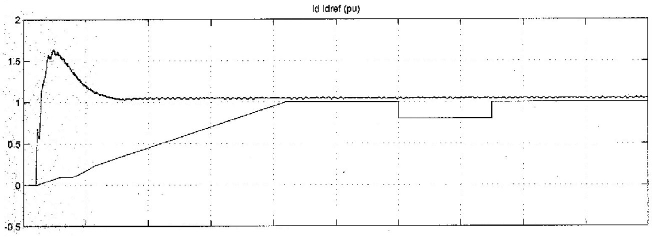
L= 300 Km

α =20^o

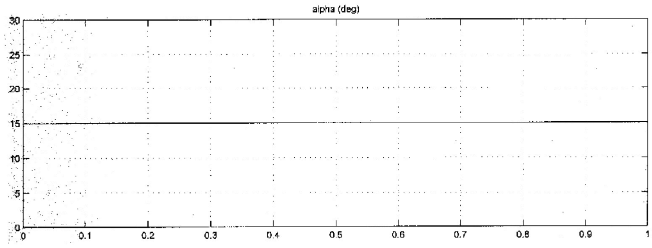
V_{dc} (pu)



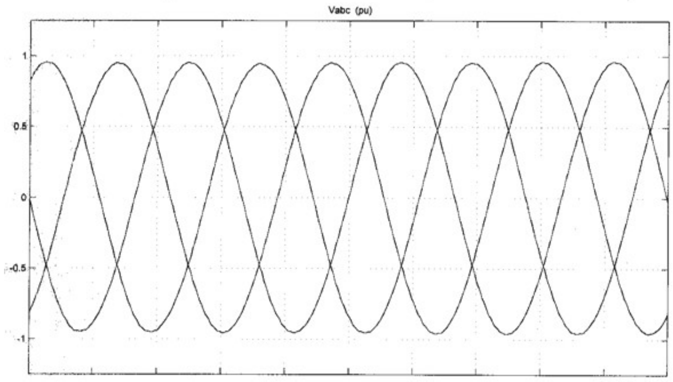
Id (Idef) (pu)



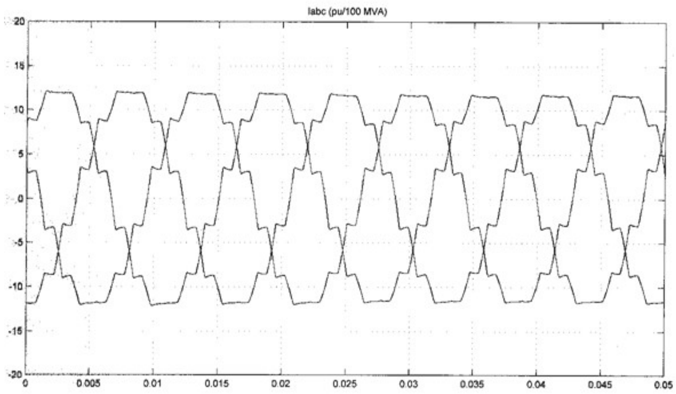
Alph (deg)



V_{abc}(pu)



I_{abc}(pu)



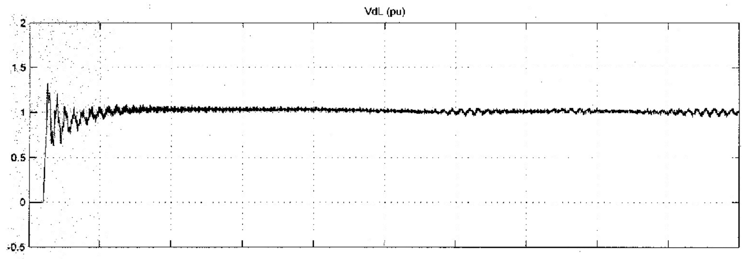
Scope3-4

Case 3

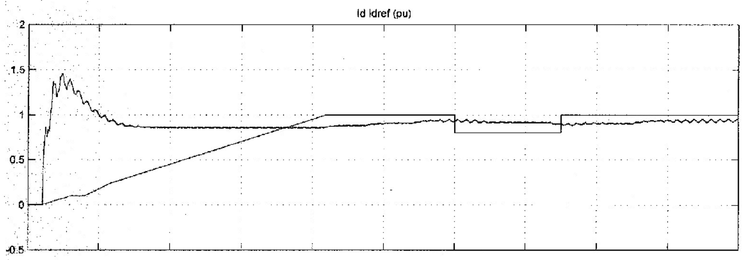
L= 600 Km

α =15^{o}

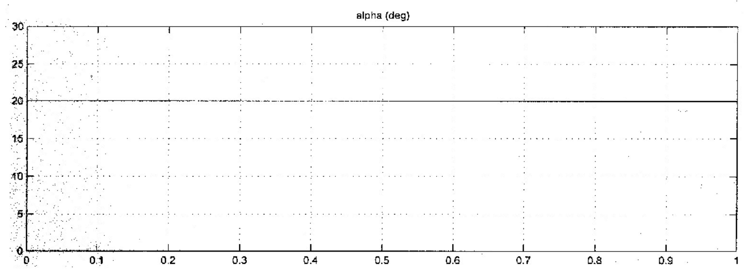
V_{dc} (pu)



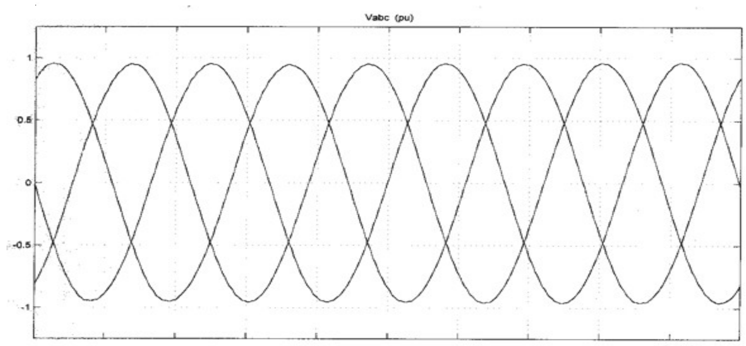
I_{dc} (Idef) (pu)



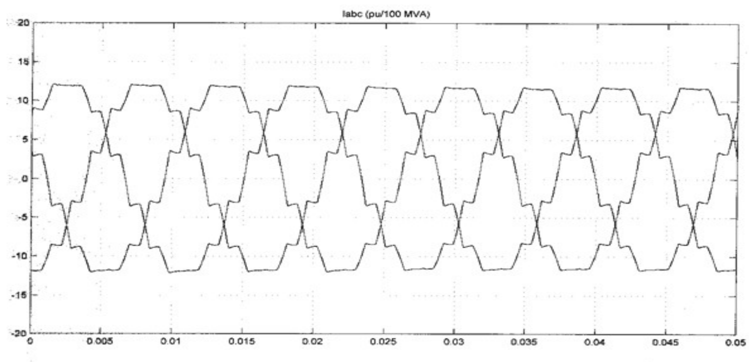
Alpha (deg)



V_{dc} (pu)



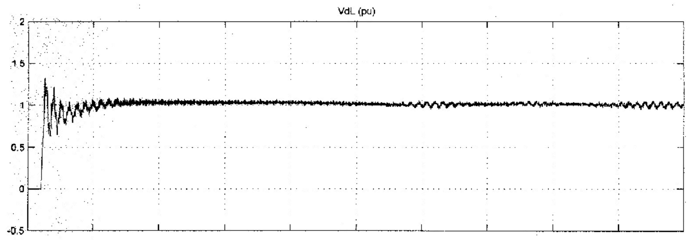
I_{dc} (pu)



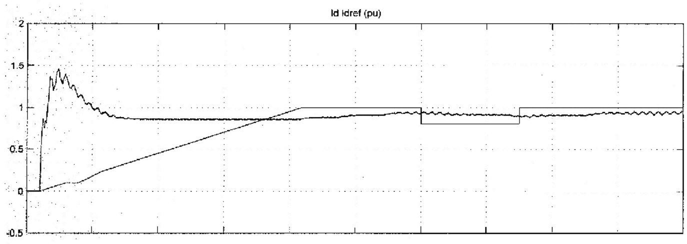
Scope 5-6

Case4
L=600Km
α=20?

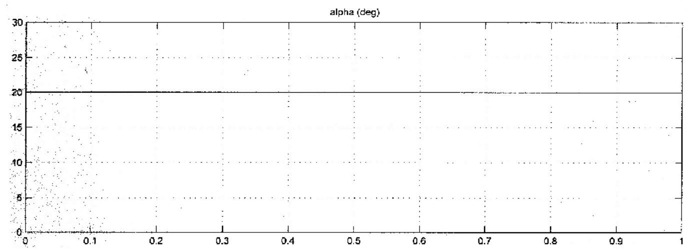
V_{dc}(pu)



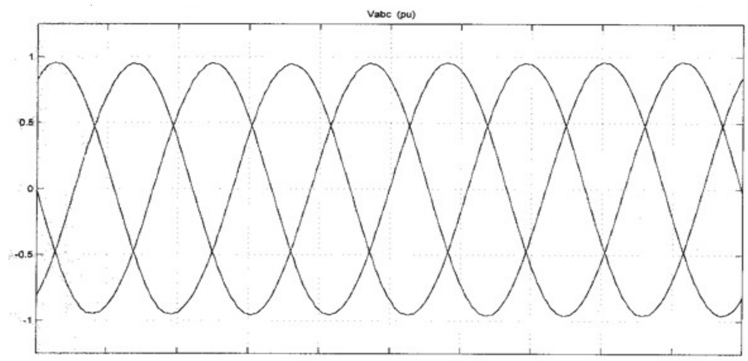
I_{dc}(pu)



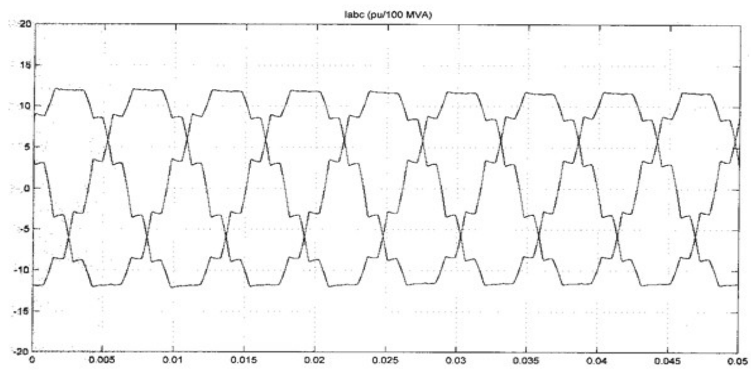
Alpha(deg.)



V_{dc}(pu)



I_{dc}(pu)



Scope 7-8

6 .Results:

The results have been arrangement in table. (3). It is illustrated in the scopes1 to 8, the scale is used 1 p.u/ 100 MVA, these results has clearly demonstrated the modeling steady- state operation. In case (1 , 2) the distance of transmission line is equal 300 Km and firing angle (α) will be changed from $15^o - 20^o$, we take the different values of firing angles but the best values from the view of optimum output and decreases the reactive power in the converter therefore the value of (α) changed $15^o - 20^o$. Then we calculate the value of I_{abc}, V_{abc} represents the input of AC source system and the value of I_d, V_d represents the output of converter (rectifier). If the value of firing angle increasing the value of direct current will be decrease. In case (3,4) the distance of transmission line increasing into 600 Km and used the same value of firing angle have been taken in the case (1,2), the value of direct current and direct voltage on the transmission line will be reduce and the system power transmitted over a DC link is controlled.

Table (3)

Length (Km)	Vabc peak (pu)	Iabc (pu)	Vdc (pu)	Id (pu)	α (deg)
300	0.984	12.3	1.093	1.063	15
300	0.985	12.2	1.011	0.97	20
600	0.982	12.5	1.091	0.968	15
600	0.983	12.4	1.000	0.928	20

Conclusions:

From table (3) the following points can be concluded:

1- **Reactive compensation is not required on a DC line; improved switches would make the control of reactive power of converter possible, permitting it to flow in or out of the converter.**
2- **The switching problem on DC lines lies not only in the need for DC circuit breakers but also in the converters which are essentially a group of synchronously controlled switches.**
3- **Importance of tuned and high pass filters is extracting the unwanted harmonics from trapezoidal transformer winding current to give nearly sinusoidal source current, the scopes (2,4,6,8) illustrated the harmonics in I_{abc} output waves.**
4- **The simulation as developed is very useful in plotting the converter system characteristics and determining the corresponding firing angle in easy and iterative manner.**
5- **HVDC system can be constructed according to stages in proportion with the voltage development and the load requirements for example Nelson revere project in Canada, this stages used the transmission line in low voltage and very long line .**

References:

1. R.B.Gupta, “*power system analysis and design*”, Rajkamal electric press Dalhi, 1993.

2. B.M.Weedy “*electric power systems*” , Biddles ,Britian1998

3. Wikipedia, , "*high voltage direct current*" ,Free encyclopedia 2005.

4. William D.Sevenson “*Element of power system analysis*”,Tienwah press,Singapore ,1990

5.Narain G,"*HVDC*" Hingorani in IEEEE spectrum magazine,1996.

6. Siemens, I,“high voltage direct current Basics” Emmevierre , M.V.R ,soc, coop a.r. 2005

7. Cyril, W .Lander (second edition) “power electronics” , McGraw-Hill press1987

8.Luces M. Faulken berry and Walter Coffer ,"Electrical power distribution and transmission ,R.R Donnellely & sons ,Virginia,1996.

٩.H.P.Lips , Fellow IEEE, “Technology for HVDC thyristor valves” , 2002

تحليل وتمثيل خطوط النقل التي تستخدم التيار المستمر باستخدام برنامج خاص بالحاسبة الاكترونية

الدكتور المهندس جميل كاظم عبد الجشعمي /الكلية التقنية/بغداد

المستخلص:-

هناك بعض الاقطار المتجاورة تربط الشبكات الكهربائية مع بعضها البعض لغرض رفع درجة الوثوقية بالشبكة وتعتمد ربط هذه الشبكات على المسافه الجغرافية بين نقاط الربط وكمية القدرة المطلوبة. مع التقدم العلمي والحاجة الى المزيد من نقل الطاقة الكهربائية وتقليل الخسائر نتيجة النقل برزت الحاجة الى استخدام نقل الطاقة الكهربائية بأستخدام التيار المستمر وخاصة للفولتيات العالية والمسافة الطويلة وكذلك عند اختلاف الترددات بين نقاط الربط . لذا يتم استخدام محطات للتحويل في كلا نهايات نقاط الربط.وهي تقوم بتحويل التيار المتغير الى التيار المستمر بأستخدام المعدلات والمستمر الى متغير بأستخدام المغيرات والعكس بالعكس وحسب متطلبات الحمل مع مراعاة الناحية الاقتصادية من حيث الفولتيات العالية والمسافات الطويلةللحصول على الكفاءة المطلوبه. في هذا البحث تم تمثيل خط نقل نموذجي باستخدام برنامج خاص بالحاسبة الاكترونية و بطول (٣٠٠)(٦٠٠) كم ولمختلف زوايا القدح و المقارنة بينهما من حيث الكفاءة والناحية الاقتصادية.