BFO based Control of Multi Terminal VSC-HVDC for Voltage Deviation

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Abstract— Multi-Terminal High-Voltage Direct Current (MTDC) transmission system has become an auxillary for transmitting power especially over long distances. .In AC grids, frequency are a global variable and for MTDC systems, DC voltage can be considered as it's dual. Unlike frequency, DC voltage cannot be equal across the MTDC system. The Control of DC voltage in MTDC systems is one of the important challenges. The dynamic of MTDC system is very fast, DC voltage control methods cannot rely only on remote information. Therefore, they can work based on either local information or a combination of local and remote information. The BFO algorithm is used to maintain the constant DC voltage operation during load switchings, step changes in power demand and also provides secured power to passive loads during loss of a DC voltage by regulating VSC-HVDC terminal without the use of communication. In this paper, the BFO algorithm along with Voltage Droop Method (VDM) is implemented in MATLAB/SIMULINK and it used to maintain the electromechanical stability of Multi-Terminal VSC-HVDC system.

Keywords: MTDC, HVDC, VDM, BFO

I. INTRODUCTION

High Voltage Direct Current (HVDC) systems has been an alternative method of transmitting electric power from one location to another with some inherent advantages over AC transmission systems. The efficiency and rated power carrying capacity of direct current transmission lines highly depends on the converter used in transforming the current from one form to another (AC to DC and vice versa). A well configured converter reduces harmonics, increases power transfer capabilities, and reliability in that it offers high tolerance to fault along the line. The classical HVDC has the need for active network connection at both ends (and hence its inability to supply passive loads), its consumption of reactive power at both terminals, its inability to reverse the direction of current flow, and its susceptibility to commutation failures have been the down sides of classical HVDC. These constraints have limited the use of classical HVDC to power transmission between two points. In the light of this understanding, Voltage sourced converter - HVDC (VSC-HVDC), a recent arrival in the area of high voltage technology has eliminated all the mentioned drawbacks of classical HVDC and opened new application areas and possibilities.[1]

Distributed generation has many advantages greatly due to its reducing the emission of greenhouse gases, increasing the reliability of the system and alleviating the pressure of power transmission, but output power is affected by the environment and when there is a fault in the power system, the distributed generation must be quitted which has restricted its application. The flexible multi-terminal DC grid technology is one of the effective techniques to solve this problemHVDC transmission systems designed and operated so far are point to point systems with two terminals (converter stations). A multiterminal DC (MTDC) system has more than two converter stations, some of them operating as rectifiers and others as inverters. The simplest way of building a MTDC system from an existing two terminal system is to introduce tappings. Parallel operation of converters and bi poles can also be viewed as multiterminal operation. Unlike in AC systems, the task of extending two terminal systems to multiterminal systems is not trivial. The complexities of control and protection increase considerably, and the use of HVDC breakers is generally required in the MTDC system.[2,3,4]

MTDC is a DC equivalent of AC grid which will have DC transmission network connecting more than two AC/DC converter stations. The range of operating voltage of the dc transmission is expected to be within specified upper and lower limits. The upper limit of the operating DC voltage can be determined by the ratings of the DC cables, DC circuit breakers or the forward blocking capacity of the IGBTs used in the VSC. The lower limit of the operating DC voltage is determined by the maximum of the operating AC voltages of all the converter stations incorporated in the MTDC system. The challenges of operating MTDC systems, like controlling the DC voltage, power flow in DC lines, interaction between converters, have been discussed in [5]. One of the most important issues is that the DC voltage across the MTDC system must be kept in an acceptable range. DC over-voltage could damage the converters, whereas DC under-voltage may result in reducing the converter controllability [6] Power inverters are widely used as the interface to integrate distributed generation (DG) units, renewable energy sources and energy storage systems into smart grids .They are often operated in parallel for enhanced system redundancy and reliability, as well as for high power and/or low cost. For HVDC transmission, Line commutated converters are used. But nowadays voltage source converters are used because VSC HVDC allows the common DC bus voltage allowing straight forward parallel connections, they permit independent control of active and reactive power[7]. VSC-HVDC consists of three phase switch mode converter and uses pulse width modulation(PWM) for controlling its phase voltages.

II. VSC BASED HVDC TRANSMISSION

The HVDC transmission technology can be realized by using current source converters (CSCs) commutated thyristor switches, known as traditional HVDC or classic HVDC, or by using voltage source converters (VSC-based HVDC). Due to the rapid development of power electronic devices with turn-off capability and of DSPs, which are generating the appropriate firing patterns, the VSC are getting more and more attractive for HVDC transmission. Usually, the VSCs are using insulated gate bipolar transistor (IGBT) valves and pulse width modulation (PWM) for creating the desired voltage wave form.[8,9,10].The first HVDC transmission using VSC was installed in 1997 in Gotland (Sweden).

A. Advantages OS VSC Based HVDC

- VSC converter technology provides rapid and independent control of active and reactive power without needing extra compensating equipment; the reactive power can be controlled at both terminals independently of the DC transmission voltage level.
- The commutation failures due to disturbances in the AC network can be reduced or even avoided if VSC-HVDC technology is used.
- The VSC-HVDC system can be connected to a "weak" AC network or to a network where no generation source is available (the VSC can work independently of any AC source), so the short circuit level is low.
- Self (forced) commutation with voltage source converters permits black start, which means that the VSC is used to synthesize a balanced set of three phase voltages as a virtual synchronous generator.
- Due to its modular, compact and standardized construction, the converter can be easily and rapidly installed/commissioned at the desired site.

B. Applications of VSC based HVDC

1) Power Supply to Insular Loads

Due to some of its advantages such as: dynamic voltage control, black start capability or forced-commutation the VSC-HVDC transmission is capable to supply remote locations (i.e. islands) using submarine cables and without any need of running expensive local generation. An example of this application is the Gotland Island System.

2) Offshore Applications

The VSC-based HVDC technology represents a very suitable way of transmitting from wind farms to the main AC grid. The ability of controlling reactive power as well as the AC voltage and its contribution to the grid stability makes the VSC-HVDC technology very popular for such applications. Moreover, the technology is flexible and new units can be easily added if the expand of the WF is desired.

3) Underground/Underwater Cables

The use of HVDC cable systems is not constraint by any distance limitations as in the case of AC cable systems. Moreover, the losses are reduced when an HVDC cable system is used. The XLPE (Cross Linked Poly-Ethylene) extruded HVDC cables can overcome RoW constrains and the power transfer capacity is increased the same time.

C. Multi-Terminal DC System

An MTDC is expected to consist of several VSC-HVDC terminals connected to each other by DC network. The MTDC should work with a fixed DC voltage level or with in a small window of upper and lower limits. Each of the terminals should be able to adopt different control strategy depending upon terminal specific needs. VSC-HVDC should monitor and control DC side parameters as well as AC side parameters. DC bus parameter control On the DC side, the VSC-HVDC may operate in constant DC voltage mode, constant power mode, or constant DC current mode [8]. When the VSC-HVDC is supplying power to passive load, none of the DC parameters is controlled. AC bus parameter control On the AC side, the VSC-HVDC may operate in constant AC voltage mode or constant reactive power mode depending on the type of the grid connection. Frequency droop can also be added optionally in the AC bus control.

D. Multi Terminal Topologies

Multi terminal HVDC-VSC systems are composed of a number of different converters which are connected to a common HVDC circuit.

The topologies are

- Point to point topology
- General ring topology
- Star topology
- Star with a central switching ring topology
- Wind farms ring topology
- Substations ring topology
- The multi terminal HVDC system has to assure the following:
- The DC voltage has to be controlled both in normal and faulted operation.
- In the event of a fault in the land based AC grid, the system has to be able to provide the support to the AC grid specified by the grid code.

III. CONTROL METHODS

Voltage sources inverters does not need any external reference to stay synchronized, they can operate in parallel with other inverters by using frequency and voltage droops forming autonomous microgrids. In distributed generation (DG) systems, there may be more than one inverter acting in parallel. Therefore, distributed uninterruptible power supply (UPS) systems as well as the parallel operation of voltage source inverters with other inverters or with the grid, are sensitive to disturbances from the load or other sources and can easily be damaged by over current. Hence, careful attention should be given to system design and the control of parallel operation of inverters. The conventional control strategies for the parallel-connected inverters can be classified into two types; active load sharing or current distribution. The droop control method for the parallel-connected inverters can avoid the communication mismatch of reference current. It is also defined as wireless control (WC) with no interconnection between the inverters. In this case, the inverters are controlled in such a way that the amplitude and frequency of the reference voltage signal will follow a droop as the load current increases and these droops. To ensure the steady operation of the multi-terminal high voltage direct current transmission based on voltage source converter (VSC-HVDC) grid, the basic control requirements are to maintain the stability of the DC voltage. DC voltage serves as an indicator of power balance and operation stability in an MTDC system, the DC voltage control of the VSC-MTDC system has become a priority to ensure overall system stability. In order to keep the DC voltage stable ,the voltage control methods are used. Theoretically, mainly three basic methods that control the DC voltage of the VSC-MTDC system, namely, (1) master slave method, (2) the voltage margin method (VMM), (3) the voltage droop method (VDM), have been proposed[11,12,13]

The first method can achieve high operation accuracy because the master converter can keep the DC voltage at the reference value and other slave converters can regulate power according to the power references. However, master-slave control method is tightly dependent on fast communication and the remote information is required. Since the DC voltage control is totally lost if the master converter fails, the master slave control method suffers from poor reliability. Some authors [14,15] proposed control strategies, which are a combination of VDM and VMM .To reduce dependency on fast communication and increase system reliability, decentralized control strategies such as VMM and VDM have been proposed. In VMM, one converter is responsible for maintaining its DC voltage in the desired level, whereas other terminals operate at the constant power mode. Given some technical constrains, when the master converter is no longer able to supply or extract the active power necessary for controlling its DC voltage, another converter will operate as the master converter. However, a margin must be considered between the references DC voltages of terminals. The transition between these two reference voltages places great stress on the converter. Moreover, the voltage margin must be large enough to avoid interactions between controllers. VDM is independent of communication. In VDM, which originates from power-frequency droop control in AC systems, all or some converters participate in regulating the DC voltage and sharing the power imbalance simultaneously in an appropriate way. VDM exhibits higher reliability than the master slave control and does not lead to voltage oscillation associated with VMM.

IV. BACTERIAL FORAGING OPTIMIZATION ALGORITHM (BFOA)

Bacterial Foraging Optimization Algorithm (BFOA) is proposed by Kevin Passino (2002), is a new comer to the family of nature inspired optimization algorithms. Application of group foraging strategy of a swarm of E.coli bacteria in multi-optimal function optimization is the key idea of this new algorithm. Bacteria search for nutrients is a manner to maximize energy obtained per unit time. Individual bacterium also communicates with other by sending signals. A bacterium takes foraging decisions after considering two previous factors. The process, in which a bacterium moves by taking small steps while searching for nutrients, is called chemotaxis. The key idea of BFOA is mimicking chemotactic movement of virtual bacteria in the problem search space.

p : Dimension of the search space,
S : Total number of bacteria in the population,
Nc : The number of chemotactic steps,
Ns : The swimming length.
Nre : The number of reproduction steps,
Ned : The number of elimination-dispersal events,
Ped : Elimination-dispersal probability,
C(i): The size of the step taken in the random direction specified by the tumb.

Bacterial Foraging optimization consist of four stages

- Chemotaxis
- Swarming
- Reproduction and
- Eliminational-Dispersal.

The Chemotaxis is the process that simulates the movement of an E.coli cell through swimming and tumbling via flagella. In swarming A group of E.coli cells arrange themselves in a traveling ring by moving up the nutrient gradient when placed amidst a semisolid matrix with a single nutrient chemo-effecter. The cells when stimulated by a high level of succinate, release an attractant aspartate, which helps them to aggregate into groups and thus move as concentric patterns of swarms with high bacterial density.

In reproduction stage, the least healthy bacteria eventually die while each of the healthier bacteria (those yielding lower value of the objective function) asexually split into two bacteria, which are then placed in the same location. This keeps the swarm size constant.

In Elimination and Dispersal process, Gradual or sudden changes in the local environment where a bacterium population lives may occur due to various reasons e.g. a significant local rise of temperature may kill a group of bacteria that are currently in a region with a high concentration of nutrient gradients. Events can take place in such a fashion that all the bacteria in a region are killed or a group is dispersed into a new location. To simulate this phenomenon in BFOA some bacteria are liquidated at random with a very small probability while the new replacements are randomly initialized over the search space.

V. SIMULATION STUDIES AND RESULT

Bacterial foraging optimization algorithm (BFOA) Based Control of Multi-terminal VSC-HVDC For Voltage Deviation is simulated in MATLAB/SIMULINK model is shown in figure 1.

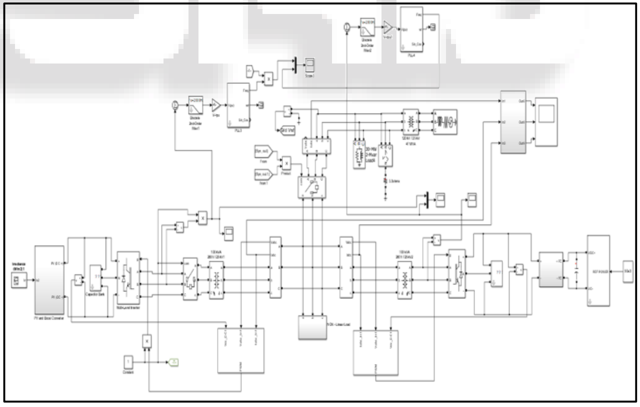

Fig. 1: simulation of BFO based control

Two parallel inverters with droop controller is implemented with dynamic load, phase lock loop Is implemented to measure frequency. Capacitor banks are used for energy balance. Voltage measurements blocks are used to measure voltage across bus, filters are placed to damp out fluctuations. Solar energy and other fuel cells are used as the input to the inverter. Irradiance value of 1000lux is given to the solar panel and the boost converter, the output is fed into the inverter. On the other side fuel cells or other renewable sources can be used as the input to the inverter. Droop control method is implemented for reliable power sharing.

VSC based two parallel connected inverters are implemented with nonlinear and three phase load without using the BFOA among with droop control. The voltage fluctuation waveforms are shown in Figure 2,3.

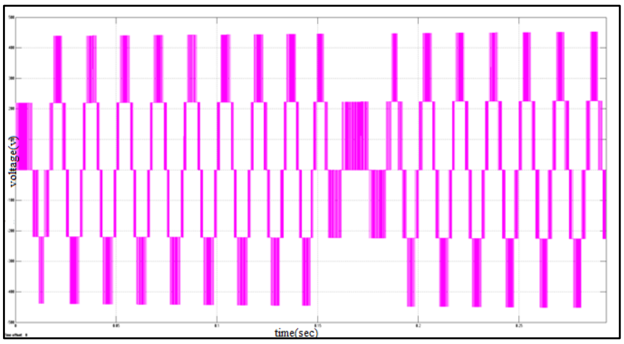

Fig. 2: voltage waveform

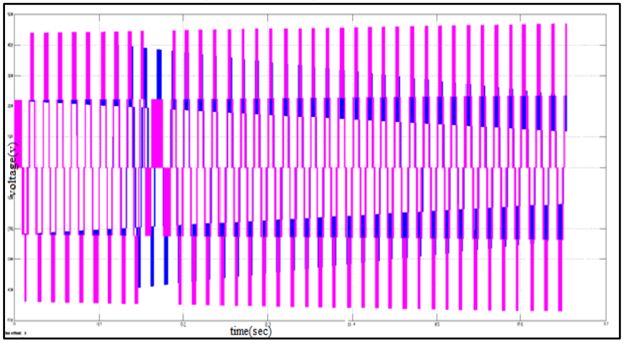

Fig. 3: Combined voltage waveform of two parallel connected converter.

The BFOA along with droop control will results in amplitude, frequency and phase synchronization among the output voltages of inverters. The amplitude and frequency of the reference voltage signal will follow droop as the load current increases and these droops are used to allow independent inverters to share the load. The output waveform is represent in Figure 4,5.

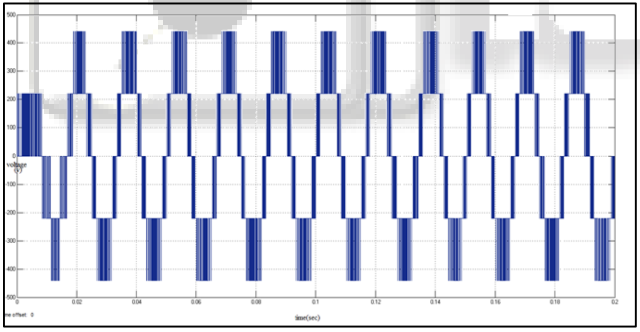

Fig. 4: BFO based voltage waveform

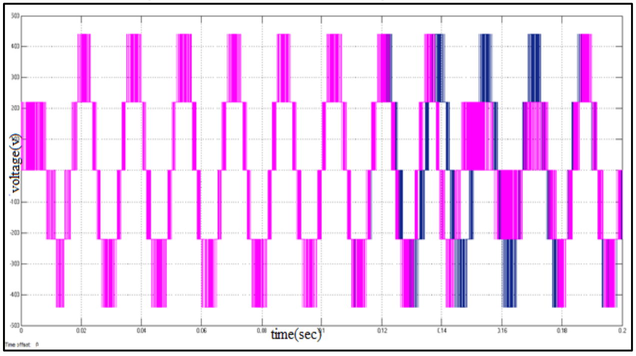

Fig. 5: voltage waveform

VI. CONCLUSION

Among the several forms used to connect voltage source inverters in parallel, it is possible to classify them in two groups: 1) the systems without communication and 2) the systems with communication. Parallelism with communication, as for instance in master-slave systems, uses an external cable for synchronization of the references and division of the loads. In the case of a failure in that communication, the whole system can fail, unless another unit assumes the control. Seeking to avoid that type of problem, it was developed a system that works in parallel without any communication among the units. One of the methods more commonly implemented is known as Drooping Method. In this paper, the goal was to develop a system that besides highly reliable, it also had capacity for expansion as the loads increase, without the need of alterations in the equipments already installed. To increase the reliability and robustness of the system, it was adopted parallel operation of the inverters without communication among the units. The proposed paper has a BFO algorithm and Droop control method for parallel connected inverters. This method can effectively control the voltage and reduce the fluctuations among parallel-connected inverters. The voltage and frequency fluctuations are reduced without the use of communication channels. A prototype consisting of two inverters has been developed and the proposed control has better performance.

REFERENCES

[1] M. Barnes and A. Beddard, "Voltage Source Converter HVDC Links – The State of the Art and Issues Going Forward," Energy Procedia, vol. 24, pp. 108-122, 2012.

[2] N. Flourentzou, V. G. Agelidis, and G. D. Demetriades, "VSC-Based HVDC Power Transmission Systems: An Overview," IEEE Trans. Power Electron., vol. 24, no. 3, pp. 592–602, 2009.

[3] W. Lu and B.-T. Ooi, "Optimal acquisition and aggregation of offshore wind power by multiterminal voltage-source HVDC," IEEE Trans. Power Del., vol. 18, no. 1, pp. 201–206, Jan. 2003.

[4] Y. Wang, Z. Yuan, and J. Fu, "A Novel Strategy on Smooth Connection of an Offline MMC Station Into MTDC Systems, " IEEE Trans. Power Del., vol. 31, no. 2, pp. 568–574, Apr. 2016.

[5] Dirk Van Hertem and Mehrdad Ghandhari. "Multi-terminal VSC HVDC for the European supergrid: Obstacles. Renewable and Sustainable Energy Reviews,'' 14(9):3156–3163, December 2010.

[6] L. Xu and L. Yao. "Dc voltage control and power dispatch of a multi-terminal hvdc system for integrating large offshore wind farms. IET Renewable Power Generation," 5(3):223–233, 2011.

[7] Egea-Alvarez, A. Junyent-Ferré, O. Gomis-Bellmunt, "Active and reactivepower control of grid connected distributed generation systems, in: L. Wang(Ed.), Modeling and Control of Sustainable Power Systems". Green Energy and Technology, Springer, Berlin, Heidelberg, 2012, pp. 47–81.

[8] T.Ackermann, "Transmission systems for offshore wind farms, "IEEE PowerEng.Rev., vol. 22, no. 12, pp. 23–27, Dec. 2002.

[9] N. B. Negra, J. Todorovic, and T.Ackermann, "Loss evaluation of HVAC and HVDC transmission solutions

for large offshore wind farms,"Elect. PowerSyst. Res.,vol.76, no.11,pp.916–927,2006.

[10] N. Flourentzou, V. G. Agelidis, and G. D. Demetriades, "VSC-based HVDC power transmission systems: An overview," IEEE Trans. Power Electron.,vol.24,no.3,pp.592–602,Mar.2009.

[11] Raza, A.; Dianguo, X.; Yuchao, L.; Xunwen, S.; Williams, B.W.; Cecati, C "Coordin. ated operation and control of VSC based multiterminal high voltage DC transmission systems."IEEE Trans. Sustain. Energy 2016, 7, 364–373. 21.

[12] Chen, H.R.; Xu, Z. "A novel DC voltage control strategy for VSC based multi-terminal HVDC system." Autom. Electr. Power Syst. 2006, 30, 28–33.

[13] Yao, L.Z.; Wu, J.; Wang, Z.B.; Li, Y.; Lu, Z.X. "Pattern analysis of future HVDC grid development." Proc. CSEE 2014, 34, 6007–6020.

[14] L. Xu and L. Yao. "Dc voltage control and power dispatch of a multi-terminal hvdc system for integrating large offshore wind farms". Renewable Power Generation, IET, 5(3):223–233, May 2011.

[15] T. Haileselassie and K. Uhlen. "Multiterminal hvdc for offshore windfarms control strategy." In European Power Electronics Energy Chapter Seminar 2009, pages 1–6, Nov 2009.