Resincap Journal of Science and Engineering
Volume 3, Issue 8 August 2019
ISSN: 2456-9976

The Load Flow Analysis of AC-DC Hybrid Distribution Systems.

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ABSTRACT

In this paper proposes a unified load flow (LF) model for AC-DC hybrid distribution systems (DSs). The proposed model can be applied in hybrid DSs with mixed configurations for AC/DC buses and AC/DC lines. A new classification of DS buses is also introduced for LF analysis. A set of generic LF equations has been derived based on comprehensive analysis of the possible ACDC hybrid system configurations. Three binary matrices, which are used as a means of describing the configuration of the AC and DC buses and lines, have been employed in the construction of the unified power equations. These matrices enable a single configuration at a time to be activated in the power equations. The proposed LF model is generic and can be used for both grid-connected and isolated hybrid DSs. The new model has been tested using several case studies of hybrid DSs that include different operational modes for the AC and DC distributed generators (DGs). As a means of evaluating the effectiveness and accuracy of the proposed model, the LF solution was compared to the solution produced by Matlab. A comparison of the results reveals the efficacy of the proposed model.

Keywords

Load flow analysis, AC-DC hybrid distribution systems, voltage source converter (VSC), distributed generation.

1. INTRODUCTION

Since the beginning of the 21st century, the manner in which electric power is generated and utilized has changed significantly. Heightened environmental concerns have led many countries to begin increasing electric power production from renewable distributed generators (DGs), such **as** photovoltaic (PV) panels. Battery storage systems have also been connected to distribution systems (DSs) in order to increase the reliability and dispatch ability of renewable DGs . In addition, electric vehicles (EVs) are expected to become the dominant means of transportation in upcoming years ,which will significantly increase DC loads connected to DSs in the future. These changes have stimulated a need for the use of DC power in DSs. For the optimal accommodation of all types of anticipated loads and DGs, both AC and DC, the belief is that future DSs should be hybrid systems that include AC and DC buses, AC and DC lines, and AC-DC converters. Such predictions underscore the need for the development of a unified AC-DC load flow (LF) model that can be used for the planning and operation of future hybrid DSs. The benefits of using DC power alongside AC power in DSs have been demonstrated in numerous research studies . For example, the work reported in revealed that the utilization of DC power in a distribution network improved the voltage profile and the power capacity of the network feeders. In [6]–[8], using DC power in a distribution network led to lower power losses than occur in a purely AC network. The authors of introduced an AC-DC bilayer DS that avoids the overloading of secondary distribution transformers. Other researchers have also investigated and proven the advantages associated with the use of DC power in residential and commercial properties. Several researchers] have discussed LF analysis for AC-DC hybrid power systems, and most have focused on high-voltage direct current (HVDC) systems. For example, the authors of provide a detailed analysis of a VSC based HVDC model and introduce an equivalent injected power approach for calculating the AC-DC power flow. In the LF calculation for AC-DC hybrid power systems is performed using a sequential approach, in which the AC and DC LF equations are solved independently at each iteration until the boundary conditions of the AC-DC converters are satisfied. Because the sequential method is complicated and time-consuming, an integrated approach is presented in two further studies . In the integrated method, both AC and DC LF equations are solved together at each iteration in order to overcome the drawbacks associated with the sequential method. However, both the sequential and integrated LF methods presented in are based on decoupled analysis; i.e., the AC and DC networks have separate power equations. In this type of analysis, the main hybrid grid is divided into several AC and DC sub grids that have to be solved iteratively until convergence is reached. Traditionally, these methods are suitable for HVDC systems, in which the number of DC nodes is limited. The authors of have presented hybrid LF equations in the formulation of the optimal power flow problem. However, their models are suitable only for HVDC system configurations, and in an effort to simplify the LF calculations, most of them have ignored the power losses from the AC-DC converters. From the aforementioned discussion, it is obvious that the results of research conducted in the area of AC-DC hybrid DSs are still inconclusive. The hybrid LF methods presented in have focused on grid-connected systems. These methods cannot deal with isolated hybrid DSs, since they do not include consideration of the unavailability of a slack bus or the frequency variation in the AC sub networks. In addition, the AC-DC LF algorithms presented in the literature are based on decoupled LF analysis, in which the main hybrid network is divided into several AC and DC sub networks that have to be solved iteratively. In the smart grid era, future hybrid DSs are expected to include i) a variety of types of AC and DC loads and DGs, and ii) huge numbers of AC and DC buses and lines that are merging together and cannot be easily clustered to fit the LF methods in the literature. Such methods are expected to suffer from computational complexity and numerical solution instability if they are used for large highly-coupled hybrid DSs. Other studies have introduced LF methods for AC-DC hybrid microgrids .These methods, however, are designed for hybrid microgrid topologies and are also based on decoupled LF analysis.

This research work introduces a unified LF model that can be applied to hybrid DSs with varied AC-DC configurations. The proposed model is unique regarding the formulation of the unified AC-DC LF equations. In this model, the AC and DC portions of the hybrid network are solved simultaneously considering different operational modes for the system DGs. The proposed model can be applied to i) radial or meshed; ii) isolated or grid-connected; and iii) easily clustered or highly coupled hybrid DSs. The developed model employs three binary matrices to describe the AC-DC configuration of any hybrid DS. VSCs are used in the proposed model for ACDC power conversions. Generic AC-DC power equations are constructed based on comprehensive analysis of the possible hybrid DS configurations. The new model has been used for solving the LF problem of grid-connected and isolated hybrid DSs. As a means of evaluating the effectiveness and accuracy of the proposed model, the LF results were compared tot hose obtained from MATLAB software.

The unified LF model proposed in this paper can be used for the following applications:

1.1 Planning of Hybrid DSs

The proposed model has the flexibility to handle any AC-DC network configuration, and thus can be used to find the optimal configuration of hybrid DSs . In this case, the binary configuration matrices become the decision variables of the planning problem.

1.2 Reconfiguration of Hybrid DSs

The reconfiguration technique can be applied for hybrid DSs in the case of abnormal conditions In this case, the LF solution of the reconfigured network can be readily obtained by updating some binary elements in the configuration matrices.

1.3 Isolated Systems

With the absence of a stiff grid (e.g., the DS substation), the hybrid DS forms an isolated (or islanded) system (e.g., the AC-DC hybrid microgrid) with variable voltage and frequency. The AC and DC DGs in such isolated systems are mainly controlled using the droop characteristics in order to achieve proportional power sharing . The proposed model takes into consideration the droop-based operational modes for the isolated system DGs.

2. MODELING AND ANALYSIS OF AC-DC HYBRID DSS

Hybrid DSs consist of a variety of AC and DC components, including loads, generating units, lines, and buses. These components can be interconnected in different hybrid configurations. This section explains the classification of AC/DC buses and discusses the VSC steady-state model used in the proposed LF model. The proposed classification of the AC-DC hybrid configurations that was used for deriving the unified AC-DC power equations is also presented and analyzed.

2.1 Classification of AC and DC Buses

As depicted in Fig. 1, hybrid DS buses can be either AC or DC. Hybrid DSs include DC loads and DC DGs alongside the conventional AC loads and AC generators. Examples of DC DGs include PV panels and fuel cells. EVs and modern elevators represent examples of DC loads. In the case of AC buses, AC-DC converters are necessary for connecting DC loads and DC DGs to an AC bus, as shown in Fig. 1(a). This arrangement is reversed in the case of DC buses, as shown in Fig. 1(b).

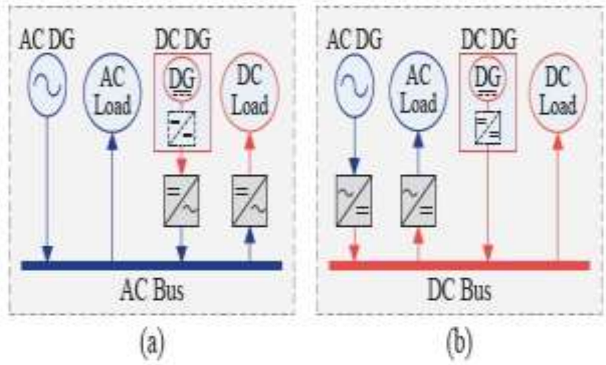

Fig.1. Connection of loads and DGs to (a) an AC Bus and (b) a DC Bus.

In the proposed LF model, AC buses are classified as follows.

- ➢ AC slack (or reference) bus: The voltage magnitude and voltage angle of the bus are known, while the active and reactive powers generated at the bus are unknown.
- ➢ ii) AC load (or P-Q) bus: The active and reactive powers of the loads connected at the bus are known, while the voltage magnitude and voltage angle of the bus are unknown.
- ➢ iii) AC voltage-controlled (or P-V) bus: The active power generated at the bus and the voltage magnitude of the bus is known, while the bus voltage angle and the generated reactive power are unknown.
- ➢ AC droop-based DG bus: This type is used in isolated hybrid DSs for power sharing among AC DGs . The frequency and the voltage magnitude of the AC DG are regulated based on the generated active and reactive powers, respectively.

The two main parameters for each DC bus are the DC voltage and the DC power, and there is only one DC power balance equation that can be defined for each DC bus. Therefore, the following classification of DC buses is introduced:

- DC load (or Pdc) bus: The net DC power (from the loads and/or DGs) injected into the bus is known, while the DC bus voltage is unknown.
- DC voltage-controlled (or Vdc) bus: The DC bus voltage is known, and the power generated at the bus is unknown.
- DC droop-based DG bus: This type is used in isolated hybrid DSs for power sharing among DC DGs . The DC voltage is regulated based on the generated DC power.

2.2 AC-DC Converter Model

In this study, VSCs are installed in the network lines for ACDC power conversions. The DC side of the VSC is a unipolar circuit that has two DC lines, as shown in Fig. 2. The converter impedance Zc shown in Fig. 2 includes the elements connected between the point of common coupling (PCC) and the AC bus of the VSC, such as power transformers, phase reactors, or low pass filters. Since Zc is connected between two AC buses, it can be modeled as described

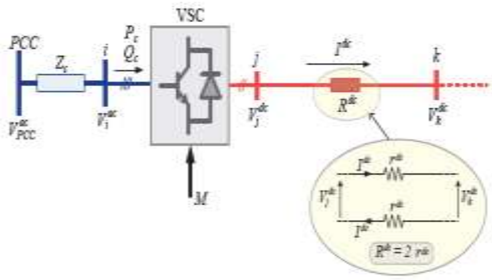

Fig.No 2. Model of a voltage source converter.

2. SYSTEM DEVELOPMENT

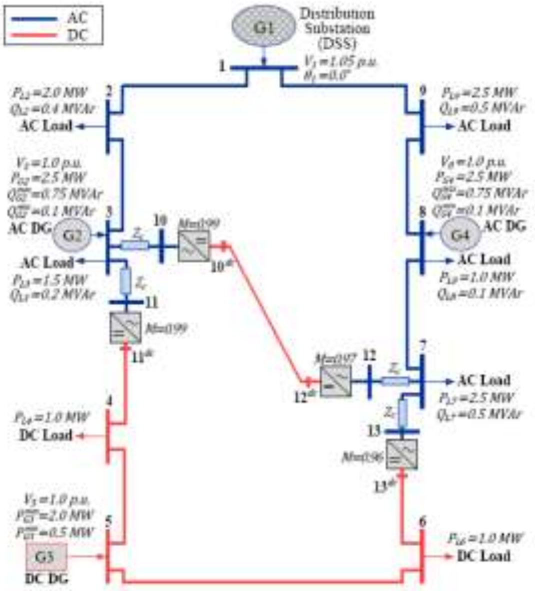

Fig.No.3 13 Bus Test System

For the proposed work the 13 bus system is used and the system is consist of the 13 zones each including of different types of elements. The system is consisting of four distributed generator in which the G1 is the distributed substation. This distributed substation is connected to the buses from bus no.1 to 2 and from 1 to 9 the bus no. 2 has the AC load. And the bus no. 9 also has the AC load with different active reactive power. The bus no.2 to 3 has the DC distributed generator with the two impedances across the bus no.10 and bus no. 11 both the buses have the voltage convertors as the AC bus has DC load. The bus no.11 to 4 has DC load. The bus no.4 to 5 has the DC distributed generator at the bus no.5 the bus no. 5to 6 has the only DC generator to DC load. The bus no. 6 has the DC load. From this bus the bus no. 13 and bus no. 7 has the impedance with the voltage convertors. The bus no.12 and 10 are interconnected with AC to DC convertor. The bus no.7 to 8 both has the AC load with different active reactive power. The bus no. 8 has the AC distributed generator G4. The bus no. 8 to 9 has again AC load on the AC distributed generator.

2.1 Impedance of The 13-Bus Test System

Bus 5 is a V_{dc} bus and the remaining buses are considered as load buses. The results obtained from the proposed LF model and the steady-state solution provided by the MATLAB software are listed in results. The LF model converged with a total power mismatch of the test system is equals to the equation given below

$$(\|P^{inj}n - P^{cal}\|2 + \|Q^{inj}n\|2)$$

To evaluate the accuracy of the proposed load flow model, the load flow solutions were calculated from the system variables by the Newton Raphson method and the Gauss Sidle method in the MATLAB software and the results are obtained with power losses and total time elapsed for the iterative calculation.

Table No .1. Impendence of the 13-bus system

From Bus	To bus	Resistance	Reactance
1	2	0.2218	0.3630
1	9	0.2218	0.3630
2	3	0.8870	1.4520
3	10	0.0500	0.7540
3	11	0.0500	0.7540
4	5	0.2208	-
4	11	0.4415	-
5	6	0.2208	-
6	13	0.4415	-
7	8	0.4435	0.7260
7	12	0.0500	0.7540
7	13	0.0500	0.7540
8	9	0.4435	0.7260
10	12	0.8830	-

4. RESULT

Table No .2 The Results Obtained From The Gauss-Seidel Method

No. of Iteration	Total Power Losses		Max. Power Mismatch	Elapse Time
	Gen. Side	Load Side		
101	0.329	-22.205	4.5687	2.458 Sec

Table No .3 The Result Obtained From The Newton Raphson Method

No. of Iteration	Total Power Losses		Max. Power Mismatch	Elapse Time
	Gen. Side	Load Side		
11	0.329	-22.205	4.5622	0.907 Sec

The load flow solution formed by the Newton Raphson method is in eleven iterations with the maximum power mismatch is 4.5622 with the total time elapsed is 0.907 sec. Which is very time convenient than the Gauss Seidel method with higher accuracy. So the Newton Raphson method is effectively applicable for the analysis of any complex hybrid distribution system

CONCLUSION

The hybrid distribution system is analyzed by the general algebraic methods with the MATLAB software. The13 bus system is taking in the proposed work. And the load flow analysis is done by the methods of Newton Raphson and Gauss Seidel. These methods are implemented on the possible AC-DC hybrid configurations on the 13 bus system. Both the methods can solve the load flow analysis for the AC and DC power into one unified solution. Both the methods produced the result with higher accuracy and both methods are capable to solve the power equations for hybrid distribution system. And gives the load flow results for AC-DC hybrid configuration. But when the results are observed and compared with each other. The Newton Raphson method has the minimum iterations with less computational time. The load flow results are obtained by Newton Raphson method is more reliable and efficient as it gives the load flow result in minimum elapsed time and minimum iterations than the Gauss Seidel method. So the Newton Raphson method is very efficient and more convenient for solving the load flow analysis of any hybrid distribution system.

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