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Design and Control Of Multi Area AC/LVDC Network

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ABSTRACT:

The tremendous increase in the evolution of DC renewable sources paired with the increase in the amount of appliances working on DC in the household led to the development of the concept of DC micro-grids. In order to provide a flexibility of integrating the conventional AC grid with a bi-directional converter, the hybrid AC/LVDC micro-grid design is suggested consisting of multi-areas. Multi tie line connections between AC and LVDC part of the micro-grid is achieved through individual bi-directional AC/DC controllers capable of four quadrant operation.

A bi-directional converter is capable for the control of real and reactive power flow between AC and DC network of micro-grid. The modeling of such a bi-directional converter is discussed in this work. The control of bi-directional converter is done using vector control approach. Multiple LVDC micro-grids are designed and integrated with a conventional IEEE 9 bus test system. Transient stability analysis is conducted on such a system for different case studies to verify the successful integration in the MATLAB/SIMULINK environment to verify the performance of proposed system.

KEYWORDS:

AC/LVDC network, Bi-directional converter, IEEE 9 bus system, LVDC network, Vector controlled approach.

1. INTRODUCTION:

The outlook change toward renewable sources of energy generation is driven by vulnerability made because of fast exhaustion of conventional fossil fuels. By chance, a vast rate of these renewable sources creates on inherent DC power output. This output needs to be converted properly for servicing the traditional AC loads. Simultaneously, quick development and advancement in power electronics in the present decade have seen a surge of appliances utilizing DC power for their operation. This has produced a restored interest for the improvement of DC power networks in traditional electrical systems. Thus need of several conversion stages between AC and DC has emerged.

A power structure with these functionalities can be framed under smart grid [1]-[3]. Smart grid is the vision of the future electric system. The key technologies required to achieve the vision of the smart grid include [4]. There are 3 reasons to convert the conventional grid to smart grid.

- The energy demand is rapidly increased owing to new technologies.
- The loss and illegal usage seen in transmission and distribution lines.
- To provide enough energy for the increased demand and to integrate the distributed energy sources.

A micro-grid [5] is an electrical entity that facilitates advanced control/protection strategies. The proposed micro-grid operational and controlling is proposed in this paper [6]-[10]. Micro-grid can be operated in two modes of Operation i.e., connected mode and an isolated mode [11]. In connected mode, the control of the micro-grid voltage and frequency is controlled by the main grid. In stand-alone operation mode, the micro-grid needs to generate and manage its own voltage, and in alternate current operation case, it must also control the frequency of the micro-grid voltage.

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In industries DC technologies have been mostly used, such as automotive, aerospace, telecom, or electricity transmission. Low Voltage DC (LVDC) distribution systems, where the various converters are connected to the main dc bus, were proposed for the industrial sector, the supply of variable speed drives. Power from either solar panels or the grid, if necessary, is stored in the powerwall or equivalent device. It has low voltage, high current solid state circuit breakers. The use of multiple adapters is reduced. Usage of DC power for domestic appliances is more efficient than AC power.

2. DESIGN AND MODELING OF BI-DIRECTIONAL CONVERTER:

Design and modeling of a bi-directional converter is done using a Vector control approach [13]. Vector Control is one of the most widely used control techniques of bi-directional converter. It can control Active Power as well as Reactive Power independently. Synchronously rotating frame axis controls the flow of real and reactive powers in the system.

Block diagram of a vector controlled bi-directional is shown in Fig.1. Schematic diagram of the converter shown in Fig.2, the power flow is in either direction.

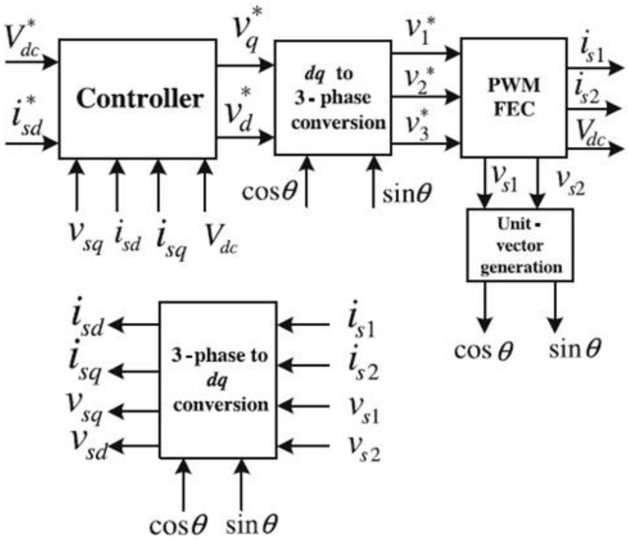

Fig.1 Block diagram of vector controlled bi-directional converter

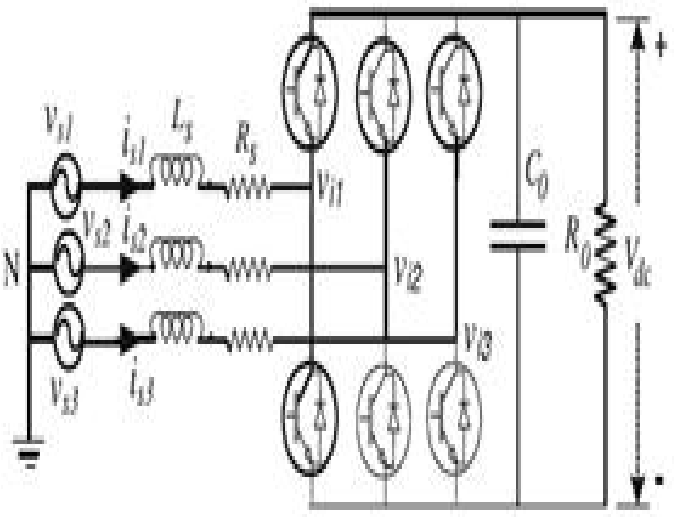

Fig.2. Schematic diagram of bi-directional converter

In this paper, the layout of the proposed system as well as the modeling of the bi-directional converters is explained. Simulink model of bi-directional converter model is integrated with the conventional IEEE 9 bus system.

2.1. SYSTEM CONFIGURATION :

The schematic diagram of a typical AC/LVDC network can be seen from the Fig.3. The system consists of bi-directional converter modeling, injection current generation modeling and the embedded function block.

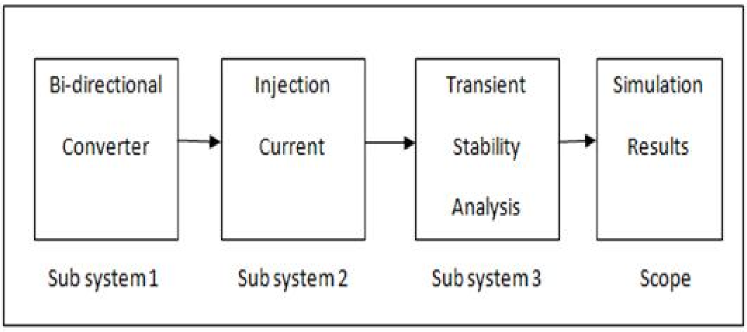

Fig.3. Schematic diagram of system

2.2. MODELING OF BI-DIRECTIONAL CONVERTER:

Bi-directional converter is responsible for the control of real and reactive power flow in the four quadrants between the AC network and the DC network of the micro-grid. The bi-directional converter is tested as LVDC grid which acts as generator or LVDC grid which acts as a load at particular bus in the conventional test system. The major operations of this converter are:

- Maintaining constant DC voltage of the micro-grid.
- To facilitate power exchange between the networks, by maintaining constant bus voltages at the respective buses.

2.3. CURRENT CONTROL LOOP:

Current control loop as inner control loop is fast control which will generate the voltage references which are fed to PWM converter which will produce input for system transfer function. An independent loop is used for control of i_s , which controls reactive power. After power transformation into synchronously rotating frame (d-q), real and reactive powers are calculated. Simulink model of Current Controller is as shown in Fig.4.

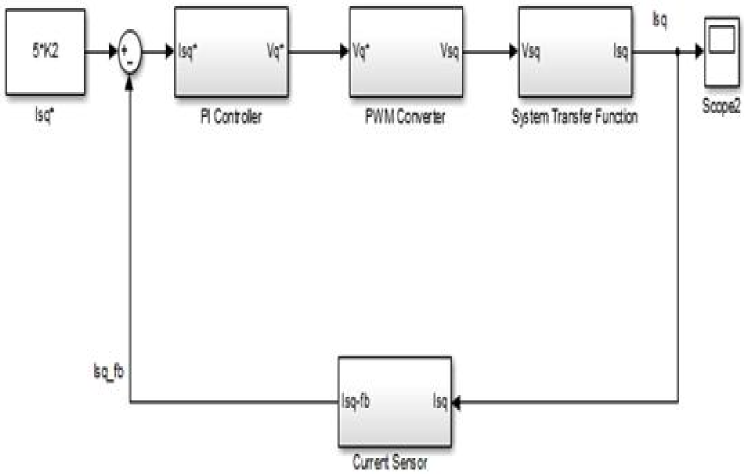

Fig.4. Simulink model of current control loop

2.4. VOLTAGE CONTROL LOOP:

The outer loop controls active power, reactive power and as well as to maintain the regulation of the DC link voltage to the reference value. The q-axis current loop controls the flow of real power p, since i_s is a

measure of p. The output current from the inner loop controller is given to the output capacitor from which the DC voltage is obtained. During all conditions, nominal bus voltages are to be maintained. In order to decouple both dynamics, voltage control loop should be slower than inner control loop. Simulink model of voltage control loop is as shown in Fig.5.

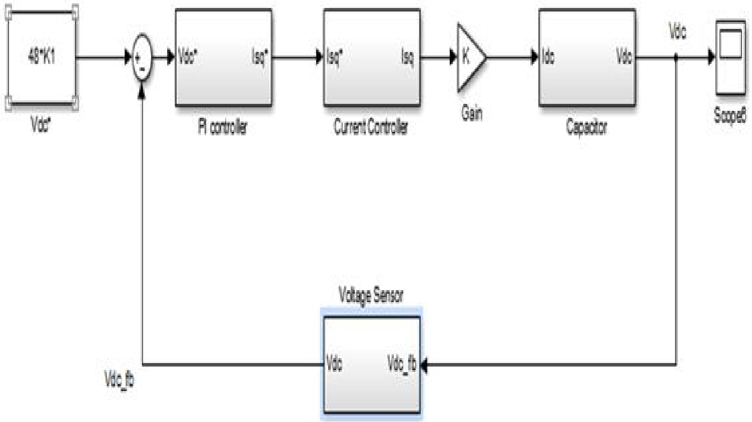

Fig.5. Simulink model of voltage controller

Power systems are designed to provide continuous power supply that maintains voltage stability. Power system security depends on detailed studies of system to check and ensure security. Transient stability of conventional IEEE 9 bus system is analyzed in the proposed model. Transient stability analysis without fault is equal to load flow analysis.

Coding for the transient analysis of the conventional system and the proposed system is developed in the MATLAB embedded function block. Algorithm for the transient stability analysis which is load flow analysis is developed. Injection current of the converter is obtained from the voltage obtained from the output of the converter.

3. INTEGRATION OF SIMULINK MODEL:

MATLAB algorithm can be integrated with the Simulink models with the use of embedded function block. Simulink provides a graphical editor, customizable block libraries, and solvers for modeling and simulating dynamic systems.

Bi-directional converter performs different functionalities. This has been observed for multi-area system. Single area network of the system can be described from the case 1 and case 2.

3.1. CASE 1:

In this case 1, one bi-directional converter is integrated at bus 5 in conventional system. This bi-directional converter is acting as LVDC load by taking real power from the bus. Voltage at bus 5 is used to calculate current injection. Impedance and injection current of the converter is added to the pre-fault impedance matrix and injection current matrix of the system at bus 5. Transient stability analysis is performed and the results are observed.

Line diagram of the system when converter is added at bus 5 is as shown in the Fig.6. Simulink model of bi-directional converter where LVDC grid which acts as load or LVDC grid acting as generator when integrated with function block is as shown in Fig.7. Similar line diagram and Simulink model is considered for case 2.

3.2. CASE 2:

In this case 2, one bi-directional converter is integrated at bus 5 in conventional system. This bi-directional converter acts as LVDC grid generator as it gives real and reactive power to the bus system. Voltage at bus 5 is used to calculate current injection. Impedance and injection current of the converter is added to the pre-fault impedance matrix and injection current matrix of the system at bus 5. Transient stability analysis is performed and the results are observed.

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In next cases two bi-directional converters are used in the conventional system. Operation of multi-area system network can be described from the following case studies.

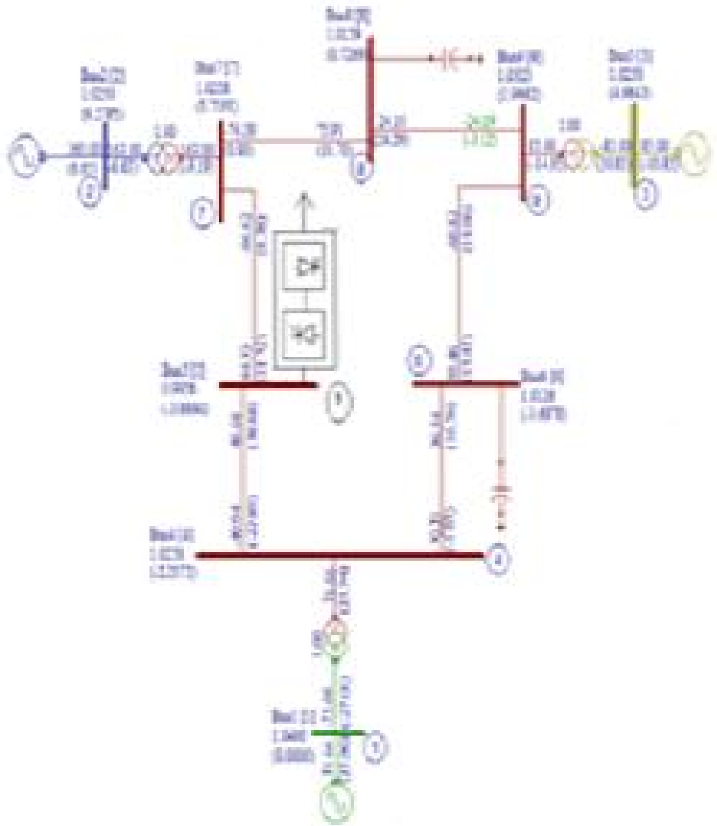

Fig.6. Line diagram of system when LVDC grid is connected at bus 5

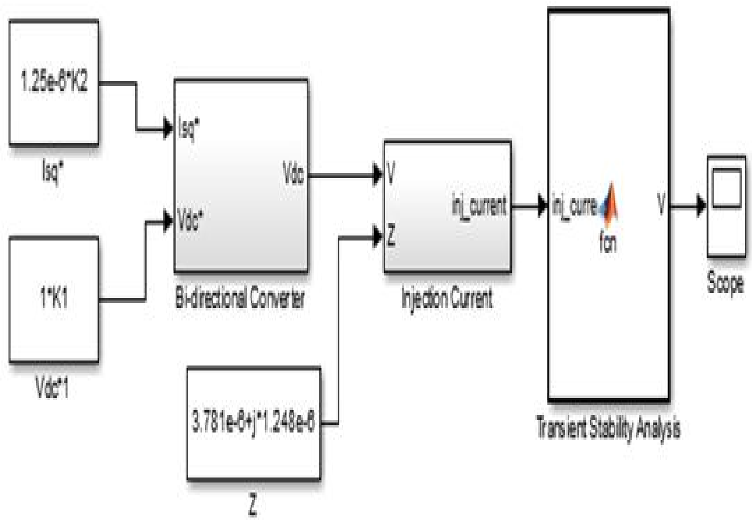

Fig.7. Simulink model of one converter integrated with embedded function block

3.3. CASE 3:

First converter is connected at bus 5, and second converter is connected at bus 8. Converter at bus 5 acts as LVDC grid generator as it gives real and reactive power to the bus system. Converter at bus 8 acts as LVDC

load by taking real power from the bus. Voltage at bus 5 and bus 8 are used to calculate currents injected at both the buses.

Line diagram of the system when converter is added at bus 5 and bus 8 is as shown in the Fig.8. Simulink model of both bi-directional converters where LVDC grid acts as generator or LVDC grid acts as a load when integrated with function block is as shown in Fig.9. Similar line diagram and Simulink model of the system are considered for case 4-case 5.

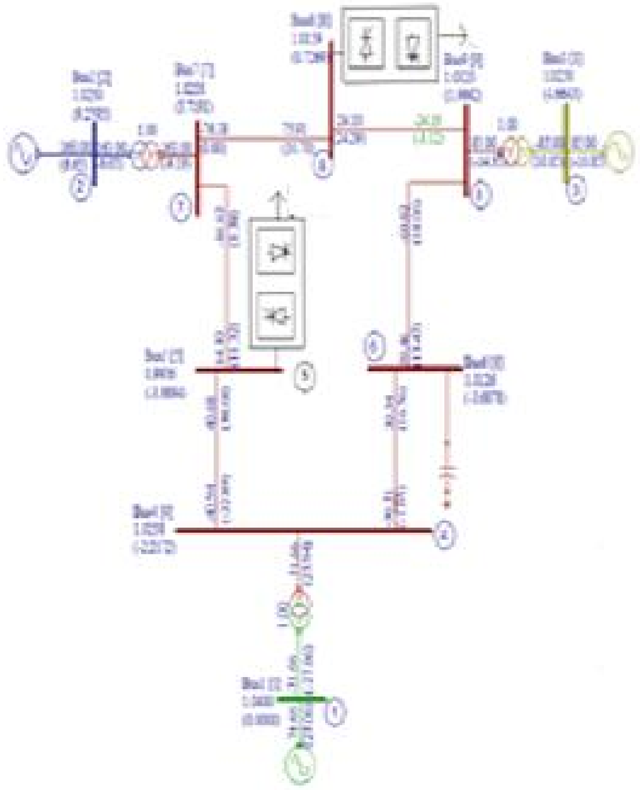

Fig.8. Line diagram of system when LVDC grid is connected at bus 5

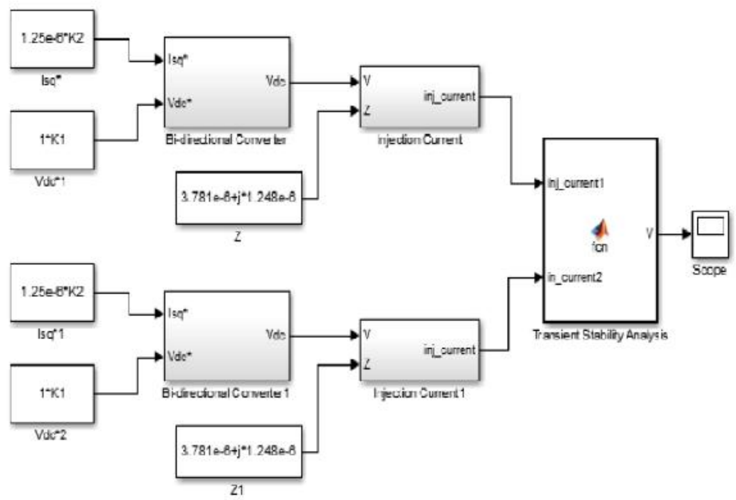

Fig.9. Simulink model of two converters integrated with embedded function block

3.4. CASE 4:

First converter is connected at bus 5, and second converter is connected at bus 8. Impendence and injection current of the two converters are added to the pre-fault impedance matrix and injection current matrix of the system at bus 5 and bus 8 respectively. Transient stability analysis is performed and the results are observed.

3.5. CASE 5:

First converter is connected at bus 5, and second converter is connected at bus 8. Converter at bus 5 acts as LVDC load by taking real power from the bus. Converter at bus 8 acts as LVDC grid generator as it gives real and reactive power to the bus system. Voltages at bus 5 and bus 8 are used to calculate currents injected at both the buses. Transient stability analysis is performed and the results are observed.

3.6. CASE 6:

First converter is connected at bus 5, and second converter is connected at bus 8. Converters at bus 5 and bus 8 acts as LVDC loads by taking real power from the bus. Voltages at bus 5 and bus 8 are used to calculate currents injected at both the buses.

4. RESULTS AND DISCUSSIONS:

In this paper the results obtained by using proposed model are discussed and also the results for different case studies are listed.

4.1. SIMULATION RESULTS OF BIDIRECTIONAL CONVERTER:

Simulation studies for vector controlled bi-directional converter control loops are conducted. In the converter the power flow is in either direction. The control of real and reactive powers is maid individually. The output of the control loops are represented individually.

4.1.1. CURRENT CONTROL LOOP:

Inner loop controller is faster than the outer control loop. The reactive control can be done by taking d-axis as reference where V_d is zero. There is independent loop for the control of i_s , d-axis current loop controls the reactive power. The output of inner loop controller is as shown in the Fig.10.

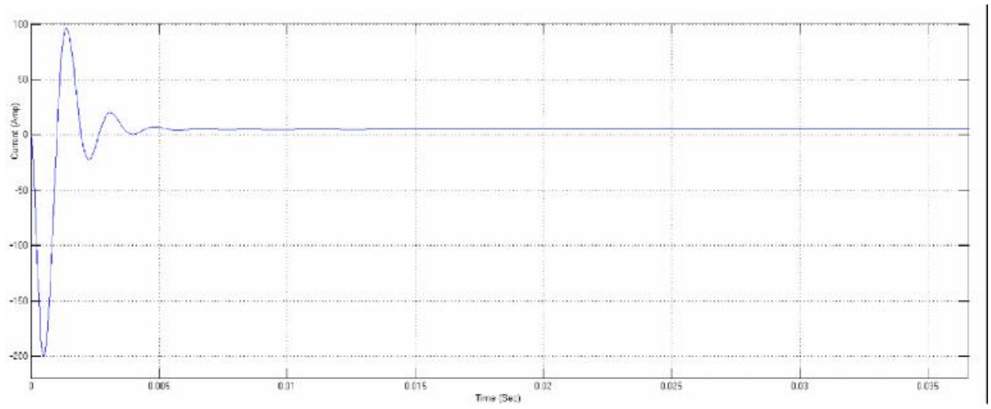

Fig.10. Output of current control loop

4.1.2. VOLTAGE CONTROL LOOP:

In order to decouple both dynamics, voltage control loop should be slower than inner control loop. The outer loop controls active power, reactive power and as well as to maintain the regulation of the DC link voltage to the reference value. The output current from the inner loop controller is given to the output capacitor from which the DC voltage is obtained. To ensure decoupling control of i_s , feed forward terms v_q are added. The output of outer loop controller is as shown in the Fig.11. The output DC voltage reaches to steady state after some time duration. The control of real power and reactive power can be observed from the output graph.

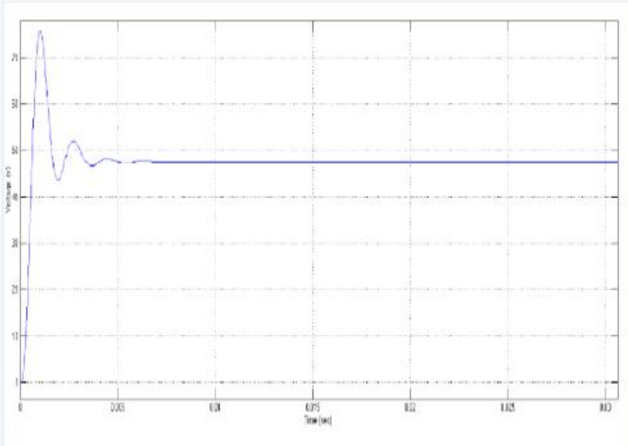

Fig.11. Output of voltage control loop

4.2. LOAD FLOW ANALYSIS RESULTS:

In a three phase AC power system active and reactive power flows from the generating station to the load through different networks buses and branches. The flow of active and reactive power is called power flow or load flow. Power flow studies provide asystematic mathematical approach for determination of various bus voltages, phase angles active and reactive power flows through different branches, generators and loads under steady state conditions.

Load flow analysis for the proposed system when bi-directional converters are integrated at different buses of conventional system is executed. The solution to the power flow problem for the proposed system provides information on the voltage magnitudes and angles, real and reactive power supplied or absorbed at each bus. Load flow analysis for six different cases is performed and the results are tabulated.

Load flow analysis of the system is initially executed in MiPower software. Voltage magnitude, real and reactive powers obtained from the load flow analysis states the performance of the bi-directional converter. LVDC grid may generate or LVDC may act as load. Six case studies are performed and are represented as shown below.

4.2.1. CASE 1:

In this case 1, one bi-directional converter is integrated at bus 5 as load to the conventional system. The load flow analysis for the system is executed in MATLAB function. Voltage magnitude, angles, real and reactive powers supplied or absorbed at particular bus of the system are tabulated in Table.1.

Table.1. Load flow results of the system when LVDC grid acts as load at bus 5

Bus No.	Voltage Magnitude(p.u.)	Angle (degree)	Real Power (MW)	Reactive Power (MVAR)
1	1.0400	0.00	288.56	72.37
2	1.0250	24.00	163.00	26.10
3	1.0250	16.64	85.00	5.69
4	1.0266	5.40	0.00	0.00
5	1.0410	13.55	-125.00	0.00
6	1.0109	5.45	0.00	0.00
7	1.0354	18.49	0.00	0.00
8	1.0213	14.34	0.00	0.00
9	1.0336	13.94	0.00	0.00

4.2.2. CASE 2:

In this case 2, one bi-directional converter is integrated at bus 5 as generator to the conventional system. The load flow analysis for the system is executed in MATLAB function. The converter at bus 5 gives the real and reactive power to the bus. Power flow in either direction of AC/LVDC network when bi-directional converter is integrated with traditional system is justified by conducting load flow analysis.

Voltage magnitude, angles, real and reactive powers supplied or absorbed at particular bus of the system are tabulated in Table.2.

Table.2. Load flow results of the system when LVDC grid is generating at bus 5

Bus No.	Voltage Magnitude (p.u.)	Angle (degree)	Real Power (MW)	Reactive Power (MVAR)
1	1.0400	0.00	61.86	-10.43
2	1.0250	15.67	163.00	-5.00
3	1.0250	9.90	85.00	-12.71
4	1.0390	1.16	0.00	0.00
5	1.0429	3.79	125.00	50.00
6	1.0215	0.33	0.00	0.00
7	1.0369	10.17	0.00	0.00
8	1.0237	6.68	0.00	0.00
9	1.0364	7.21	0.00	0.00

4.2.3. CASE 3:

In this case 3, one bi-directional converter is integrated at bus 5 as generator and second converter integrated at bus 8 as load. The load flow analysis for the system. The converter at bus 5 gives the real and reactive power to the bus and the converter at bus 8 takes the real power from the bus. Power flow in either direction of AC/LVDC network when bi-directional converter is integrated with traditional system is justified by conducting load flow analysis. Voltage magnitude, angles, real and reactive powers supplied or absorbed at particular bus of the system are tabulated in Table.3.

Table.3: Load flow results of the system when LVDC grid is generating at bus 5 and LVDC grid acts as load at bus 8

Bus No.	Voltage Magnitude (p.u.)	Angle (degree)	Real Power (MW)	Reactive Power (MVAR)
1	1.0400	0.00	61.86	-10.43
2	1.0250	5.64	163.00	-5.00
3	1.0250	0.27	85.00	-12.71
4	1.0463	-1.88	0.00	0.00
5	1.0509	-1.72	125.00	50.00
6	1.0276	-5.02	0.00	0.00
7	1.0320	0.12	0.00	0.00
8	1.0130	-5.49	-100.00	0.00
9	1.0334	-2.43	0.00	0.00

4.2.4. CASE 4:

In this case 4, both bi-directional converters integrated at bus 5 and bus 8 acts as generators. The load flow analysis for the system is executed in MATLAB function. The converters at bus 5 and bus 8 give the real power to the bus. Power flow in either direction of AC/LVDC network when bi-directional converter is integrated with traditional system is justified by conducting load flow analysis.

Voltage magnitude, angles, real and reactive powers supplied or absorbed at particular bus of the system are tabulated in Table.4.

Table.4 Load flow results of the system when LVDC grid is generating at bus 5 and bus 8

Bus No.	Voltage Magnitude (p.u.)	Angle (degree)	Real Power (MW)	Reactive Power (MVAR)
1	1.0400	0.00	-132.90	29.90
2	1.0250	25.38	163.00	-21.48
3	1.0250	19.26	85.00	-2.68
4	1.0261	4.11	0.00	0.00
5	1.0292	9.22	125.00	50.00
6	1.0093	5.56	0.00	0.00
7	1.0428	19.92	0.00	0.00
8	1.0460	18.36	100.00	30.00
9	1.0402	16.58	0.00	0.00

4.2.5. CASE 5:

In this case 5, one bi-directional converter integrated at bus 5 acts as load and second converter integrated at bus 8 as generators. Power flow in either direction of AC/LVDC network when bi-directional converter is integrated with traditional system is justified by conducting load flow analysis. Voltage magnitude, angles, real and reactive powers supplied or absorbed at particular bus of the system are tabulated in Table: 5.5.

Table.5 Load flow results of the system when LVDC grid acts as load at bus 5 and LVDC grid is generating at bus 8

Bus No.	Voltage Magnitude (p.u.)	Angle (degree)	Real Power (MW)	Reactive Power (MVAR)
1	1.0400	0.00	99.92	47.04
2	1.0250	11.63	163.00	2.77
3	1.0250	8.01	85.00	-19.67
4	1.0155	-3.12	0.00	0.00
5	0.9699	-7.75	-125.00	0.00
6	1.0051	-3.07	0.00	0.00
7	1.0281	6.09	0.00	0.00
8	1.0369	5.64	100.00	30.00
9	1.0374	5.32	0.00	0.00

4.2.6. CASE 6:

In this case 4, both bi-directional converters integrated at bus 5 and bus 8 acts as loads. The load flow analysis for the system is executed in MATLAB function. The converters at bus 5 and bus 8 give the real and reactive

power to the bus. Power flow in either direction of AC/LVDC network when bi-directional converter is integrated with traditional system is justified by conducting load flow analysis. Load flow analysis of the system is executed in Mi Power, and the results obtained from MATLAB are compared with it. Performance of the proposed system is analyzed by the results obtained at each bus in the system.

Voltage magnitude, angles, real and reactive powers supplied or absorbed at particular bus of the system are tabulated in Table.6.

Table.6 Load flow results of the system when LVDC grid acts as load at bus 5 and bus 8

Bus No.	Voltage Magnitude (p.u.)	Angle (degree)	Real Power (MW)	Reactive Power MVAR
1	1.0400	0.00	288.56	72.37
2	1.0250	-8.71	163.00	26.10
3	1.0250	-11.42	85.00	5.69
4	1.0126	-9.08	0.00	0.00
5	0.9698	-18.70	-125.00	0.00
6	1.0022	-13.79	0.00	0.00
7	1.0140	-14.34	0.00	0.00
8	0.9979	-18.87	-100.00	0.00
9	1.0229	-14.14	0.00	0.00

5. CONCLUSIONS:

In this paper, Design and control of the multi area AC/LVDC network is achieved. The power flow in either direction of AC/LVDC network is achieved. Bi-directional converter has been modeled for the flexibility of power flow in either directions of the grid. Vector Control is one of the most widely used control techniques. The bi-directional converter is controlled by using the Vector control method. Coding for Transient stability analysis has developed in MATLAB. Integration of Simulink model with the transient stability analysis of conventional test system is performed. Load flow analysis of the proposed system is executed for different test cases are executed. Voltages magnitudes, angles, real and reactive powers at each bus for different test case are observed. Simulation model of the bi-directional converter has been developed and executed for LVDC grid voltage requirements. By using the simulation results we can analyze the proposed method and also bi-directional converter can act as generator or load. The results will be observed by load flow analysis.

The proposed model is implemented in MATLAB/SIMULATION environment. The load flow results obtained from MATLAB simulations are tabulated. The power flow in either direction of AC/LVDC network is achieved. Finally the results are observed by load flow analysis.

6. FUTURE SCOPE:

Future scope of project will include:

- In this project conventional IEEE 9 bus system is used as test system. It can also be extended for larger networks.
- In this project transient stability analysis without any fault is executed. Transient stability analysis with disturbances for the system can be analyzed.

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