Power Flow Analysis Of AC – DC Power Network Using Numerical Methods

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Abstract- The HVDC system is adopted due to the limitations in HVAC such as reactive power losses, stability etc. HVDC technology provides qualities that make it particularly appealing for specific transmission applications such as massive electricity delivery across greater distances, interconnections which are asynchronous, lengthy submarine cable crossovers, and power flexibility that is rapid. Thus, High Voltage Direct Current transmission lines must be modelled and included in the Alternating Current power flow estimation for the entire AC-DC system. The conventional approach involves solving AC-DC system using Simultaneous technique in which the equations for AC and DC power systems are solved together. Due to computation burden of Simultaneous technique, the Sequential approach is adopted in which AC and DC power flow equations are solved independently, The AC and DC systems are linked by infusing an equal quantity of actual and reactive power into the AC buses at the terminals. In this work, an IEEE 5 bus system in which HVDC system is linked to buses 4 and 5 (Bus 4 has a rectifier, whereas Bus 5 has an inverter) and an IEEE 30 bus system with HVDC link between buses 9 and 28 (Bus 9 has a rectifier, whereas Bus 28 has an inverter) are taken as sample systems for performing AC-DC power flow analysis. The numerical methods for assessing AC-DC power flow, such as Gauss Seidel and Newton Raphson, are implemented using MATLAB programming. The results obtained for different combinations complement with the results stated in the literature. The future work shall include the application of recurrent neural network for AC-DC power flow analysis.

Keywords – High Voltage Direct Current, High Voltage Alternating Current, Simultaneous Technique, Sequential Technique, Gauss Seidel, Newton Raphson, Recurrent Neural Network

I. INTRODUCTION

1.1 Introduction –

Nikola Tesla and Thomas Edison, two highly talented innovators, engaged in a war in the late 1880s for the supremacy of AC (Alternating Current) and DC (Direct Current) systems, respectively. However, because to the various benefits of AC over DC at the time, the former was driven out of the competition, and AC triumphed.[1] Nevertheless, traditional HVAC transmission systems have certain drawbacks, including lesser dependability in providing electric power, environmental concerns, efficiency, power dissipation, infrastructure costs, and, most importantly, the system's voltage stability. The significant issues that arise as a result of voltage stability are caused by massive power dissipation in long-distance transmission lines[2]. DC has unquestionably shown its superiority to the AC system in areas such as long-distance transmission, energy storage systems, and so on. Due to the deployment of renewable energy technologies, power generation, for which AC was previously thought to be superior over DC, is now leaning towards DC.[1]

Because of its greater stability, lengthy HVDC transmission is preferable than HVAC transmission e.g. i) precision control instantaneously, ii) the ability to link several synchronized zones in a flexible manner, iii) the transmission range distance is limited by the reactive power flow caused by excessive cable capacitance in submarine cables, iv) constant frequency control, power redistribution in the AC system, and dampening capabilities to provide further stability to the AC power network.[3] As a result, researchers are working on a hybrid distribution system that will include both AC and DC grids. Some recent researches have highlighted the benefits of using DC power in combination with AC power in distribution systems.[1] As HVDC is incorporated into the HVAC network, a novel power flow is formed that is more intricate. The resulting equation is a mixed equation of AC and DC power flow. The AC–DC power flow problem can be solved in two ways: (1) simultaneously or unified, or (2) sequentially or alternating. The sequential technique, which solves the AC system equations and the DC system equations independently in each iteration and then successively uses the interface variables computed from the AC power flow until convergence is achieved. [4]

The sequential approach of an AC-DC system is described in this paper. At the terminal AC buses, the DC system is recognized as actual and reactive power injections. The AC and DC equations are solved independently in this manner, and the power flow utilizing the Gauss Seidel and Newton Raphson methods for AC power flow should be altered to include DC equations in the AC systems. As a result, this research proposes a more straightforward and accurate method for resolving AC-DC power flow.

1.2 Literature Review –

The modelling of AC/DC converters and the technique for including the equations for DC conversion and transmission lines in NR AC system power flow were described by D. A. Braunagel and L. A. Kraft. The DC equations are provided in per unit format that is consistent with the per unit AC equations, and they may be solved concurrently rather than serially. The assumptions employed in the development of the equations describing the AC/DC converters are also included in this work.[5]

A. Panosyan and B. R. Oswald improvised the well-known Newton-Raphson approach for power flow analysis to obtain compatibility for AC - DC systems with integrated DC links in the AC network. The elements of the residual vector and Jacobian matrix for the AC network are preserved and are simply supplemented with a new vector and matrix that describe the changes caused by the AC connection. The AC real and reactive power at the AC - DC buses, as well as their dependence on the AC system variables, are included in the modified Jacobian equation.[6]

El-Nobi, G. El-Saady, A. Ibrahim and Ahmed H. Okilly presented the AC/DC algorithm to handle a power flow problem with DC linkages using a sequential method. The sequential technique is utilized, in which the AC and DC systems are solved independently and the AC and DC systems are coupled by infusing an equal quantity of actual and reactive power into the terminal AC buses. It is easy to create and incorporate a sequential technique into current AC-based load flow systems.[7]

A novel technique to AC-DC power flow was described by T Smed and G.B. SheblC. The converters are treated as voltage-dependent loads, and the power flow equations' dc variables are omitted. For hybrid AC/DC systems, a simple and reliable mechanism for quick decoupled power flow is proposed. Extended variable methods are unified methods that are difficult to design and combine with advances in ac power flow solution approaches, such as the rapid decoupling method.[8]

H. Fudeh and C. M. Ong unveiled a novel ac-dc power-flow technique for multiterminal AC/DC systems that employs a unique way to solving the multiterminal DC system's equations. This study highlights crucial characteristics such as discrete taps, the contrast between planned voltage and scheduled angle controls, fixed taps and extended phase controls, and current.[9]

II. AC-DC POWER FLOW ANALAYSIS

2.1 Modelling of HVDC system –

For a suitable model of a HVDC system, few assumptions considered as in are:

a.   At the terminal bus bar, the three AC voltages are symmetrical and sinusoidal.
b.   The operation of the converter is precisely balanced.
c.   The voltages and direct currents are both smooth.
d.   The magnetizing admittance is disregarded since the converter transformer is lossless.
e.   Constant active and reactive power injections at the two terminal buses in the AC system demonstrate the integration of the DC connection into the AC load flow[10].

Based on the foregoing assumptions, the equivalent circuit of a system with HVDC link (with converter at i[th] bus and inverter at j[th] bus) is shown in figure 2.1. and the equations pertaining to the HVDC link are as follows;
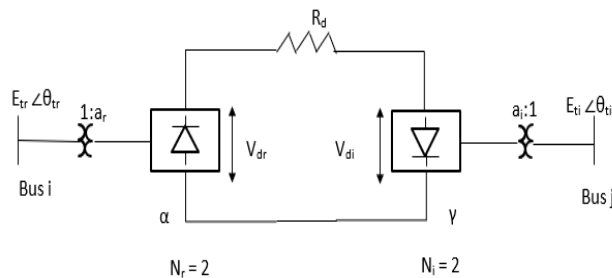

Fig. 2.1 Equivalent circuit of HVDC system

$$V_{dr} = (3\sqrt{2}/\pi)\ N_r\ a_r\ E_{tr}\ \cos\varphi_r = V_{dor}\ \cos\varphi_r \qquad -----(2.1)$$

$$V_{dr} = V_{dor}\ \cos\alpha - (3/\pi)X_{cr}\ N_r\ I_d \qquad -----(2.2)$$

$$V_{di} = (3\sqrt{2}/\pi)\ N_i\ a_i\ E_{ti}\ \cos\varphi_i = V_{doi}\ \cos\varphi_i \qquad -----(2.3)$$

$$V_{di} = V_{doi}\ \cos\gamma - (3/\pi)\ X_{ci}\ N_i\ I_d \qquad -----(2.4)$$

$$I_d = (V_{dr} - V_{di})/R_d \qquad -----(2.5)$$

The subscripts 'r' and I in the preceding equations designate the rectifier and inverter sides, respectively.

Where ,

E_{tr} (E_{ti})	: AC terminal voltage at rectifier (inverter)
a_r (a_i)	: Transformer tap ratio at rectifier (inverter)
N_r (N_i)	: Number of 6 pulse converters connected in series at rectifier (inverter) side
X_{cr} (X_{ci})	: Individual transformer leakage impedance at rectifier (inverter)
φ_r (φ_i)	: Power factor angle at rectifier (inverter)
α	: Firing angle
γ	: Extinction angle
R_d	: DC link resistance

However, proper solution variables must be chosen to solve the aforementioned equations. As a result, the total set of solution vectors for a two-terminal HVDC connection is

$$Xc = [V_{dr}\ V_{di}\ I_d\ a_r\ a_i\ \cos\alpha\ \cos\gamma\ \varphi_r\ \varphi_i] \qquad\qquad -----(2.6)$$

According to equation (2.6), there are nine unknown variables in total that must be addressed in order to fully identify the HVDC connection. However, as shown in equations (2.1)-(2.5), we only have 5 independent equations. As a result, out of the nine unknown variables, four must be defined before and the other five can be solved using equations (2.1)-(2.5). The control specification can be used to specify these four variables. There are numerous combinations of control specifications, and the following are some of the ones that are of importance in this study:

Combination 1: α , P_{dr} , γ , V_{di}
Combination 2: a_r , P_{dr} , a_i , V_{di}
Combination 3: α , V_{dr} , γ , P_{di}

The remaining 5 variables may be solved using numerical methods employing these four given control values from equations (2.1)-(2.5).

2.2. AC-DC Power Flow –

Either of the following two techniques can be used to solve the power flow problem of an AC system with one or more HVDC links:

- Simultaneous solution technique

- Sequential solution technique.

In the simultaneous solution technique, the equations for the AC system and the equations for the DC system are solved concurrently. In the sequential approach, the AC system and DC systems are solved separately, and the AC and DC systems are linked by injecting an equal quantity of actual and reactive power at the terminal AC buses. In other words, the impact of an HVDC connection between buses i and 'j' of an AC system (rectifier at bus i and inverter at bus 'j') is introduced into the AC system by injections $P^{(R)}{}_{DCi}$ and $Q^{(R)}{}_{DCi}$ at the rectifier bus 'i' and $P^{(I)}{}_{DCj}$ and $Q^{(I)}{}_{DCj}$ at bus 'j' (the super scripts 'R' and 'I' denote the rectifier and inverter respectively).

Therefore, at bus 'i' and 'j', the net injected power is: $P_{Totali} = P_{ACi} + P^{(R)}{}_{DCi}$; $Q_{Totali} = Q_{ACi} + Q^{(R)}{}_{DCi}$; $P_{Totalj} = P_{ACj} + P^{(I)}{}_{DCj}$; $Q_{Totalj} = Q_{ACj} + Q^{(I)}{}_{DCj}$. The AC system is solved again with these net injected powers, and the analogous injected powers are calculated ($P^{(R)}{}_{DCi}$, $Q^{(R)}{}_{DCi}$, $P^{(I)}{}_{DCj}$, $Q^{(I)}{}_{DCi}$) and the total injected powers (P_{Totali} , Q_{Totali} , P_{Totalj} , Q_{Totalj}) are updated. This approach of solving AC and DC system values alternately is performed until the discrepancies between two subsequent iterations in AC and DC system quantities are less than a threshold value[11].

Despite the fact that the simultaneous approach gives a system solution without switching between AC and DC, the sequential strategy is actually rather straightforward to execute. In the same way as Gauss Seidel (G-S) and Newton Raphson (N-R) may be used to solve power flow problems in pure AC systems [12]-[14], they can also be used to solve power flow problems in AC - DC systems.

2.2.1 Sequential AC-DC Power Flow –

　　　For solving AC – DC power flow, the Sequential technique is used, in which the AC and DC power flow equations are calculated separately and the AC and DC systems are coupled by infusing an equivalent quantity of active and reactive power at the terminal AC buses. One of the following strategies can be used to solve the sequential AC – DC power flow:

- Gauss Seidel Method
- Newton Raphson Method

2.2.2 Power Flow Algorithm –

　　　The flowchart for the AC/DC power flow using Gauss Seidel technique and Newton Raphson method is shown in figure 2.2 and 2.3 respectively. The steps for power flow analysis using Gauss Seidel and Newton Raphson are given below.

For combination 1,

Step 1: Read the data from the AC and DC systems, as well as the initial values for both.
Step 2: With α, P_{dr}, γ, V_{di} specified, Calculate V_{dr} and I_d.
Step 3: Calculate φ_r and φ_i using V_{dr} and V_{di} respectively
Step 4: Using φ_r and φ_i, Calculate the real and reactive power injections (P_{di}, Q_{dr}, Q_{di}) in the bus.
Step 5: Calculate the net injected power at rectifier side bus and inverter side bus.
Step 6: Form Y_{bus} for AC system
Step 7: Calculate Q_g for generator buses and check for Q limit.
Step 8: Compute V_{bus} using Gauss Seidel method / Newton Raphson method for AC buses and check for convergence. If not converged go to step 7. If converged go to step 8.
Step 9: Calculate the a_r and a_i after finding final solutions of the voltage magnitudes.
Step 10: Result for AC-DC power flow and find the transmission losses.

For combination 2,

Step 1: Read the data from the AC and DC systems, as well as the initial values for both. With flat start, E_{tr} and E_{ti} are known.
Step 2: With a_r, P_{dr}, a_i, V_{di} specified, Calculate V_{dr} and I_d.
Step 3: Calculate P_{di} using V_{di} and I_d.
Step 4: Calculate the net real power injected at rectifier side bus and inverter side bus.
Step 5: Form Y_{bus} for AC system.
Step 6: Calculate $\cos\varphi_r$, $\cos\varphi_i$, α, γ, Q_{di} and Q_{dr} using E_{tr} and E_{ti}.
Step 7: Calculate the net injected reactive power at rectifier side bus and inverter side bus.
Step 8: Calculate Q_g for generator buses and check for Q limit.
Step 9: Compute V_{bus} using Gauss Seidel method / Newton Raphson method for AC buses and check for convergence. If not converged go to step 6. If converged go to step 10.
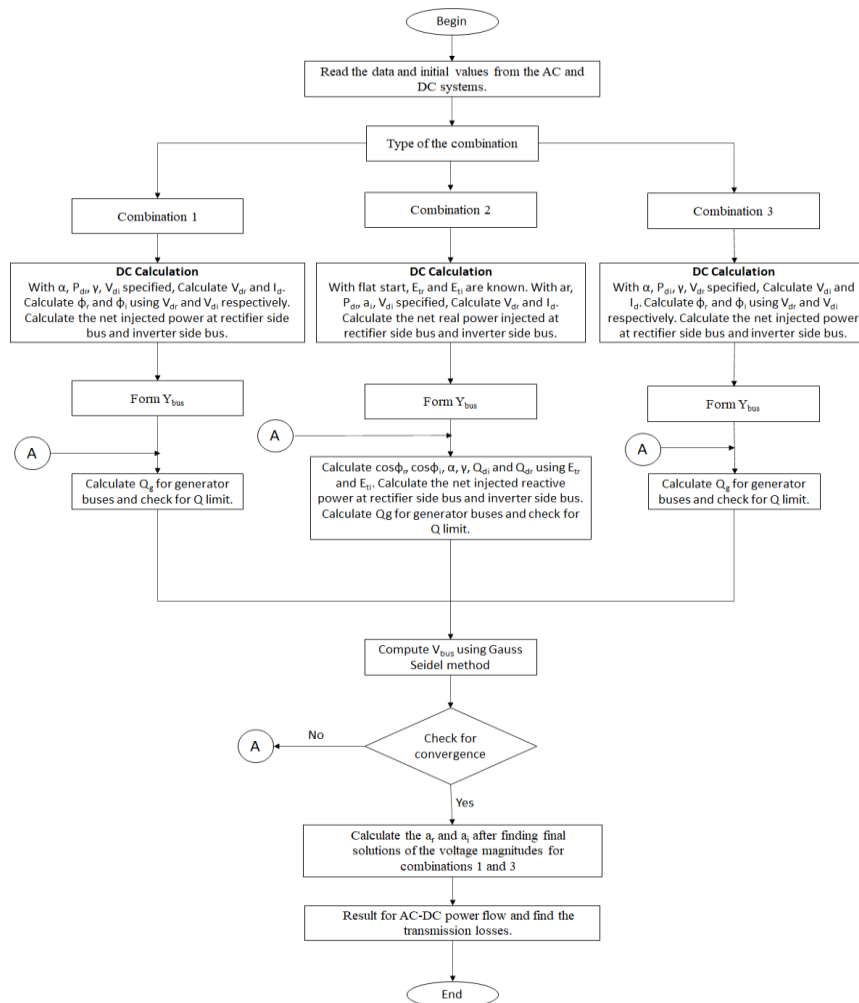Step 10: Result for AC-DC power flow and find the transmission losses.

Figure 2.2 Flowchart for the AC/DC power flow using Gauss Seidel technique

For combination 3,

Step 1: Read the data from the AC and DC systems, as well as the initial values for both.
Step 2: With α, P_{di}, γ, V_{dr} specified, Calculate V_{di} and I_d.
Step 3: Calculate φ_r and φ_i using V_{dr} and V_{di} respectively
Step 4: Using φ_r and φ_i, Calculate the real and reactive power injections (P_{dr}, Q_{dr}, Q_{di}) in the bus.
Step 5: Calculate the net injected power at rectifier side bus and inverter side bus.
Step 6: Form Y_{bus} for AC system
Step 7: Calculate Q_g for generator buses and check for Q limit.
Step 8: Compute V_{bus} using Gauss Seidel method / Newton Raphson method for AC buses and check for convergence. If not converged go to step 7. If converged go to step 9.
Step 9: Calculate the a_r and a_i after finding final solutions of the voltage magnitudes.
Step 10: Result for AC-DC power flow and find transmission losses
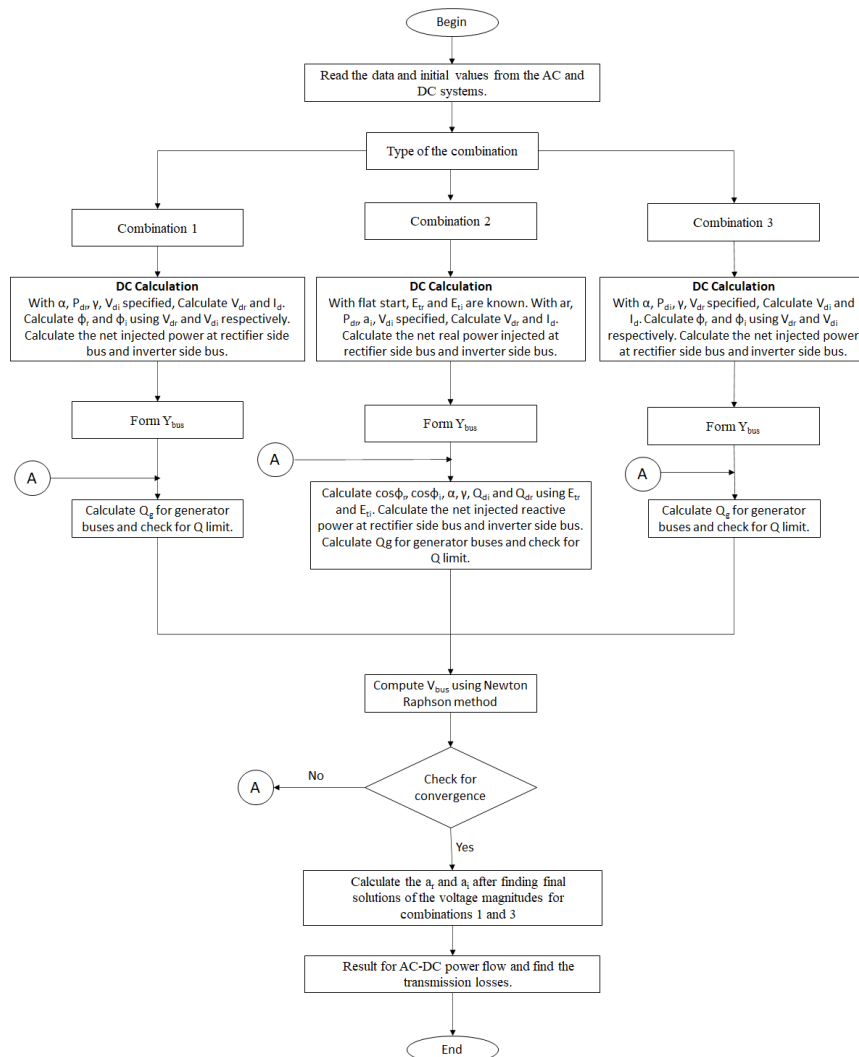
Figure 2.3 Flowchart for the AC/DC power flow using Newton Raphson technique

III. RESULTS AND DISCUSSION

For AC – DC power flow analysis, IEEE 5 bus system samples with two terminal HVDC link connected between bus 4 and bus 5 (rectifier at bus 4 and inverter at bus 5) and IEEE 30 bus system samples with two terminal HVDC link connected between bus 9 and bus 28 (rectifier at bus 9 and inverter at bus 28) are used. The AC-DC power flow is solved using an IEEE 5 bus system. A bipolar HVDC connection is established between buses 4 and bus 5 in this system (rectifier at bus 4 and inverter at bus 5). Other pertinent information regarding this connection is as follows: $R_d = 10.0\ \Omega$; $N_r = N_i = 2$; $3/\pi\ X_{cr} = 3/\pi\ X_{ci} = 6.0\ \Omega$. The sample IEEE 5 bus system is shown in figure 3.1.

Figure 3.1 IEEE 5 bus system with HVDC link between buses 4 and 5

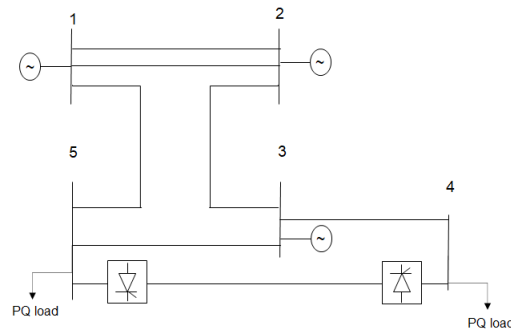The AC-DC power flow is also solved using an IEEE 30 bus system. A two terminal HVDC connection is established between buses 9 and bus 28 in this system (rectifier at bus 9 and inverter at bus 28). Other pertinent information regarding this connection is as follows: $R_d = 10.0\ \Omega$; $N_r = N_i = 2$; $3/\pi\ X_{cr} = 3/\pi\ X_{ci} = 6.0\ \Omega$. The sample IEEE 30 bus system is shown in figure 3.2.
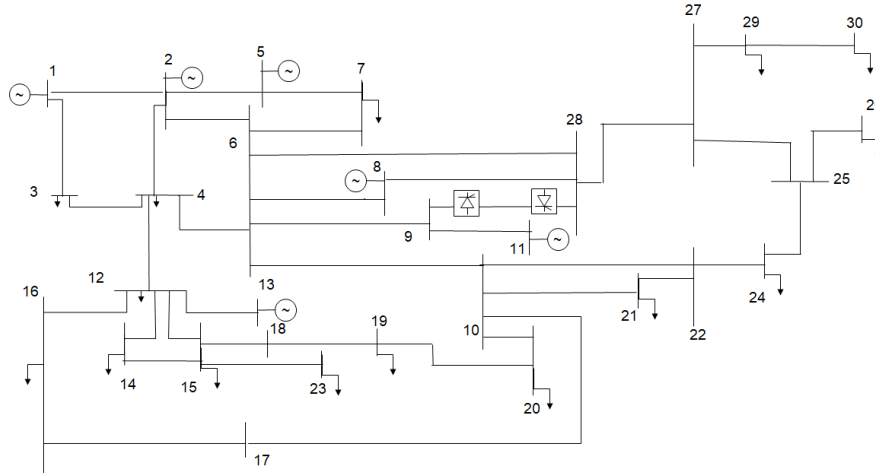
Figure 3.2 IEEE 30 bus system with HVDC link between buses 9 and 28

The results of power flow analysis using Gauss Seidel method for IEEE 5 bus system for different combinations are tabulated in Table 3.1 and the results of power flow analysis using Newton Raphson method for IEEE 5 bus system for different combinations are tabulated in Table 3.2. The results of power flow analysis using Gauss Seidel method for IEEE 30 bus system for different combinations are tabulated in Table 3.3. The results of power flow analysis using Newton Raphson method for IEEE 30 bus system for different combinations are tabulated in Table 3.4. The results obtained from the G-S and N-R for both IEEE 5 bus and IEEE 30 bus system for combinations 1, 2 and 3 are obtained and compared. The comparison of N-R and G-S methods is shown in Table 3.7. The comparison between Gauss Seidel method and Newton Raphson method for 5 bus system and 30 bus system is illustrated in figure 3.5 and figure 3.6

(a)

(b)

(c)

Figure 3.5 Comparison of Values obtained from Gauss Seidel and Newton Raphson for: (a) Combination 1; (b) Combination 2; (c) Combination 3

Table 4.1 G-S results of 5 bus system for combination 1, 2 and 3

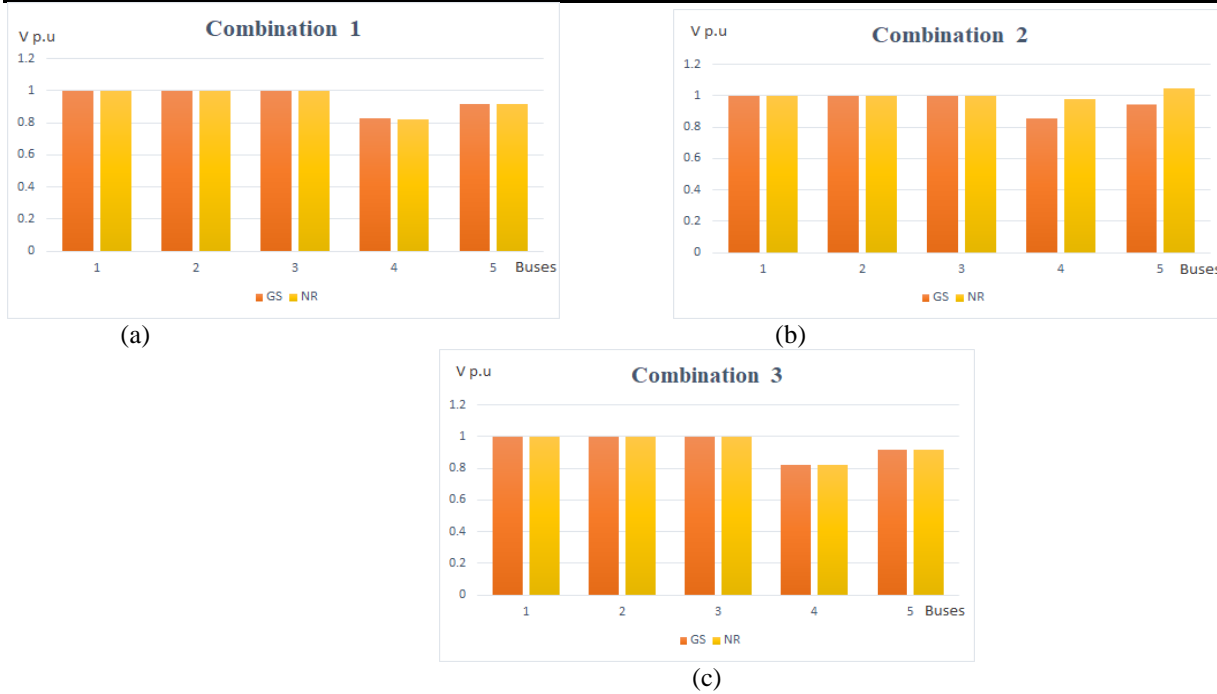| Bus no.	Combination 1 P_{dr}=100MW, α = 5, γ = 18,V_{di} =250KV				Combination 2 P_{dr}=100MW, a_r=1, a_i=1,V_{di}=250KV				Combination 3 P_{di}=100MW, α=5, γ=18,V_{dr}=250KV			
	|V| (pu)	Θ (deg)	P_{inj} (pu)	Q_{inj} (pu)	|V| (pu)	Θ (deg)	P_{inj} (pu)	Q_{inj} (pu)	|V| (pu)	Θ (deg)	P_{inj} (pu)	Q_{inj} (pu)
1	1.0000	0	0.7846	-0.5143	1.0000	0	0.7027	-0.3323	1.0000	0	0.7924	-0.5271
2	1.0000	1.3662	0.5	-0.1946	1.0000	1.8222	0.5	-0.1988	1.0000	1.3485	0.5	-0.1822
3	1.0013	-1.4352	1	1.5000	1.0000	-0.8870	1	1.1167	0.9997	-1.4485	1	1.5
4	0.8258	-6.8386	-2.15	-0.8133	0.8549	-6.6075	-2.15	-0.6572	0.8225	-6.8698	-2.1665	-0.8212
5	0.9167	-6.3119	0.1345	-0.7784	0.9424	-6.2181	0.1345	-0.4710	0.9149	-6.3462	0.15	-0.7871
Iteration	29				9				29			

Table 4.2 N-R results of 5 bus system for combination 1, 2 and 3

Bus no.	Combination 1 P_{dr}=100MW, α = 5, γ = 18,V_{di} =250KV				Combination 2 P_{dr}=100MW, a_r=1, a_i=1,V_{di}=250KV				Combination 3 P_{di}=100MW, α=5, γ=18,V_{dr}=250KV			
	|V| (pu)	Θ (deg)	P_{inj} (pu)	Q_{inj} (pu)	|V| (pu)	Θ (deg)	P_{inj} (pu)	Q_{inj} (pu)	|V| (pu)	Θ (deg)	P_{inj} (pu)	Q_{inj} (pu)
1	1.0000	0	0.7853	-0.521	1.0000	0	0.6943	0.5125	1.0000	0	0.7924	-0.5256
2	1.0000	1.3709	0.5	-0.1845	1.0000	1.6189	0.5	-0.1851	1.0000	1.3466	0.5	-0.1844
3	1.0000	-1.4125	1	1.4839	1.0000	-0.9796	1	-0.3291	1.0000	-1.4549	1	1.5
4	0.8248	-6.8292	-2.15	-0.8133	0.9764	-7.7013	-2.15	-0.6	0.8227	-6.8732	-2.1665	-0.8212
5	0.9158	-6.3142	0.1345	-0.7784	1.0508	-6.8066	0.1345	-0.4	0.9151	-6.3468	0.15	-0.7871
Iteration	6				9				6			

Table 4.3 G-S results of 30 bus system for combination 1, 2 and 3

Bus no.	Combination 1 $P_{dr}=100MW$, $\alpha=5$, $\gamma=18$, $V_{di}=250KV$				Combination 2 $P_{dr}=100MW$, $a_r=1$, $a_i=1$, $V_{di}=250KV$				Combination 3 $P_{di}=100MW$, $\alpha=5$, $\gamma=18$, $V_{dr}=250KV$			
	$|V|$ (pu)	Θ (deg)	P_{inj} (pu)	Q_{inj} (pu)	$|V|$ (pu)	Θ (deg)	P_{inj} (pu)	Q_{inj} (pu)	$|V|$ (pu)	Θ (deg)	P_{inj} (pu)	Q_{inj} (pu)
1	1.0500	0	2.4560	0.1690	1.05	0	1.4684	-0.0098	1.05	0	2.4595	0.1688
2	1.0338	-5.1372	0.3586	0.0569	1.0338	-3.0115	0.3586	-0.1359	1.0338	-5.1452	0.3586	0.0599
3	1.0241	-8.1436	-0.0240	-0.0120	1.0296	-4.6672	-0.024	-0.012	1.0239	-8.1541	-0.024	-0.012
4	1.0172	-9.8065	-0.0760	-0.0160	1.023	-5.6874	-0.076	-0.016	1.017	-9.8195	-0.076	-0.016
5	1.0058	-13.897	-0.6964	0.0987	1.0058	-10.373	-0.6964	0.0694	1.0058	-13.912	-0.6964	0.0999
6	1.0125	-11.718	0	0	1.0159	-7.0218	0	0	1.0123	-11.733	0	0
7	0.9955	-14.262	-0.6280	-0.1090	0.9977	-10.038	-0.628	-0.109	0.9954	-14.277	-0.628	-0.109
8	1.0230	-12.917	-0.4500	0.3585	1.023	-8.0239	-0.45	0.2596	1.023	-12.936	-0.45	0.3663
9	0.9683	-14.142	-1.0000	-0.2133	0.9745	-8.103	-1	-0.2898	0.9671	-14.177	-1.0165	-0.2212
10	0.9669	-15.659	-0.0580	-0.0200	0.9663	-8.4372	-0.058	-0.02	0.966	-15.688	-0.058	-0.02
11	1.0913	-12.119	0.1793	0.6484	1.0913	-6.0745	0.1793	0.6166	1.0913	-12.151	0.1793	0.6551
12	1.0279	-14.844	-0.1120	-0.0750	1.026	-8.1133	-0.112	-0.075	1.0276	-14.873	-0.112	-0.075
13	1.0883	-13.631	0.1691	0.4713	1.0883	-6.8867	0.1691	0.4866	1.0883	-13.659	0.1691	0.4735
14	1.0067	-15.851	-0.0620	-0.0160	1.0044	-8.761	-0.062	-0.016	1.0063	-15.881	-0.062	-0.016
15	0.9958	-15.879	-0.0820	-0.0250	0.9953	-8.6121	-0.082	-0.025	0.9954	-15.908	-0.082	-0.025
16	0.9945	-15.444	-0.0350	-0.0180	0.9936	-8.405	-0.035	-0.018	0.9939	-15.473	-0.035	-0.018
17	0.9695	-15.819	-0.0900	-0.0580	0.9689	-8.655	-0.09	-0.058	0.9687	-15.848	-0.09	-0.058
18	0.9727	-16.562	-0.0320	-0.0090	0.9734	-8.7988	-0.032	-0.009	0.9721	-16.592	-0.032	-0.009
19	0.9624	-16.765	-0.0950	-0.0340	0.9633	-8.9104	-0.095	-0.034	0.9617	-16.795	-0.095	-0.034
20	0.9627	-16.549	-0.0220	-0.0070	0.9632	-8.8527	-0.022	-0.007	0.9619	-16.579	-0.022	-0.007
21	0.9558	-16.154	-0.1750	-0.1120	0.9563	-8.4742	-0.175	-0.112	0.955	-16.183	-0.175	-0.112
22	0.9572	-16.137	0	0	0.9574	-8.5127	0	0	0.9563	-16.165	0	0
23	0.9744	-16.343	-0.0320	-0.0160	0.974	-8.8981	-0.032	-0.016	0.9738	-16.372	-0.032	-0.016
24	0.9546	-16.600	-0.0870	-0.0670	0.9538	-9.1086	-0.087	-0.067	0.9539	-16.629	-0.087	-0.067
25	0.9658	-16.672	0	0	0.9626	-9.544	0	0	0.9652	-16.699	0	0
26	0.9471	-17.139	-0.0350	-0.0230	0.9439	-10.017	-0.035	-0.023	0.9465	-17.166	-0.035	-0.023
27	0.9819	-16.417	0	0	0.9768	-9.786	0	0	0.9814	-16.441	0	0
28	1.0189	-12.339	0.9845	-0.3784	1.0174	-6.9818	0.9845	-0.3161	1.0186	-12.354	1	-0.3871
29	0.9611	-17.752	-0.0240	-0.0090	0.9564	-11.021	-0.024	-0.009	0.9606	-17.778	-0.024	-0.009
30	0.9491	-18.717	-0.1060	-0.0190	0.9442	-12.048	-0.106	-0.019	0.9486	-18.743	-0.106	-0.019
Iteration	159				31				159			

Table 4.4 N-R results of 30 bus system for combination 1, 2 and 3

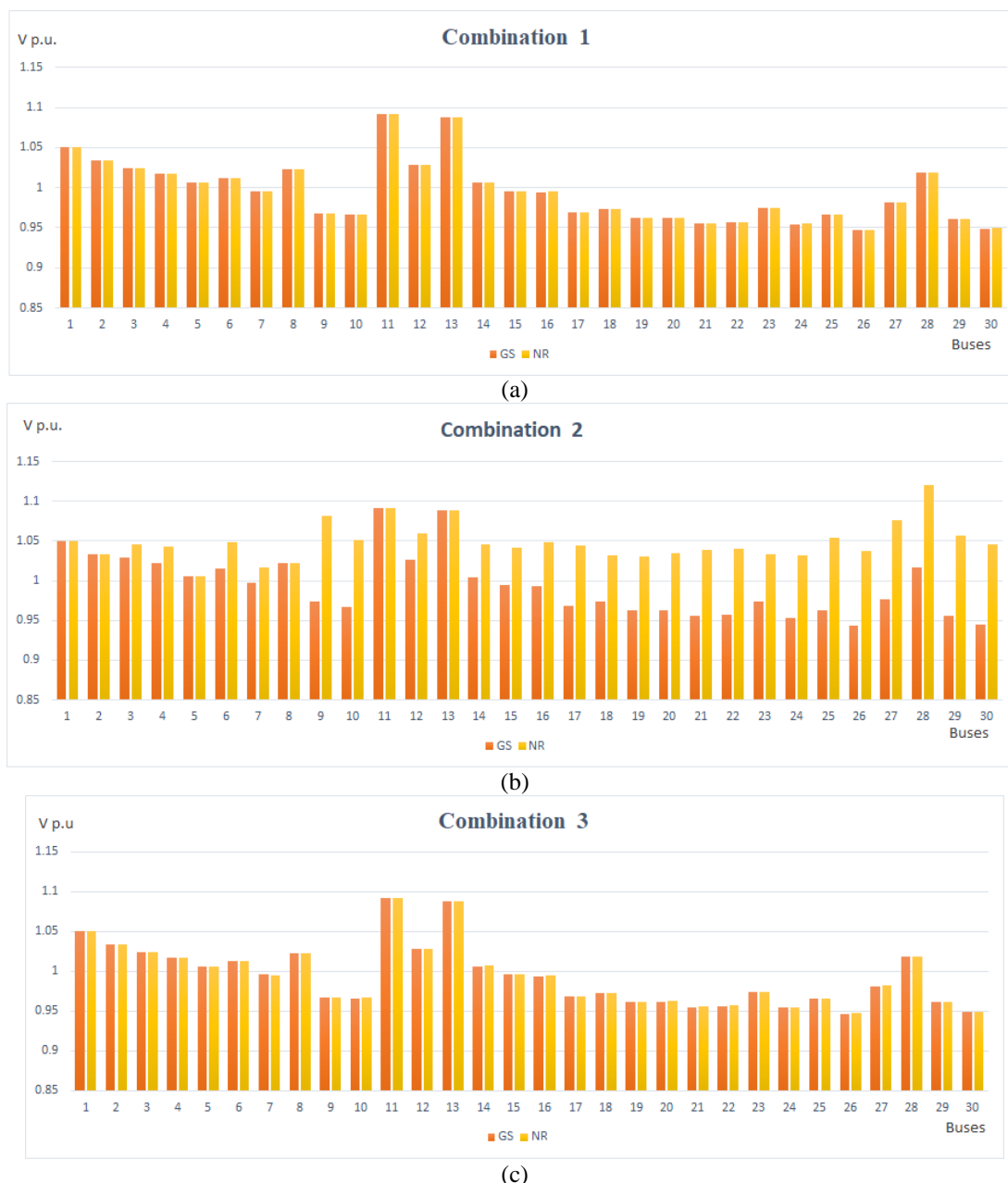| Bus no.	Combination 1 P_{dr}=100MW, α = 5, γ = 18, V_{di} =250KV				Combination 2 P_{dr}=100MW, a_r=1, a_i=1, V_{di}=250KV				Combination 3 P_{di}=100MW, α=5, γ=18, V_{dr}=250KV			
	|V| (pu)	Θ (deg)	P_{inj} (pu)	Q_{inj} (pu)	|V| (pu)	Θ (deg)	P_{inj} (pu)	Q_{inj} (pu)	|V| (pu)	Θ (deg)	P_{inj} (pu)	Q_{inj} (pu)
1	1.0500	0	2.4818	0.1732	1.0500	0	2.5157	0.2967	1.0500	0	2.4853	0.1729
2	1.0338	-5.1926	0.3586	0.0621	1.0338	-5.219	0.3586	-0.2962	1.0338	-5.2006	0.3586	0.0652
3	1.0240	-8.2339	-0.024	-0.012	1.0455	-8.606	-0.024	-0.012	1.0238	-8.2446	-0.024	-0.012
4	1.0170	-9.9134	-0.076	-0.016	1.0432	-10.346	-0.076	-0.016	1.0168	-9.9265	-0.076	-0.016
5	1.0058	-13.989	-0.6964	0.0993	1.0058	-13.855	-0.6964	-0.0893	1.0058	-14.003	-0.6964	0.1006
6	1.0124	-11.839	0	0	1.0488	-12.427	0	0	1.0122	-11.855	0	0
7	0.9955	-14.371	-0.628	-0.109	1.0173	-14.616	-0.628	-0.109	0.9953	-14.387	-0.628	-0.109
8	1.023	-13.043	-0.45	0.3599	1.023	-12.942	-0.45	-1.0457	1.023	-13.063	-0.45	0.3676
9	0.9682	-14.296	-1	-0.2133	1.0814	-15.659	-1	0	0.967	-14.330	-1.0165	-0.2212
10	0.9671	-15.843	-0.058	-0.02	1.0509	-16.799	-0.058	-0.02	0.9662	-15.872	-0.058	-0.02
11	1.0913	-12.273	0.1793	0.6489	1.0913	-13.848	0.1793	0.0548	1.0913	-12.305	0.1793	0.6555
12	1.028	-15.014	-0.112	-0.075	1.059	-14.902	-0.112	-0.075	1.0278	-15.044	-0.112	-0.075
13	1.0883	-13.802	0.1691	0.4702	1.0883	-13.725	0.1691	0.2295	1.0883	-13.831	0.1691	0.4724
14	1.0069	-16.030	-0.062	-0.016	1.0455	-15.917	-0.062	-0.016	1.0065	-16.061	-0.062	-0.016
15	0.996	-16.064	-0.082	-0.025	1.0412	-16.162	-0.082	-0.025	0.9956	-16.093	-0.082	-0.025
16	0.9947	-15.623	-0.035	-0.018	1.048	-15.975	-0.035	-0.018	0.9941	-15.652	-0.035	-0.018
17	0.9697	-16.001	-0.09	-0.058	1.0446	-16.759	-0.09	-0.058	0.9689	-16.031	-0.09	-0.058
18	0.973	-16.759	-0.032	-0.009	1.0324	-17.08	-0.032	-0.009	0.9723	-16.79	-0.032	-0.009
19	0.9626	-16.965	-0.095	-0.034	1.0304	-17.429	-0.095	-0.034	0.9619	-16.996	-0.095	-0.034
20	0.9629	-16.746	-0.022	-0.007	1.0347	-17.329	-0.022	-0.007	0.9621	-16.776	-0.022	-0.007
21	0.9561	-16.349	-0.175	-0.112	1.0394	-17.19	-0.175	-0.112	0.9552	-16.379	-0.175	-0.112
22	0.9574	-16.331	0	0	1.0402	-17.161	0	0	0.9565	-16.360	0	0
23	0.9746	-16.532	-0.032	-0.016	1.0339	-16.814	-0.032	-0.016	0.974	-16.562	-0.032	-0.016
24	0.9548	-16.791	-0.087	-0.067	1.0326	-17.344	-0.087	-0.067	0.9541	-16.820	-0.087	-0.067
25	0.9661	-16.854	0	0	1.0541	-17.508	0	0	0.9655	-16.881	0	0
26	0.9474	-17.320	-0.035	-0.023	1.0371	-17.898	-0.035	-0.023	0.9468	-17.348	-0.035	-0.023
27	0.9822	-16.586	0	0	1.0759	-17.336	0	0	0.9818	-16.611	0	0
28	1.019	-12.479	0.9845	-0.3784	1.1202	-13.728	0.9845	0	1.0187	-12.494	1	-0.3871
29	0.9615	-17.923	-0.024	-0.009	1.0571	-18.446	-0.024	-0.009	0.961	-17.949	-0.024	-0.009
30	0.9495	-18.886	-0.106	-0.019	1.0463	-19.241	-0.106	-0.019	0.949	-18.913	-0.106	-0.019
Iterations	5				7				5			

(a)

(b)

(c)

Figure 3.6 Comparison of Values obtained from Gauss Seidel and Newton Raphson for 30 bus system: (a) Combination 1; (b) Combination 2; (c) Combination 3

Table 3.7 Comparison of G-S and N-R

Parameters		Gauss - Seidel			Newton - Raphson		
		Combination 1	Combination 2	Combination 3	Combination 1	Combination 2	Combination 3
Iteration	5 bus system	29	9	29	6	9	6
	30 bus system	159	31	159	5	7	5
Computation time (sec)	5 bus system	0.0412	0.0471	0.0386	0.0673	0.0951	0.0927
	30 bus system	0.2835	0.0922	0.2891	0.1221	0.1177	0.0995

The N-R approach converges quicker than the G-S method. Because of its sluggish rate of convergence, the G-S technique usually requires accelerating factors to enhance the iteration process. The N-R approach appears to be the most appealing methodology for addressing AC – DC power flows due to its strong convergence properties.

IV.CONCLUSION

In this paper, a simplified model of a DC link is built, and the power flow analysis of an AC – DC system is demonstrated using the Gauss Seidel and Newton Raphson techniques. The fundamental concept is to employ nodal injection theory on all buses that are linked to a DC system. The results of the Power Flow Analysis for the AC-DC power network were successfully accomplished using the Gauss Seidel and Newton Raphson techniques. Ultimately, the results of the power flow analysis using Gauss Seidel and Newton Raphson prove that the Newton Raphson approach is more efficient in solving the power flow analysis because it requires fewer iterations, despite the fact that the computing time is longer than the Gauss Seidel method, which is allowable. The Sequential technique using Newton Raphson method is efficient because:

- It is easy to execute in AC – DC power flow algorithm
- The number of iterations is reduced
- The programming is the simplest to create and alter.

The future scope of this study shall include the recurrent neural network application for solving the AC-DC power flow analysis. The Newton Raphson technique is a good choice for power flow analysis since it requires less repetitions. In order to solve the AC - DC load flow, a traditional power flow research employing Newton Raphson can be used. For large power systems, however, generating Jacobian matrices and taking their inverses is challenging. A recurrent neural network is used to avoid this. Over the traditional way of power flow employing the Newton–Raphson (N-R) methodology, the Recurrent Neural Network offers the benefits of being easier to use, more versatile in application, quick convergence, and a better optimum solution[15]. Based on the power system's power mismatches, the recurrent neural network formulates an energy function and optimizes the function.

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