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POWER FLOW ANALYSIS OF AC/DC HYBRID SYSTEMS IN SMART GRIDS

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ABSTRACT

Smart grids eliminate the difficulties in areas such as generation, transmission, distribution, consumption and operation of electrical energy. Smart grids are spreading rapidly in the industry thanks to their ability to reduce global warming and eliminate environmental constraints. With these network applications, the energy obtained from the sources is established with or without network connection and the energy is maximized. Smart grids can operate autonomously in combination with or separated from the conventional grid system. It can also be used in applications where there are both AC source, DC source and hybrid AC/DC source energy systems. In this study, DC grid system connected to IEEE 33 bus test system is designed and analyzed. The power flow values of the hybrid AC/DC system are obtained.

Keywords: *Hybrid AC/DC, Smart grid, IEEE 33 bus, DC system*

AKILLI ŞEBEKELERDE AC/DC HİBRİD SİSTEMLERİN GÜÇ AKIŞ ANALİZİ

Akıllı şebekeler, elektrik enerjisinde üretim, iletim, dağıtım, tüketim ve işletme gibi alanlardaki zorlukları gidermektedir. Akıllı şebekeler, küresel ısınmada azalma ve çevresel kısıtlamaları ortadan kaldırmadaki yetenekleri sayesinde endüstride hızla yayılmaktadır. Bu şebeke uygulamalarıyla kaynaklardan elde edilen enerji, şebeke bağlantılı veya şebekeden bağımsız olarak kurularak, enerjiden maksimum seviyede faydalanılmaktadır. Akıllı şebekeler, klasik şebeke sistemiyle beraber veya ayrılarak özerk olarak çalışabilmektedir. Ayrıca hem AC kaynaklı, hem DC kaynaklı, hem de hibrid AC/DC kaynaklı enerji sistemlerinin bulunduğu uygulamalarda kullanılabilmektedir. Bu çalışmada IEEE 33 bara test sistemine bağlı DC şebeke sistemi tasarlanmış ve analizi yapılmıştır. Hibrid AC/DC sistemin güç akış değerleri elde edilmiştir.

Anahtar Kelimeler: *Hibrid AC/DC, Akıllı şebeke, IEEE 33 bara, DC sistem*

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1. Introduction

Desire to provide quality and economic electrical energy throughout the world has been a subject of constant concern. From industry to rail transportation; lighting, communication systems in all kinds of sectors and areas that come to mind electric energy is used. Research has shown that a well-designed, conserved or integrated electrical power grid can minimize any interruptions or malfunctions that interfere with the functioning of human life. The rapid increase in electricity demand, depletion of fossil energy sources, developments in power electronics technologies and the use of renewable energy sources for energy production, the use of distributed generation constituted the concept of smart grids [1], [2].

Smart grid is reduced due to the losses occurring in transmission lines and increase efficiency in this case. The increase in the concept of energy efficiency in recent years has increased the importance of the studies on smart grids. In addition, with the help of smart grid models, the negative effects that deteriorate the power quality of the industrial facilities are eliminated and power losses in the transmission lines are reduced. Thus, more efficient and reliable networks can be created. Smart grids have many advantages [3], [4]. Some of these advantages are presented in the table 1 [5].

Table 1. Comparison of Traditional Grids and Smart Grids [5]

Traditional Grids	Smart Grids
Electric Machinery	Digital
One-way Communication	Two-way Communication
Centralized Power Generation	Distributed Power Generation
A Small Number of Sensors	Full Grid Sensors Layout
Manual Monitoring	Automatic Monitoring
Manual Recovery	Automatic Recovery
Failures and Power Outages	Adaptive and Islanded
Few User Options	More User Options

Some advantages of smart grids over classical grids are:

- Energy quality is very high.
- High energy efficiency, low loss-leakage ratio.
- The system is easy to control and manage.
- The system is open to developing technologies and innovations.
- Fault detection is easy in case of system failure.
- The repair speed of the fault detected in the system is high.
- It provides energy to the consumer at alternative prices.
- If the consumer is also able to produce energy, it provides bidirectional energy exchange by incorporating it into the smart grid system.

In smart grid applications there are some disadvantageous situations. The factors such as technical difficulties in integration into the existing network, new standards, administrative and legal barriers can be considered as disadvantages of smart grids. The figure 1 [6] shows the various functions involved in smart grid automation.

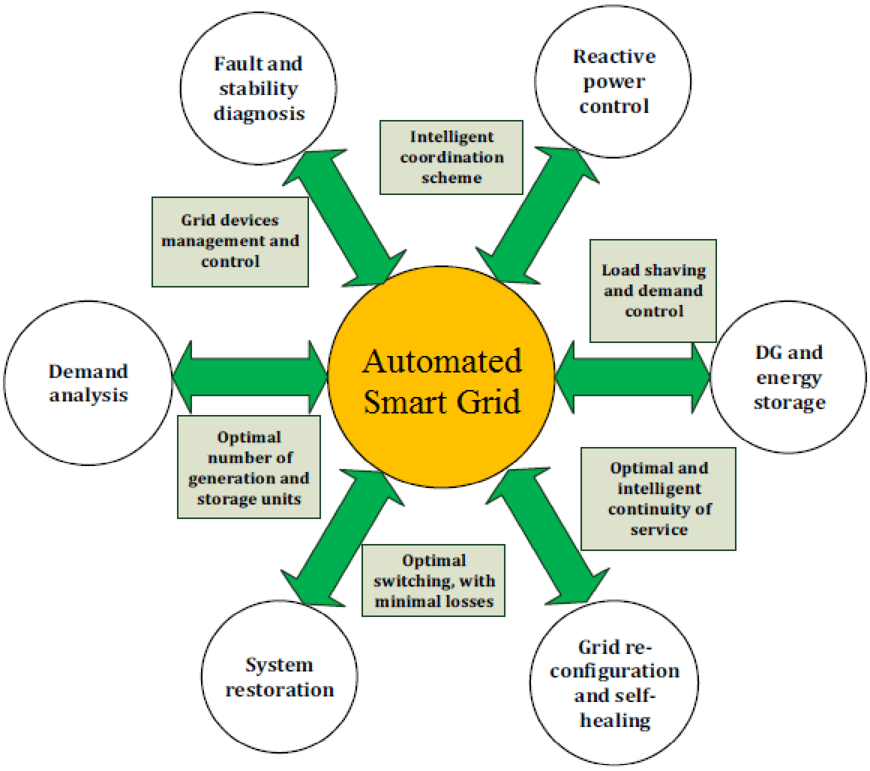

Figure 1. Smart grid automation functions [6].

2. AC/DC Hybrid Systems

Many models have been developed on smart grid structure and each designed system has brought a different definition to this structure. Although there are different definitions, all developed smart networks have three main components. These; power supplies, loads and storage devices [7].

2.1 Power Supplies

Hybrid smart grid power generation system is the systems that produce energy from at least two or more raw energy sources in practice and units that contribute to each other in parallel. These systems are generally safer and less costly than a single source of energy production. The aim of hybrid systems is to increase the efficiency by enabling the use of energy resources together. In addition, if one of the resources is absent or diminished, the others are able to meet the energy needs of the system. The most important factors that determine the number of resources and the type of resources in such applications are the sufficient level of resources in the region where energy will be produced and sufficient technology to bring the system together in some types of energy [8].

Generation sources such as generators, wind turbines, photovoltaic modules that form hybrid networks supply AC or DC loads with suitable converters. The introduction of these power electronics converters affects both the power quality of the system and requires new control arrangements.

2.2 Loads

In smart grid applications, loads can be applied in a variety of areas, residential, commercial and industrial. In general, commercial and industrial users require high power quality and reliability for critical and precise load demands. Smart grids can consist of hybrid systems consisting of DC-connected loads, AC-connected loads and both DC and AC-connected loads. In the DC connected system topology, as shown in figure 2 [11] , all generators and storage units are connected to the DC bus. If there are power supplies with AC output, they are first converted to DC. All added DC power supplies are then connected to AC user loads by inverters with a DC/AC converter in the base DC power bus. These inverters convert DC power produced in different generators and storage units into AC user load demands at the desired voltage and frequency. The inverter to be used must be sufficient for peak load demands [9], [10].

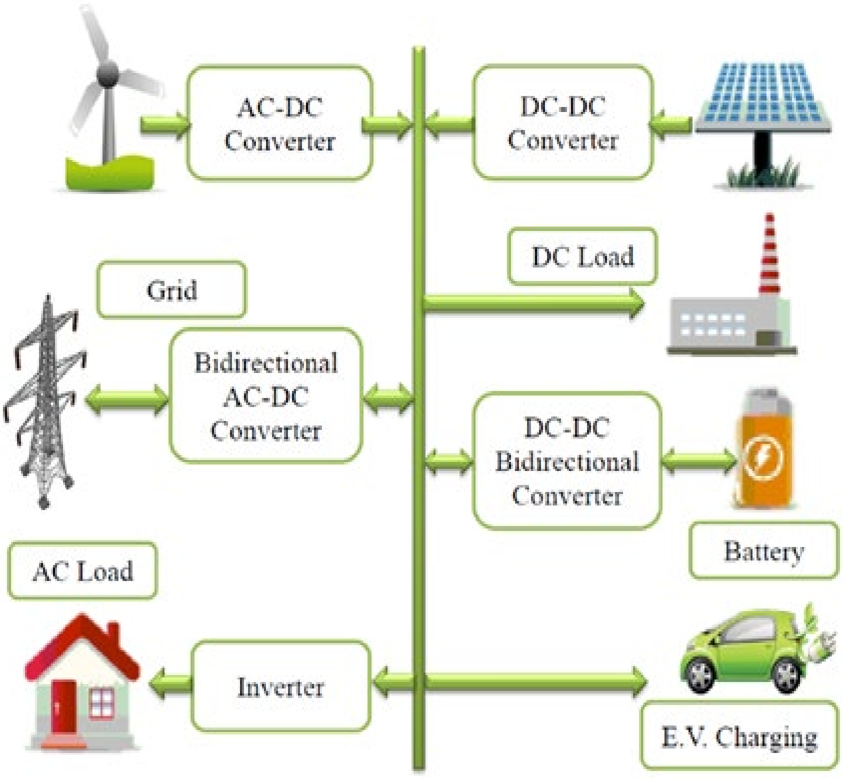

Figure 2. Structure of the DC Grid [11].

In the AC Connected system topology, as shown in figure 3 [11], all system components and AC user loads are connected to the AC bus. AC-connected system topology outperforms DC-connected system topology. Each inverter can be synchronized to its own generator so that it can supply power independently or simultaneously with the other inverter. This provides flexibility for energy sources to meet load demand [12].

AC/DC hybrid systems consist of AC and DC sources and loads as shown in figure 4 [11]. It can be connected to the mains power supply or operated independently. In grid-connected or grid-independent hybrid system applications, battery technologies and energy storage systems are also used to increase continuity in power generation [13].

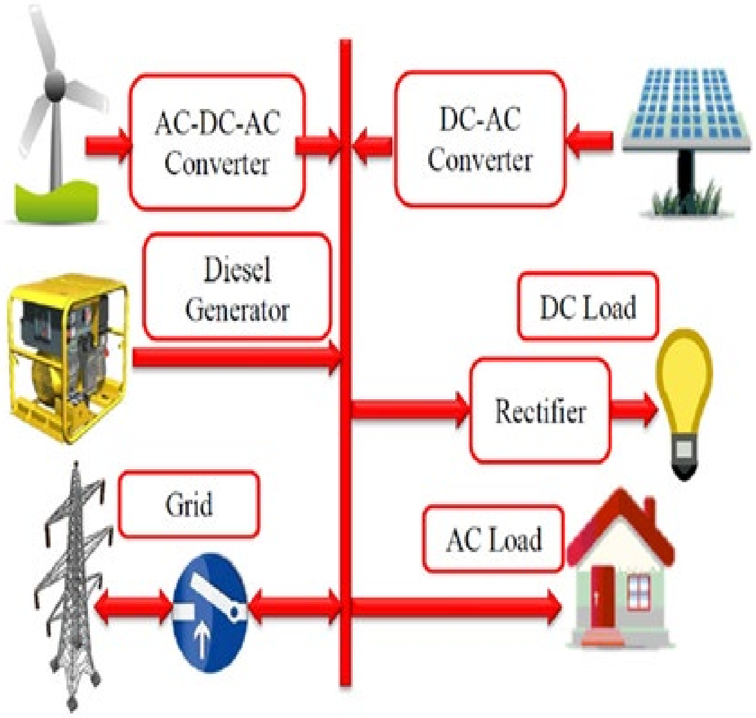

Figure 3. Structure of the AC Grid [11].

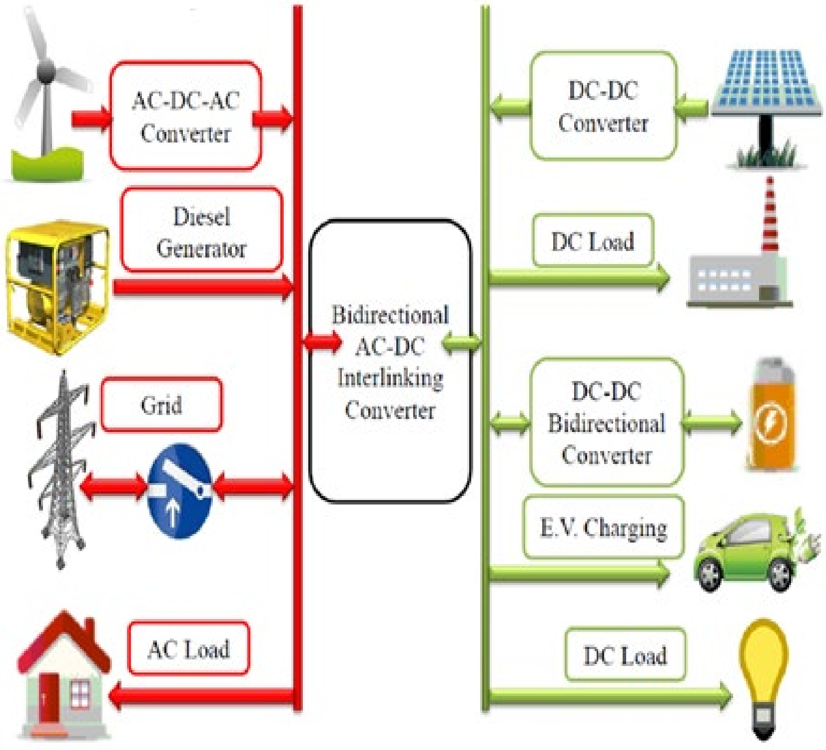

Figure 4. Structure of the AC/DC Grid [11].

2.3. Storage Devices

Energy storage technologies used in smart grids; It is an important area of interest for electricity generation and distribution companies, plant operators and electric vehicle manufacturers. The ability to store large amounts of energy can provide great flexibility for the operations of electricity companies. In this way, the demanded energy does not have to be produced at the same time. Solutions for power quality problems such as the development of energy storage technologies, voltage drop and interruptions are provided at both system and equipment level. However, energy storage; system efficiency, enabling the integration of renewable energy sources, increasing network stability and reliability, as well as reducing greenhouse gas emissions. Although direct storage of electrical energy is expensive, it can be stored in different forms for conversion to electrical energy when needed. The main energy storage units used in smart grids are; flywheels, super capacitors, superconducting magnetic energy storage and electrochemical cells [14]. The figure 5 shows the most important storage technologies for the smart grids [15].

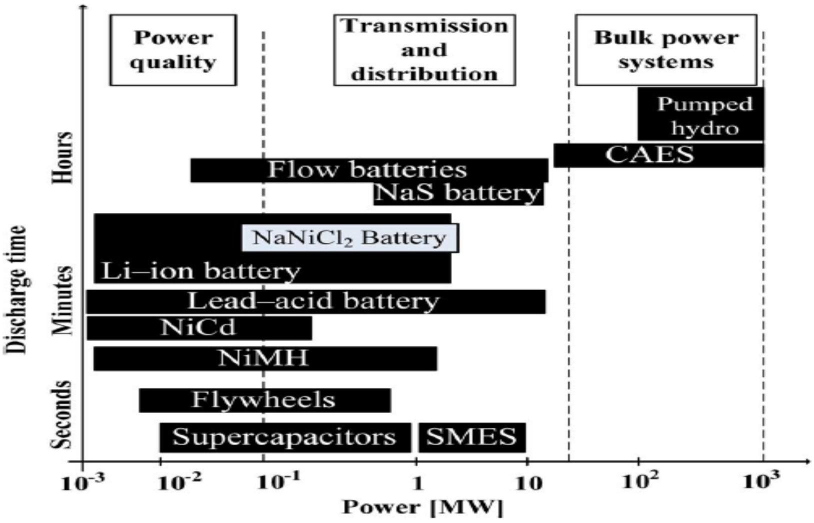

Figure 5. Storage technologies for the smart grids [15].

3. Case Study

The base values for the per-unit conversion in this system are Sbase=1 MVA, Vacbase=12.66 kV, and Vdcbase=6.8 kV. The effciency and the power factor of the VSCs are given as 98% and 95 %. Figure 6 [16] shows the DC grid system and the impedances of this system [16] is shown in table 2. The figure 7 [17] shows the IEEE 33 bus system and the data of the system is within the standards [18]. The numbers in the circle indicate buses and the others indicate lines. The model converged with a total power mismatch of 5.09×10^{-13} p.u. The bus voltage limits are taken as Vmin=0.9 p.u. and Vmax=1.05 p.u.

Table 2. Impedances of DC Grid Test System [16]

From Bus	To Bus	Resistance	Reactance
1	2	0.2208	-
1	4	0.2208	-
2	3	0.4415	-
4	5	0.4415	-

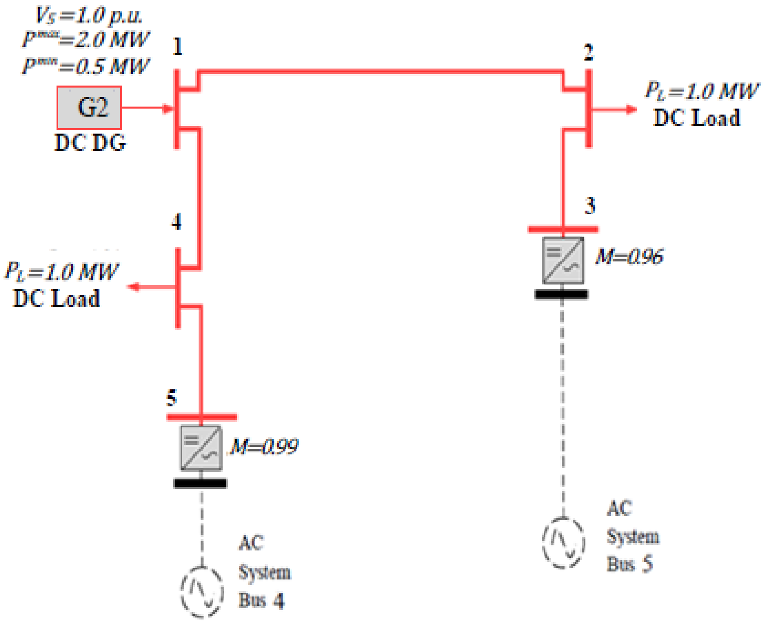

Figure 6. The line diagram DC grid test system [16]

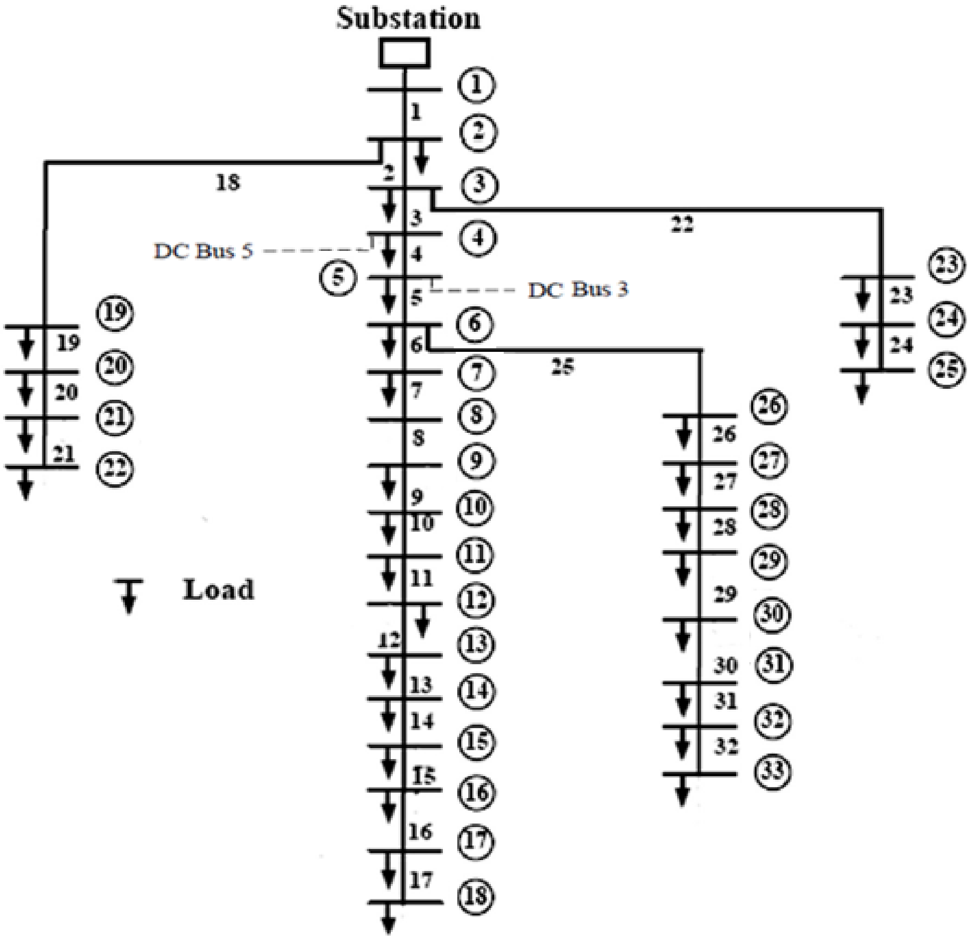

Figure 7. The line diagram of IEEE 33 bus test system with integrated DC buses [17]

4. Conclusions

Table 3. Voltage and power values of IEEE 33 bus test system

Bus	Voltage	Angle	Load		Generation	
No	Magnitude	Degree	MW	MVar	MW	MVar
1	1.000	0.000	0.000	0.000	4.254	2.553
2	0.997	0.012	0.100	0.060	0.000	0.000
3	0.981	0.084	0.090	0.040	0.000	0.000
4	0.973	0.142	0.630	0.248	0.000	0.000
5	0.966	0.215	-0.136	-0.034	0.000	0.000
6	0.948	0.121	0.060	0.020	0.000	0.000
7	0.944	-0.112	0.200	0.100	0.000	0.000
8	0.930	-0.266	0.200	0.100	0.000	0.000
9	0.924	-0.341	0.060	0.020	0.000	0.000
10	0.918	-0.405	0.060	0.020	0.000	0.000
11	0.917	-0.398	0.045	0.030	0.000	0.000
12	0.916	-0.386	0.060	0.035	0.000	0.000
13	0.910	-0.479	0.060	0.035	0.000	0.000
14	0.907	-0.560	0.120	0.080	0.000	0.000
15	0.906	-0.599	0.060	0.010	0.000	0.000
16	0.905	-0.622	0.060	0.020	0.000	0.000
17	0.903	-0.702	0.060	0.020	0.000	0.000
18	0.902	-0.711	0.090	0.040	0.000	0.000
19	0.996	0.001	0.090	0.040	0.000	0.000
20	0.993	-0.066	0.090	0.040	0.000	0.000
21	0.992	-0.086	0.090	0.040	0.000	0.000
22	0.991	-0.106	0.090	0.040	0.000	0.000
23	0.978	0.053	0.090	0.050	0.000	0.000
24	0.971	-0.036	0.420	0.200	0.000	0.000
25	0.968	-0.080	0.420	0.200	0.000	0.000
26	0.946	0.160	0.060	0.025	0.000	0.000
27	0.943	0.217	0.060	0.025	0.000	0.000
28	0.932	0.300	0.060	0.020	0.000	0.000
29	0.924	0.378	0.120	0.070	0.000	0.000
30	0.920	0.484	0.200	0.600	0.000	0.000
31	0.916	0.399	0.150	0.070	0.000	0.000
32	0.915	0.376	0.210	0.100	0.000	0.000
33	0.915	0.368	0.060	0.040	0.000	0.000
Total			4.029	2.403	4.254	2.553

Table 4. Voltage and power values of DC grid system

Bus	Voltage	Angle	Load		Generation	
No	Magnitude	Degree	MW	MVar	MW	MVar
1	1.000	0.000	0.000	0.000	1.711	0.000
2	0.998	0.000	1.000	0.000	0.000	0.000
3	1.002	0.000	-0.500	0.000	0.000	0.000
4	0.994	0.000	1.000	0.000	0.000	0.000
5	0.992	0.000	0.200	0.000	0.000	0.000
Total			1700	0.000	1.711	0.000

Due to the advancement in smart grid technologies, the integration of DC grid systems into AC systems is increasing. The development of AC/DC hybrid systems in smart grid is rapidly progressing and various analyzes are performed for AC/DC hybrid power flow analysis. The main information obtained from the power flow analysis studies are the amplitude of the voltage, phase angle, active and reactive powers for each bus. Analyzing these values is very important for the planning and development of power systems.

In this study, in the literature standard IEEE 33 bus test system is modified by adding a DC grid system. Then, this model is analyzed by Newton-Raphson method in Matlab environment and after that power values are obtained for each bus as shown in table 3 and table 4. The results are showed that the proposed method can be used in the analysis of power systems. Furthermore, this study provides guidance for future AC/DC hybrid power system analysis studies.

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