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Power Flow Analysis in Integrated AC-DC System

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ABSTRACT

Power flow analysis is an essential tool for power system operation and planning. With the increasing use of DC technologies in power systems, there is a growing need for power flow analysis in integrated AC-DC systems. This research paper aims to investigate the impact of an HVDC link on power flow, voltage stability, and system losses in a 9-bus system with an added HVDC link. A simulation was conducted using a suitable model and methodology, and the key findings were presented. The simulation results indicate that the HVDC link has a significant impact on power flow, voltage stability, and system losses, and control measures were implemented to address any observed oscillations or control issues. The findings of this study contribute to the existing literature on power flow analysis in integrated AC-DC systems and have implications for the integration of AC and DC systems. The study recommends further research in this area to address the gaps identified in the literature.

INTRODUCTION

Recently, the power system is becoming ever more complex. It consists of a large number of interconnected subsystems and components each of which interact with and influence the overall system reliability. Furthermore, power demand has increased substantially while the expansion of power generation and transmission has been severely limited due to limited resources and environmental restrictions. Power grids are driven closer to their transfer capacities and operating closer to their dynamic and thermal limits, high cost of building new lines and the difficulties in obtaining rights of way and building permits. As a consequence, power systems are heavily loaded and the system stability becomes a power transfer-limiting factor. HVDC (High Voltage Direct Current) power system has been mainly used for solving various power system steady state control problems, which it can react appropriately to any mode of operation. This rapid response is possible due to HVDC transmission systems, which depends on power electronics technologies. High Voltage Direct Current became an attractive means of asynchronous interconnection and transmitting power over long distances by cable or overhead lines (longer than 600 km and underwater crossing longer than 50 km). HVDC transmission is used for lower transmission costs and requires less right of way and uses lines more efficiently than AC transmission. HVDC system can also be used to improve AC stability and control precisely and very rapidly power flow . In spite to the high cost of converters, HVDC transmission has been typically used for interconnecting asynchronous AC systems and for economic transmission. The increased utilization of HVDC systems has enhanced the need for comprehensive procedures to evaluate the power flow of these schemes. From a control aspect, HVDC transmission is also favourable because of its fast response and flexibility. HVDC can feed or reduce the active power into the disturbed system to control the frequency much faster than a normally controlled generator. The added DC power flow does not create any transient stability.

With the integration of HVDC transmission in AC power systems, several parameters change, particularly with regard to load flow and stability. Power flow studies form an importance in power systems planning, operational planning and design of power systems; it is also considered as the fundamental of power system network calculations. Therefore, it is necessary to adequately model the HVDC transmission links and integrate them in the load flow analysis of the complete AC–DC system. The approaches to the solution for AC–DC power flow problem can be classified into categories: (1) simultaneous or unified, (2) sequential or alternating. The simultaneous method or unified method which combines the DC system equations and their controls are incorporated with the equations of the AC system along with the AC power flow equations and solves the combined set simultaneously. The simplest implementation of this approach is to consider all equations for AC and DC systems into one set of nonlinear algebraic equation.

2. POWER FLOW ANALYSIS

Power flow analysis is a fundamental tool in power systems engineering used to determine the steady-state operating conditions of a power system. It is also referred to as load flow analysis and involves the calculation of voltage, current, and power flows in a power system under different loading conditions. The power flow analysis is critical in the design and operation of power systems, as it helps to ensure the system operates safely, reliably, and efficiently.

The power flow analysis is based on the Kirchhoff's laws and Ohm's law, and it involves the solution of a set of nonlinear equations. These equations represent the balance of power at each node in the power system, taking into account the loads, generators, and other components in the system. The solution of these equations provides the voltages, currents, and power flows in the system under different loading conditions.

The power flow analysis can be performed using either the bus admittance matrix or the node voltage method. The bus admittance matrix method is a powerful technique used for solving large power systems, whereas the node voltage method is more suitable for small power systems. In both cases, the solution involves the iterative solution of nonlinear equations, which can be solved using numerical techniques such as Gauss-Seidel or Newton-Raphson methods.

The power flow analysis is useful in many applications, including power system planning, design, and operation. For example, it can be used to determine the optimal placement and sizing of generators and other components in the system, to identify overloaded components, and to evaluate the impact of changes to the system, such as the addition of new loads or the integration of renewable energy sources.

In conclusion, power flow analysis is a critical tool in power systems engineering that is used to determine the steady-state operating conditions of a power system. It is based on the Kirchhoff's laws and Ohm's law, and it involves the solution of a set of nonlinear equations. The power flow analysis is useful in many applications, including power system planning, design, and operation, and it helps to ensure that the power system operates safely, reliably, and efficiently.

3.NEED FOR POWER FLOW ANALYSIS

It is required for many applications, including power system planning, design, and operation. Here are some of the reasons why power flow analysis is necessary:

1. Voltage and current analysis: The power flow analysis provides valuable information on the voltage and current levels in a power system under different loading conditions. It helps to ensure that the system operates within safe and stable limits, and it can also identify potential voltage stability issues.
2. Power system planning and design: Power flow analysis is essential for power system planning and design. It helps to determine the optimal placement and sizing of generators, transformers, and other components in the system to ensure that the system operates efficiently and reliably.
3. Renewable energy integration: With the increasing integration of renewable energy sources into the grid, power flow analysis is critical to evaluate the impact of these sources on the power system. It helps to ensure that the system remains stable and reliable despite the

variable and intermittent nature of renewable energy sources.

4. Load balancing: Power flow analysis is useful in balancing loads in the power system, which helps to minimize losses and improve the efficiency of the system.
5. Fault analysis: Power flow analysis can also be used to analyze faults in the power system, which helps to identify the causes of the fault and the impact on the system.

In conclusion, power flow analysis is necessary for power system planning, design, and operation. It provides valuable information on the voltage, current, and power flows in the system, which is essential for ensuring the system operates safely, reliably, and efficiently. Power flow analysis is also critical for integrating renewable energy sources into the grid, balancing loads, and analyzing faults in the system.

4.BACKGROUND

The traditional power system architecture consists of AC transmission and distribution networks, which have been the backbone of power systems for many years. However, with the increasing demand for power and the integration of renewable energy sources, the use of DC technologies in power systems has become more prevalent. The integration of DC technologies offers several advantages over traditional AC systems, such as improved power quality, increased transmission capacity, and reduced losses.

To fully realize the benefits of DC technologies, it is essential to integrate them with existing AC systems. Integrated AC-DC systems have become an important research area in recent years, as they offer a more flexible and efficient solution for power transmission and distribution. However, the integration of AC and DC networks poses several challenges, such as power flow control, voltage stability, and the interactions between AC and DC networks.

Power flow analysis is an essential tool for power system operation and planning, enabling engineers to determine the steady-state operating conditions of a power system. In traditional AC systems, power flow analysis is well established, with several methods and algorithms developed to solve the nonlinear equations governing power flow. However, power flow analysis in integrated AC-DC systems is more complex and requires the consideration of both AC and DC networks.

The integration of HVDC links in AC systems offers several advantages, such as long-distance transmission of power and improved power quality. However, the integration of HVDC links in AC systems also poses new challenges for power flow analysis, such as the interactions between AC and DC networks and the impact of HVDC links on system losses.

Therefore, the present study aims to investigate power flow analysis in integrated AC-DC systems with an added HVDC link. The study aims to analyze the impact of an HVDC link on power flow, voltage stability, and system losses in a 9-bus system. The results of the study can provide valuable insights into the integration of HVDC links in AC systems and can contribute to the development of more efficient and reliable power systems.

5.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.

Based on the foregoing assumptions, the equivalent circuit of a system with HVDC link (with converter at Ith bus and inverter at jth bus) is shown in figure 1.

HVDC link are as follows:

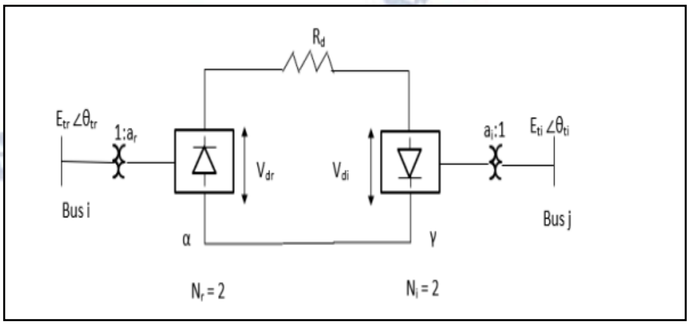

FIGURE 1 :Hvdc link

Most of the solution techniques for AC/DC power flow are divided into two different approaches. The sequential and the unified (or simultaneous) solution methods. The sequential solution methods, AC and DC system equations are solved separately in each iteration until the terminal conditions of converters are satisfied. Because of modular programming, the sequential methods are generally easy to implement and simple to incorporate various control specifications. In the unified methods, the AC as well as DC system equations are combined together with the residual equations, describing the rectifier terminal behaviours, in one set of equations to be solved simultaneously. The unified methods, with their better computing efficiency and convergence, seem more suitable than the sequential methods for use in industrial AC/DC power systems, even if they might be more complicated to program. The Gauss-Seidel (G-S), the Newton-Raphson (N-R), and the fast decoupled N-R methods may be used to solve the power flow problems in AC/DC systems as they do in the pure AC systems. The G-S method generally needs accelerating factors to improve the iteration process because of its slow rate of convergence. The N-R method, with its powerful convergence characteristics, appears to be the most attractive technique in solving the AC/DC power flows.

6.MODIFIEDSEQUENTIAL GAUSS-SEIDEL AC/DC LOAD FLOW

Equations modelling the combined AC–DC system have been derived now and we can see how these equations can be solved with an AC–DC load flow program. For a system of N buses, the general equation for the calculated voltage at converter bus is given by

$$V_k^{(i)} = \frac{1}{Y_{kk}}\left[\frac{P_k - jQ_k}{V_k^{(i-1)*}} - \sum_{n=1,}^{k-1} Y_{kn}V_n^{(i)} - \sum_{n=k+1}^{N} Y_{kn}V_n^{(i-1)} - D_k I_p k - jb_{fk}V_k^{(i-1)}\right]$$

where D =+1 for rectifiers and D=-1 for inverters. The general equation for the calculated voltage at AC buses is given by

$$V_k^{(i)} = \frac{1}{Y_{kk}}\left[\frac{P_k - jQ_k}{V_k^{(i-1)^*}} - \sum_{n=1,}^{k-1} Y_{kn}V_n{}^{(i)} - \sum_{n=k+1}^{N} Y_{kn}V_n^{(i-1)}\right]$$

here (k≠DC buses). The superscript (i) denotes the number of the iteration in which the voltage is currently being calculated and (i -1) indicates the number of the preceding iteration. In each iteration, the buses voltage is determined for all buses except for slack bus. If the new values are used to calculate the next busbar voltage in the same iteration, this process is known by the method of Gauss–Seidel. However, the new values are used in the next iteration, this process is known by Gauss method.

a sequential algorithm to perform a load flow assessment in hybridized AC-DC networks incorporating all their operational types in the steady-state model. In , a sequential method relying on Gauss-Seidel and modified Gauss techniques was used to handle the operation in an AC-DC system, with DC sides controlled by injecting current into the linking stations.

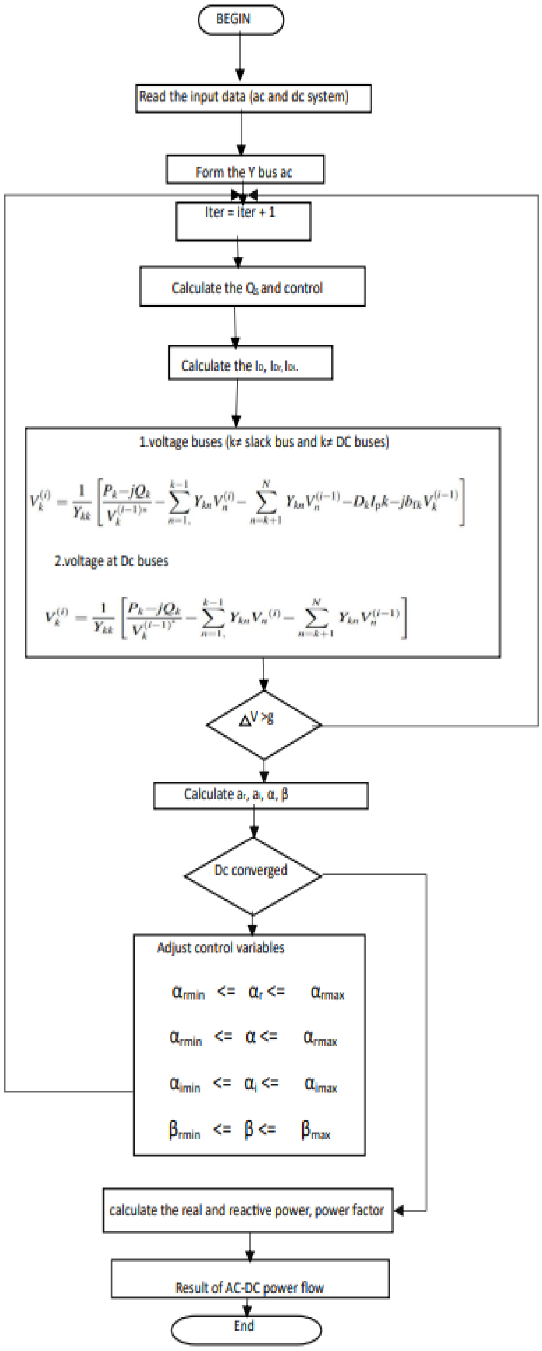

FIGURE 2 :AC–DC modifiedGauss–Seidel load flow algorithm

7.SIMULATION AND RESULTS

SINLGE LINE DIAGRAM OF 9 BUS INTEGRATED AC-DC SYSTEM

The following single line diagram represents the 9-bus ac-dc integrated system where an HVDC link is added in between the buses 4 and 5 also there are three generator buses and three load buses present.

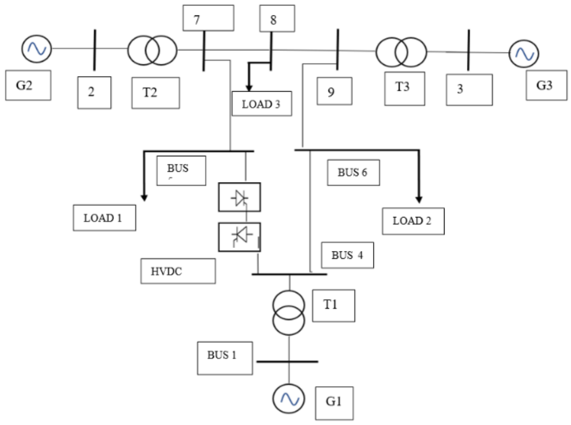

FIGURE 3 : 9 bus integrated ac-dc system

TABLE 1 : AC LOAD FLOW RESULT

Bus No.	Voltage(pu) (prev)	Voltage(pu) (prop)	Angle(deg) (prev)	Angle(deg) (prop)	P (mw)	Q (mvar)
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

FREQUENCY MAX (HZ)	RECTIFIER	INVERTER
BUS NUMBER	5	4
COMMUTATION REACTANCE	0.126	0.0725
MINIMUM CONTROL ANGLE	7	10
TRANSFORMER REGULATION RANGE	±15%	±15%
FILTER ADMITTANCE	0.4903	0.6302
RESISTANCE OF THE DC LINE	0.0034	
D.C POWER FLOW SETTING	0.5857	
INVERTER END DC VOLTAGE	1.284	

TABLE 2: Characteristics of HVDC link

AC–DC load flow result with modified Gauss–Seidel method

BUS NO	VOLTAGE	ANGLE(DEG)	POWER AT BUS
1	1.040	0.00	70.806-j48.115
2	1.025	8.32	163.000-j13.314
3	1.025	2.93	85.000-j27.000
4	1.067	-2.11	-125.000-j50.000
5	1.030	-4.05	-90.000-j30.000
6	1.103	-6.33	0.000+j0.000
7	1.038	-2.82	0.000+j0.000
8	1.032	-0.44	-100.000-j35.000
9	1.053	0.28	0.000+j0.000

Table 3:AC–DC load flow results.

The performances of the used methods have been compared with two others methods, on the same system. The results carried out in the literature on the same systems by two different authors. The modified Newton–Raphson method required five iterations only. However, the Broyden's method presented in the required 28 iterations. Despite the less iteration for the one method and a larger number for other, the modified Gauss and Gauss–Seidel method presented in this paper are very easy to formulate mathematically. The AC and DC solutions are obtained in the same iterations. The results simulation has high accuracy and short execution time. The program is simpler to implement and to modify. With this method, the DC link can be integrated into the AC network without losing the good convergence characteristic of the conventional Gauss–Seidel method. The results of power flow were obtained where the number of iterations is higher than for a system without DC line; the additional iterations are due to the number of DC constraints to be satisfied. The state variables in the DC problems can be included with small modifications.

8.CONCLUSION

In this paper, a new approach for the load flow calculations of integrated AC–DC system has been proposed. A simplified model of the DC link has been developed and the means of integrating the DC link equations with modified Gauss and Gauss–Seidel AC–DC load flow program have been illustrated. The basic idea is to apply nodal injection theory at all buses where the DC system is connected. It is assumed inject current to these buses which is calculated and solved through a set of AC–DC equations. The only modification in the equations which relates to the converter terminal is required. Consequently, the approach proposed comparatively with other methods developed:

- it is easiest to be implemented in the AC–DC power flow algorithm;
- the number of iterations is reduced;
- the different control strategies of DC link can be introduced in modified Gauss and Gauss–Seidel AC–DC load flow with only a small modification in the basic algorithm for each mode of control;
- the program is simplest to implement and to modify;
- the approach can conveniently solve AC–DC load flow for the case where any AC line is used to connect AC system, finally, it can also be used for an extended to large system with multi-terminal DC systems or including other power flow controlling devices. Therefore, modified Gauss and Gauss–Seidel's method is an economical and practical method for AC–DC load flow.

Conflict of interest statement

Authors declare that they do not have any conflict of interest.

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