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Sequential Technique Based AC-DC Power Flow Analysis for Medium and Long Transmission Systems

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Abstract **- The modern electric utility industry is currently more and more attention to HVDC transmission as a practical alternative to HVAC transmission. It is useful supplement to rapid and smooth power flow control, more economical choice and small power loss for long transmission systems. An electric power system with DC links requires a special analysis for power flow study that takes their characteristics into account. This paper presents an AC-DC load flow algorithm to solve a power flow problem with DC links. This algorithm is tested using medium and long transmission standard test systems. Digital results using the proposed sequential method are compared with a previous work. The effect of load change in HVDC control parameters is studied. A comparison between HVAC and HVDC transmission systems based on power losses are also performed.**

Index Term **– HVDC, sequential method, load flow AC-DC, power losses, load change, MATLAB SIMULINK.**

I. INTRODUCTION

The power transmission through HVDC technology is now Emerging and experiencing rapid increases in the voltage, Power carrying capacity and length of transmission lines [1].

DC line can carry as much power with two conductors as an AC line with three conductors of the same size. This implies that for a given power level DC line requires less row, less losses (about 67%of that for AC with the same current carrying capacity of conductors), simpler and cheaper towers and reduced conductor and insulator costs. The absence of skin effect with DC is also beneficial in reducing power losses marginally. DC cables also have lower losses than AC cables [2-3].

In the case of an AC power system, operation of a power system with DC transmission lines requires a power flow analysis to compute bus voltages, bus angles, active power flow, and reactive power flow for specified generation and load conditions. With DC transmission lines installed in AC systems, an additional analysis is required for a hybrid AC-DC power flow [4].

In general, two basic approaches have been used for solving the AC-DC power flow equations: sequential and Simultaneous methods.

Simultaneous solution technique is used for solving the AC-DC power flow equations [4-6]. The equations pertaining to the AC system and the equations pertaining to the DC system are solved together. In the Simultaneous method, the equations describing the various DC systems' components namely DC network, the DC terminals and their controls are incorporated with the equations of the AC system. The collective set of equations of the AC-DC systems is simultaneously solved by the Newton-Raphson method. the sequential method is used to solve the AC-DC load flow. Where the AC and DC parts are solved separately in successive manner. The solution of the AC load flow is obtained by the Newton Raphson method. The solution is then passed to the DC load flow algorithm to calculate two key parameters: transformer taps and converter angles. The solution of the DC load flow is then fed back to the AC problem. These two sub operations are interactively solved until the solution has been converged. Sequential method is used where the AC and DC systems are solved separately and the coupling between the AC and DC system is accomplished by injecting an equivalent amount of real and reactive power at the terminal AC buses. Sequential approach is easier to be developed and integrated into existing AC based power flow software.

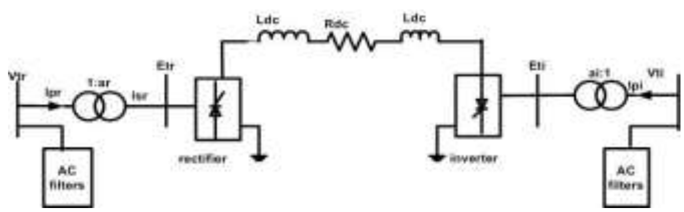

Fig. 1 Two terminal mono-polar HVDC system

II. DC SYSTEM MODEL.

The equations describing the steady state Behaviour of a mono polar line commutated converter HVDC link of Fig. 1and its equivalent circuit in Fig. 2 can be summarized as follows [2,4]:

The direct current flows from rectifier to the inverter is:

$$Id = \frac{Vd_r - Vd_i}{Rdc} \tag{1}$$

Where:

Vd_r, Vd_i are the DC voltage at rectifier and inverter terminal respectively and are calculated as:

$$Vd_r = Vdo_r * cos\alpha - B_r * \frac{3X_{cr}}{\pi} * Id \tag{2}$$

$$Vdo_r = \frac{3\sqrt{2}}{\pi} * B_r * a_r * E_{tr} \quad (3)$$

$$Vd_i = Vdo_i * cos\gamma - B_i * \frac{3X_{ci}}{\pi} * Id \quad (4)$$

or

$$Vd_i = Vdo_i * cos\beta + B_i * \frac{3X_{ci}}{\pi} * Id \quad (5)$$

$$Vdo_i = \frac{3\sqrt{2}}{\pi} * B_i * a_i * E_{ti} \quad (6)$$

Active power equations at rectifier and inverter are:

$$Pd_r = Vdr * Id \quad (7)$$

$$Pd_i = Vd_i * Id_i = Vd_r * Id - Id^2 * R_{dc} \quad (8)$$

$$Id_i = Id_r - Id_{mar} \quad (9)$$

Where

Id_{mar}: The current margin between rectifier and inverter current values usually set as 10 % of DC line current rating [2].

Etr, Eti: the converter transformer secondary voltage at rectifier and inverter respectively.

B: quantity denotes the number of six-pulse bridges at any side.

X: denotes the commutation reactance of the converter transformer.

α, γ and β :denote the firing angle of the rectifier and the extinction angle of the inverter and firing angle of inverter respectively.

Rdc: is the equivalent resistance of the DC line.

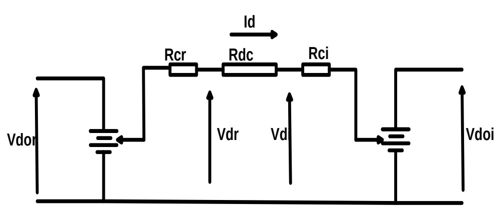

Fig. 2 equivalent circuit of HVDC system

For calculating the reactive power consumption of the converters it is necessary to calculate the overlap angle. The current phase shift is not only caused by firing angles, but also the overlap also contributes to the current delay, the overlap angles ψ_r, ψ_i can be calculated as in [9,12].

$$\psi_r = arcos\left(cos\alpha - \frac{2 * X_C * Id}{\sqrt{2} * E_{tr}}\right) - \alpha \quad (10)$$

$$\psi_i = arcos\left(cos\beta - \frac{2 * X_C * Id}{\sqrt{2} * E_{ti}}\right) - \beta \quad (11)$$

Now the reactive power at the inverter and rectifier sides can be calculated as:

$$Q_r = Pd_r\, tan\left[arcos\left[\frac{cos(\alpha) + cos(\alpha + \psi_{r})}{2}\right]\right] \quad (12)$$

$$Q_i = Pd_i\, tan\left[arcos\left[\frac{cos(\beta) + cos(\beta + \psi_{i})}{2}\right]\right] \quad (13)$$

The developed HVDC model has three independent equations (1, 2, and 4) in terms of the following seven variables defined by:

$$X = [Vd_r \quad Vd_i \quad a_r \quad a_i \quad \alpha \quad \gamma \quad Id]^T \quad (14)$$

It is observed that there are total seven unknown variables which need to be solved to completely determine the HVDC link performance. However, we have only three independent equations (1, 2, and 4). Therefore, any four variables need to be specified, according to the following valid control equations [11]:

1-For constant DC current control, the control equation is:

$$Id - Id^{sp} = 0 \quad (15)$$

2-For constant DC voltage control, the control equation is:

$$Vd - Vd^{sp} = 0 \quad (16)$$

3-For constant firing& extinction angles control, the control equations are:

$$cos\alpha - cos\alpha^{sp} = 0 \qquad at\ rectifier \quad (17)$$

$$cos\gamma - cos\gamma^{sp} = 0 \qquad at\ inverter \quad (18)$$

4-For constant power control, the control equation is:

$$Id * Vd - Pd^{sp} = 0 \quad (19)$$

5-For constant tap changer control, the control equation is:

$$a - a^{sp} = 0 \quad (20)$$

DC model can be summarized as:

$$R(X, E_t) = 0 \quad (21)$$

From equations (2) and (3) the mismatch equation R_1 can be written as:

$$R_1 = V_{dr} - \frac{3\sqrt{2}}{\pi} * a_r * E_{tr} * \cos\alpha + B_r * \frac{3X_{cr}}{\pi} * Id \quad (22)$$

From equations (15) to (20), the mismatch equations R2 and R_3 can be written as:

$$R_2\ for\ control\ equation \quad (rectifier) \quad (23)$$

$$R_3 for\ control\ equation \quad (rectifier) \quad (24)$$

From equations (4) and (6) the mismatch equation R4 can be written as:

$$R_4 = V_{di} - \frac{3\sqrt{2}}{\pi} * a_i * E_{ti} * \cos\gamma + B_i * \frac{3X_{ci}}{\pi} * I_{di} \quad (25)$$

From equations (15) to (20), the mismatch equations R5 and R_6 can be written as:

$$R_5 \quad \text{for control equation} \quad \text{(inverter)} \quad (26)$$

$$R_6 \quad for\ \text{control equation} \quad \text{(inverter)} \quad (27)$$

From equation (1), the mismatch equation R7 can be written as:

$$R_7 = V_{dr} - V_{di} - Id * Rdc \quad (28)$$

In matrixes form:

$$[R] = \quad [j_1] \quad [\Delta X] \quad (29)$$

Where

$$j_1 = \frac{\partial R}{\partial X} \quad (30)$$

$$X_k^{m+1} = X_k^m + \Delta X_k^{m+1} \quad (31)$$

Where m is the DC iteration number.

III. AC SYSTEM MODEL

Assume a system having n buses; the injected current at the bus (k) can be expressed as:

$$I_k = \sum_{j=1}^{n} Y_{kj} V_j \quad (32)$$

The complex power at K-bus is given as

$$S_k = V_k I_k^* = P_K + jQ_K \quad (33)$$

$$P_K - jQ_{K=} V_k^* I_k \quad (34)$$

$$P_K = |V_k| \sum_{j=1}^{n} |Y_{kj}| |V_j| \cos(\delta_j - \delta_k + \theta_{kj}) \quad (35)$$

$$Q_k = |V_k| \sum_{j=1}^{n} |Y_{kj}| [V_j] \sin(\delta_j - \delta_k + \theta_{kj}) \quad (36)$$

Where P_k, Q_k are the active and reactive power values injected at K-bus respectively. Thus, at each bus there are two equations but four variables namely P, Q, δ and V . Actually, at each bus we have to specify two variables and solve for the remaining two unknowns. Thus, for an n bus system 2n equations are solved. These 2n equations are nonlinear equations as they involve products of variables as well as sine and cosine functions. Newton Raphson method is used here to solve AC load flow, where the AC system model consists of sets of mismatches of active power and reactive power equations as follow:

At AC bus (k) active and reactive power mismatch equations are:

$$\Delta P_k = P_k^{sp} - \sum_{J=1}^{n} P_{kj} \quad (37)$$

$$\Delta Q_k = Q_k^{sp} - \sum_{j=1}^{n} Q_{kj} \quad (38)$$

Where:

$$P_k^{sp} = P_{Gk} - P_{Lk} \quad (39)$$

$$Q_k^{sp} = Q_{Gk} - Q_{Lk} \quad (40)$$

$$P_{kj} = V_k^2 Y_{kk} \cos\theta_{kk} + V_k V_j Y_{kj} \cos(\theta_{kj} - \delta_k + \delta_j) \quad (41)$$

$$Q_{kj} = -V_k^2 Y_{kk} \sin\theta_{kk} - V_k V_j Y_{kj} \sin(\theta_{kj} - \delta_k + \delta_j) \quad (42)$$

Equations (37, 38) are modified for converter AC bus as follow:

$$\Delta P_k = P_k^{sp} - \sum_{j=1}^{n} P_{kj} - P_{dck} \quad (43)$$

$$\Delta Q_k = Q_k^{sp} - \sum_{j=1}^{n} Q_{kj} - Q_{dck} \quad (44)$$

Where P_{dck} ,Q_{dck} the active and reactive power of HVDC system at AC buses, Assuming lossless converter transformer at rectifier and inverter, thus Equations (7, 8, 12, and 13) give active and reactive power values at rectifier and inverter AC buses.

Equations of AC load flow can be replaced by:

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = \begin{bmatrix} \frac{\partial P}{\partial \delta} & \frac{\partial P}{\partial |V|} \\ \frac{\partial Q}{\partial \delta} & \frac{\delta Q}{\delta |V|} \end{bmatrix} \begin{bmatrix} \Delta \delta \\ \Delta |V| \end{bmatrix} \quad (45)$$

OR

$$\begin{bmatrix} \Delta \delta \\ \Delta |V| \end{bmatrix} = \begin{bmatrix} \frac{\partial P}{\partial \delta} & \frac{\partial P}{\partial |V|} \\ \frac{\partial Q}{\partial \delta} & \frac{\partial Q}{\partial |V|} \end{bmatrix}^{-1} \begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} \quad (46)$$

Then at AC bus k, the bus voltage and angle at the next iteration can be calculated as:

$$|V_k|^{N+1} = |V_k|^N + |\Delta V_k|^{N+1} \quad (47)$$

$$\delta_k{}^{N+1} = \delta_k{}^N + \Delta \delta_k{}^{N+1} \quad (48)$$

Where N is the AC iteration number

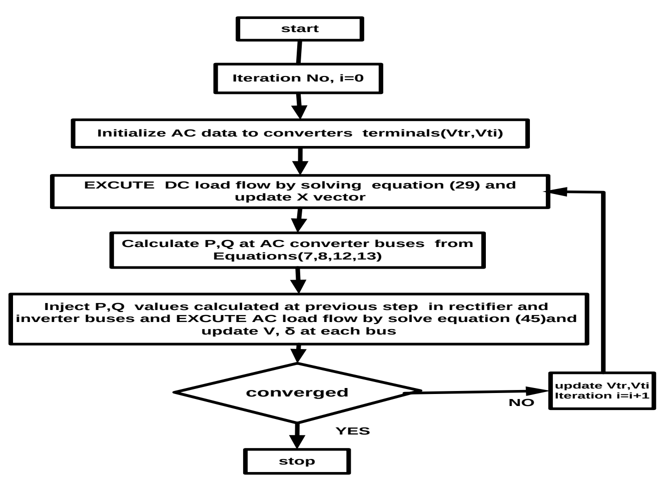

Fig. 3 flowchart of sequential AC-DC load flow.

IV. PROPOSED SEQUENTIAL AC-DC LOAD FLOW ALGORITHM.

Sequential method is used to solve AC-DC load flow, The AC load flow is performed by the load flow using Newton –Raphson method as given in section (*III*). The result of AC load flow is used as the input of The DC load flow (V_{tr}, V_{ti}) as shown in fig.4 which show amatlab Simulink subsystem accommodates a two-terminal HVDC link taking into account tap changers of converter transformers, containing the DC power flow algorithms represented by set of equations given in section (*II*). The output of the DC load flow is the active and reactive power at the rectifier and inverter AC buses (Pac_R, Qac_R, Pac_i, Qac_i) is injected at rectifier and inverter buses to execute AC load flow and so on until convergence occurs. The Flowchart depicted in fig.3 gives the steps of proposed sequential load flow algorithm.

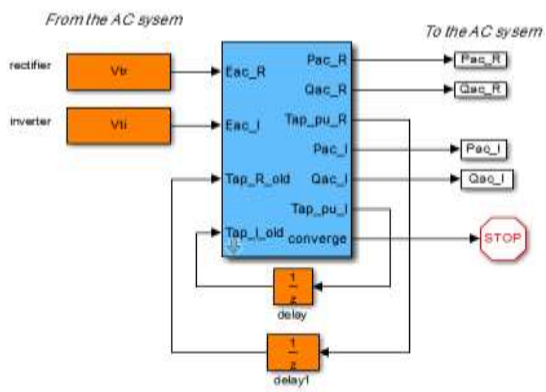

Fig. 4 HVDC load flow subsystem.

V. SIMULATION RESULTS AND DISCUSION

Two standard test systems are employed to study AC-DC load flow. The test systems are IEEE9-bus system which contains medium length transmission line between buses. The result obtained is compared with those obtained in [9].The 29-bus multi machine system having long transmission lines is also utilized [11].

A- IEEE9-BUS TEST SYSTEM.

In IEEE9-bus system, the 100Km transmission line between bus4 and bus5 is replaced by a two terminal monopolar line commutated converter HVDC transmission line as shown in fig. 5, having characteristic given in Table I.

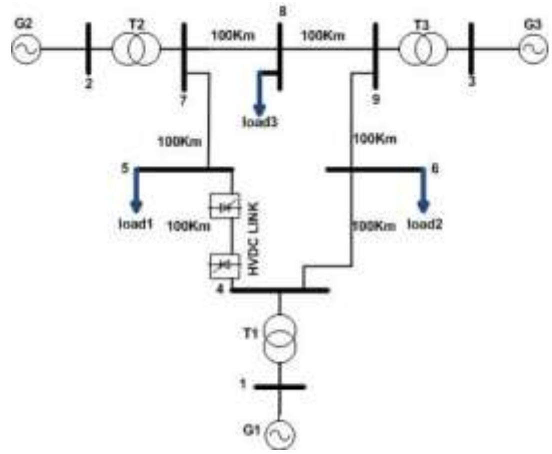

Fig. 5 IEEE9-bus system with integrated HVDC link

Table I
HVDC link data of IEEE9-BUS system

	Rectifier	Inverter
Connection bus	4	5
Commutation reactance(Xc)/bridge	2.75 Ω	3.25 Ω
Minimum control angle	α =7	γ =10
Transformer regulation range	.9375-1.125	.912-1.012
Number of tap position	15	8
Resistance of DC line	0.5Ω	
Rated DC power at rectifier	13MW	
Rated DC voltage at inverter	300KV	

Converters connected in both sides are represented by a two-six pulse bridge connected in series to represent a12-pulse bridge converter. All parameters of converter transformers in both sides are entered to the program.AC filters is used in AC terminals of rectifier and inverter, and it is adjusted to give total reactive power about 40-60% of active power rating of HVDC line which about 6 MVAR at rectifier side and 6 MVAR at inverter side.

A main program is written in Matlab package which run AC and DC load flow algorithms sequentially [12]. This program is applied to the IEEE9-bus system Simulink model with integrated HVDC link.

The main rectifier control mode is constant DC power mode, and it is set at 13MW to be received at the inverter station. The current margin is set as 0.0043KA, and the (TCC) tap changer control mode is used to hold the angle α between 7 and 12 degree at the rectifier. The main control mode at the inverter is chosen to be DC voltage, set at 300 KV, and the TCC is used to hold the angle γ between 10 and 17degree at the inverter.

Convergence within a tolerance of 0.0001 in AC load flow and DC load flow is achieved in 3 iteration steps within very small time about 50 sec .

The result of proposed sequential DC and AC load flow algorithm and result of previous work in [9] is shown in tables II and III respectively.

Table II
DC LOAD FLOW RESULT.

	Rectifier		inverter	
	proposed	previous	proposed	previous
DC Voltage(KV)	300.01	299.497	299.99	299.476
Control angles(degree)	α =10.30	7.596	γ =14.63	10.000
Transformer tap position	1.0125	0.938	0.9625	1.150
Real power(MW)	13.00	12.978	12.998	12.977
Reactive Power(MVAR)	2.419	1.804	3.438	2.355
Dc line current(KA)	Proposed= 0 .042		Previous=0.043	

Table III
AC LOAD FLOW RESULT.

Bus No.	Voltage(pu)		Angle(deg)		P MW	Q MVAR
	proposed	previous	proposed	previous		
1	1.040	1.040	0.00	0.00	75.12	-3.07
2	1.025	1.025	-1.18	2.140	162.79	40.78
3	1.025	1.025	-1.74	0.179	84.79	-4.88
4	1.043	1.037	-2.29	-2.297	13.01	-2.42
5	0.911	0.851	-19.12	-15.03	-112.0	-53.44
6	1.025	1.019	-5.90	-5.290	-90.00	-30.00
7	1.005	0.991	-6.89	-3.162	0.00	0.00
8	1.002	0.992	-8.18	-5.516	-100	-35.00
9	1.029	1.025	-4.44	-2.535	0.00	0.00

From AC and DC load flow results of IEEE9-bus system using sequential method itis noted that this method is more easy and fast convergence than modified newton Raphson method [9].It is noted that the voltage at the inverter bus is 0.851pu (195.928) kv [9], the proposed method while using the proposed sequential method the voltage at inverter is improved to 0.911pu (209.62) kv.

B- 29-BUS MULTI MACHINE TEST SYSTEM.

In 29-Bus multi machine system the 800km AC line between buses LG27 and MTL7 is replaced by two terminal HVDC line (500KV,2KA), as shown in fig. 6, having characteristic given in table IV[11].

Table IV
HVDC LINK DATA OF 29-BUS MULTI MACHINE SYSTEM

	Rectifier	Inverter
Connection bus	LG27	MTL7
Commutation reactance(Xc)/bridge	7.5Ω	7.5Ω
Minimum control angle	α =14	γ =20
Transformer regulation range	.9375-1.125	.9125-1.0875
Number of tap position	15	14
Resistance of DC line	12.6Ω	
Rated DC power at rectifier	1000MW	
Rated DC voltage at inverter	500KV	

In this section comparison between power losses and voltage profile in case of using HVAC line and using HVDC line between buses LG27 and MTL7 is obtained. The effect of system load change on the DC load flow result is also investigated. AC filters in this case is adjusted to give reactive power to HVDC system of 550MVAR at rectifier and inverter sides. The main control mode is the power control at rectifier side, and it is set at 1000MW. TCC (tap changer control) is used to hold α angle between 14 and 17 degrees. The main control mode at inverter side is voltage control set at 500KV. TCC control is used to hold the γ angle between20 and 23 degrees.

AC load flow is performed with AC line and with HVDC line between buses MTL7 and LG27.

In case of AC line convergence within tolerance of 0 .0001 is achieved after 4 iteration and in case of HVDC line convergence within tolerance of 0.0001 in AC load flow and DC load flow is achieved after 3 iteration. Results of sequential DC and AC load flows are shown in tables V and VI respectively.

Table V
DC LOAD FLOW RESULT.

	Rectifier	inverter
DC Voltage(KV)	524.63	499.40
Control angles	α =14.47	γ =22.69
Transformer tap position	0.9500	0.9975
Real power(MW)	1050.52	1000
Reactive Power(MVAR)	458.7	561.6
Dc line current(KA)	2.0023	

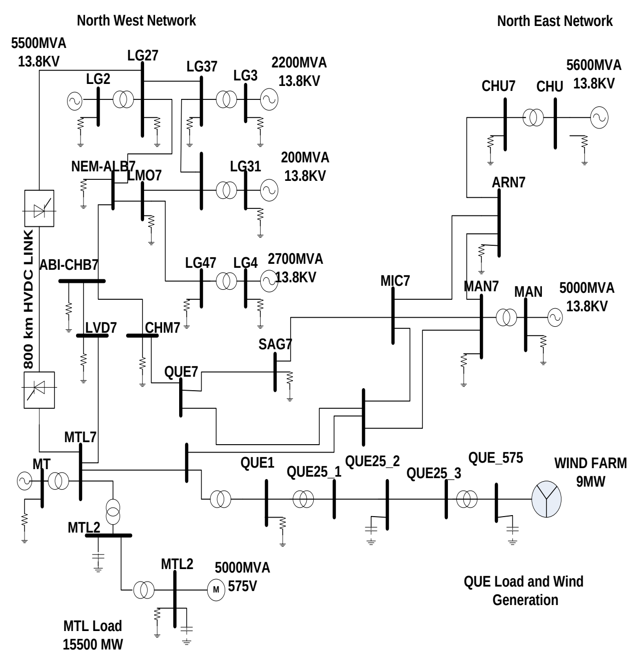

Fig.6 29-Bus multi machine system with integrated HVDC Link

Table VI
AC LOAD FLOW RESULT

	With HVAC Line				With HVDC line			
Bus	V (pu)	δ (deg)	P (MW)	Q (MVAR)	V (pu)	δ (deg)	P (MW)	Q (MVAR)
AB1_CHB7	1.120	5.7800	-28.2800	2632.00	1.062	0.71	-25.41	2365.91
ARN7	1.079	19.300	77.9000	3188.00	1.061	12.99	75.4	3083.30
CHM7	1.119	2.7300	50.4000	1307.00	1.064	-3.42	45.56	1180.35
CHU7	1.016	35.200	-52.970	535.000	1.011	29.13	-52.47	530.00
CHU_13.8	1.000	10.900	4708.62	-644.30	1.000	4.88	4708.62	-420.34
LG27	1.031	23.700	-18.900	1665.30	1.011	24.00	-13.44	994.3
LG2_13.8	1.000	0.0000	5565.00	-1439.0	1.000	0.00	5267.03	-466.98
LG31_13.8	1.000	1.3000	170.000	-20.140	1.000	0.27	169.6	4.45
LG37	1.014	25.500	-2.2300	-332.20	0.999	24.43	-2.17	-322.62
LG3_13.8	1.000	0.7400	1685.53	-232.80	1.000	-0.29	1685.53	37.47
LG47	1.028	23.100	-2.2800	-211.30	1.009	21.01	-2.20	-203.59
LG4_13.8	1.000	-1.000	2359.00	-585.30	1.000	-3.01	2359.51	-159.83
LMO7	1.054	19.900	-12.800	992.620	1.024	17.65	-12.12	937.21
LVD7	1.128	-3.700	75.5000	2815.50	1.069	-11.19	67.87	2531.42
MAN7	1.041	14.800	-15.700	352.110	1.023	8.33	-15.22	339.78
MAN_13.8	1.000	-9.400	4240.00	-1645.0	1.000	-15.92	4239.84	-877.77
MIC7	1.076	12.800	-12.800	1162.20	1.050	6.37	-12.26	1106.73
MTL2	1.073	-47.00	-72.200	3380.00	1.030	-57.19	-66.52	3117.54
MTL7	1.073	-13.00	-46.300	3448.50	1.033	-22.53	-37.90	2559.24
MTL_13.8	1.000	-37.00	4240.00	-2983.0	1.000	-46.82	4239.84	-1289.99
MTL_25	1.057	-84.00	-16053.0	-302.60	1.013	-94.87	-15693	-325.96
NEM_ALB7	1.091	12.600	-35.2000	1721.50	1.042	9.39	-32.13	1569.9
QUE1	1.077	-43.00	-6011.0	-11.500	1.027	-54.85	-6010.8	-10.42
QUE7	1.090	-5.900	-48.900	3977.60	1.042	-14.11	-44.39	3631.23
OUE_25_1	1.083	-71.00	0.00000	0.00000	1.031	-80.49	0.000	0.0000
QUE_25_2	1.114	-69.00	0.00000	5.00000	1.058	-77.58	0.000	4.510
QUE_25_3	1.113	-66.00	0.00000	0.00000	1.055	-74.22	0.000	0.000
QUE_575	1.106	-64.00	7.95000	-2.0100	1.047	-72.49	7.940	-2.19
SAG7	1.094	6.5700	3.27000	-96.270	1.050	0.35	3.010	-88.74
1	1.082	-42.00	0.00000	0.00000	1.029	-50.58	0.000	0.0000
TOTAL LOSSES			1066.00	23055.7			848.64	19824.25

From AC-DC load flow result of 29-Bus multi machine system illustrated in tables (V)and(VI), it is noted that the total active power losses is decreased from 1066MW in case of HVAC line to 848.64MW in case of HVDC line causing to saving in power generation.

C-EFFECT OF LOAD CHANGE ON THE HVDC OPERATING PARAMETERS:

In case of 29- Bus multi machine system the total available generation capacity is 27000MW, and the total load is 23000MW.The most loads concentrated at two buses (MTL7 and QUE7). The MTL load subsystem connected to the MTL7 bus (MTL2, MTL_13.8, MTL_25 buses) absorbs about 15500MW.

Table VII

EFFECT OF LOAD CHANGE ON HVDC CONTROL PARAMETERS WITH CONSTANT POWER AT RECTIFIER AND CONSTANT VOLTAGE AT INVERTER

	rectifier			inverter		
MTL buses loading condition	Firing angle` (degree)	Transformer tap range	Reactive power (MVAR)	extinction angle` (degree)	Transformer tap range	Reactive power (MVAR)
60%	14.92	0.9875	462.30	25.19	1.0875	606.40
70%	16.79	0.9750	489.30	23.22	1.0875	570.70
80%	15.35	0.9750	468.30	21.70	1.0750	544.70
90%	15.49	0.9625	470.40	22.18	1.0375	552.80
100%	14.67	0.9500	458.70	22.69	0.9875	561.60
110%	12.33	0.9375	428.30	21.73	0.9250	545.10

From table (VII), when the load changes, the voltage at each bus will change and so the DC load flow result will change in which control parameters of HVDC link must be changed to satisfy the conditions of constant power at rectifier and constant voltage at inverter, Reactive Power absorbed by converters is increased with increasing of firing angle and extinction angle at rectifier and inverter respectively. When the load decreases the voltage at rectifier and inverter AC buses will increase which lead to changing the values of transformer tap ratio and firing angles at both sides of HVDC link. In case of 29-Bus Multi Machine system the maximum available generation is about 27000MW, which about 1.17%of total connected load in the system so when the load is increased to 120% the load flow program will show error message in which generation can't cover the total loads in the system.

VI. CONCLUSION

This paper presents HVDC model equations for steady state stability analysis with AC filters and tap-changers are taken in account. Also, an algorithm for the solution of AC-DC load flow for two terminal line commutated converter HVDC systems. This algorithm is defined by sequential AC-DC load flow, and it is easily implemented in matlab Simulink program and very flexible compared with simultaneous methods and modified newton Raphson method. The problem of voltage drop at inverter station can easily solved using the proposed sequential method. Simulation results show that the more effected parameters in operation of HVDC systems with AC system are the converter transformer tap range and the firing angle in both sides of HVDC link. The effect of load change in HVDC system control parameters is very important to design converters and its transformers of HVDC system over wide range of different operation condition.

VII. REFERENCES

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