ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 12, December 2015

Analysis of Integrated Hybrid VSC Based Multi Terminal DC System Using Control Strategy

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ABSTRACT: The reason why there is much greater interest in High Voltage Direct Current (HVDC) today is due to advanced in power electronics innovations. To transmit bulk power, to control power , to modulate power and to improvement in system stability, mostly Multi Terminal DC(MTDC) system based on Voltage Source Converter(VSC) is introduced in transmission network of HVDC link.In this paper we propose an idea to integrate more renewable energy into the existing grid and to provide remote islands with reliable power supply. The idea is to expand the existing point to point line commuted converter high voltage direct current transmission link into a hybrid multi terminal high voltage direct current system. Also propoes a novel control strategy active voltage feedback control for hybrid system which does not require high speed communication system in various disturbances, like wind speed variations, load fluctuations, fault conditaion. Modeling and simulation result of this hybrid system is able to achieve more reliable conditaion and voltage feedback control work very well without any disturbances.

KEYWORDS; High Voltage Direct Current(HVDC), Multi Terminal DC(MTDC), Voltage Source Converter(VSC), Control Of HVDC.

I. INTRODUCTION

Now it is fully confidential that there is no exaggeration to say that HVDC technology was introduced as a response to the need of having a more efficient and flexible transmission system. This need became more important especially due to increase in electricity demand and number of the renewable energy sources connected to the grid such as wind power sources. HVDC system has been conventionally used to interconnect two AC power systems working either at two different frequencies or at the same frequency but without being synchronized. It is also used as a way of delivering electric power between two distant points through overhead transmission lines or submarine cables. Another feature of HVDC systems which made them to be put into service in parallel with the AC transmission systems is capability of rapidly control on the transferred power. Alternating Current(AC) system suffer so call called line losses that can range from 10-15%, but HVDC line losses are closer to just 2 %. HVDC system are 100% controllable the power will only go where you want it to go, where as AC systems flow sometimes in unpredictable ways, an attribute that contributes to rolling blackout or brownouts. In this way, HVDC systems can act like firewells,limiting grid distrubance to small geographical area.

In this paper we propose an idea to integrate large capcity renewable energy into the existing power grid, provide remote islands with reliable power supply, and regulate the frequencies. Our idea to expand an existing traditional point to point line controlled converter HVDC line into hybrid MTDC system. propose a novel steady state control strategy named active voltage feedback control for this system. This control strategy features that: (i) does not rely on telecommunication systems; (ii) can realize large scale renewable energy integration; (iii) ensures that the frequency control reserve can be shared through the whole dc grid.

II. VOLTAGE SOURCE CONVERTER (VSC) BASED MULTI TERMINAL DC (MTDC) SYSTEM

The topologies for the MTDC system have been investigated in several papers, the converter station can be either connected in series to share the same DC current, or in parallel with a common DC voltage. The connection topology affects the system design from several aspects, including power flow reversal, terminal capacity, transmission losses, insulation, ACIDC fault response, and corresponding protections. As a well-accepted solution, the parallel VSC-MTDC topology is suggested with higher system reliability without increasing the complexity in the control and protection system, and therefore has been chosen in this paper for further study.

VSC based multi terminal HVDC system contains number of VSC's either offshore or onshore connected to same HVDC link. VSC connected to generating station can be offshore or onshore depending upon renewable energy nature i.e. tidal energy, offshore wind farms, solar panels etc. But throughout this paper we will consider offshore wind farms as it have more capacity to generate electricity and can meet the needs as in previous papers. Each offshore wind farm requires an offshore substation used to install VSC converter and number of connections to HVDC link depends upon MTDC application. Before designing MTDC system, design engineer must consider techno-economic factors imposed by utility. Economic factors include geographical location, number of offshore substations, onshore platforms, HVDC link, HVDC Circuit Breaker, ultra-fast mechanically actuated disconnector, and cost. Technical aspects can be: effective utilization of MTDC lines, rating of HVDC link, protection of MTDC under abnormal conditions and support to connected AC network. MTDC system must satisfy the security and Quality of Supply Standard. as well as DC voltage of MTDC system must be constant during abnormal conditions on AC sides of VSC HVDC. Each terminal of VSC based MTDC system must be able to control active and reactive power, support AC network voltage and frequency independently. VSC based MTDC system behavior strongly depends upon the control nature which mainly rely on system topology and kind of AC grid connection.

III. PROPOSED SYSTEM

We assume a case that there is a traditional point-to-point LCC HVDC line on land rated 1000MW and 500kV. The rectifier station Grid Side Rectifier (GSREC) is located in the western energy-rich area, and connected to a strong grid (SCR=8) with sufficient active and reactive power reserves. The inverter station Grid Side Inverter (GSINV) is built in the eastern coastal part, and SCR of its connected ac grid is about 5.5. After expansion, GSINV will remain unchanged, and GSREC's rated power output will increase to 1500MW.

There are abundant wind energy resources in the sea 110km eastward from point A, so a wind farm rated 430MW is planned there, and the wind power is sent out through a VSC station called VSC2. On one hand, wind speed at sea is not influenced by surface roughness, so the wind shear is relatively small, on the other hand, visual pollution, noise pollution and even the impact on birds can be avoided or reduced, because the offshore wind farm is far away from the land.

There are two islands near the offshore wind farm, Island 1 to the north and Island 2 to the south. As Fig. 2(a) shows, there have been two power plants which rate 165MW and 85MW respectively on Island 1. To ensure reliability of its power supply, the ac grid on this island (AC Grid 1) is a ring structure with rated voltage of 110kV. Now a VSC station (VSC1) rated 200MW is planned on Island 1, then Plant 1 will be shut down. In the south, the ac grid rated voltage on Island 2 (AC Grid 2) is also 110kV, as Fig. 2(b) shows. A VSC station rated 250MW and a PV station rated 50MW will be built on Island 2 to guarantee the power supply. Note that real rotary inertia exists in AC Grid 1, whereas does not exist in AC Grid 2.

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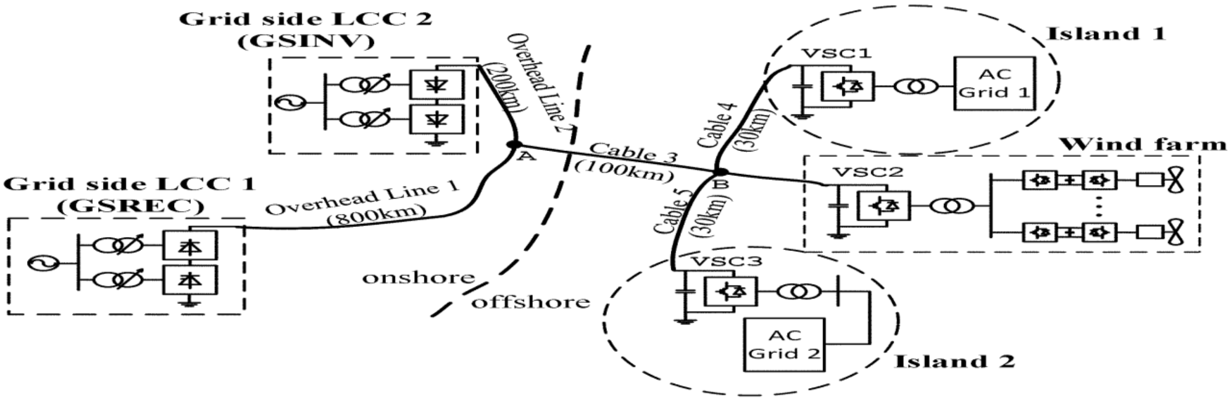

Fig. 1. Single line diagram of the proposed hybrid MTDC system

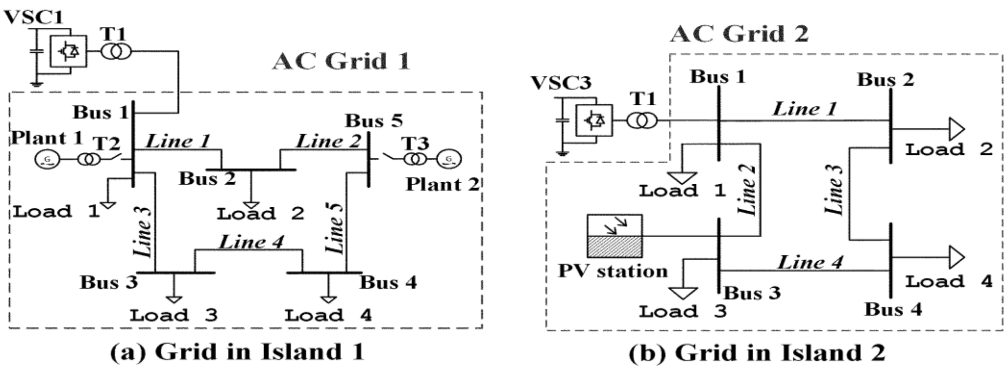

Fig. 2. Network topologies of AC Grid 1 and AC Grid 2

In this system the VSC converters are three-level bridge blocks using close to ideal switching device model of IGBT/diodes. The relative ease with which the IGBT can be controlled and its suitability for high-frequency switching, has made this device the better choice over GTO and thyristors. A converter transformer (Wye grounded /Delta) is used to permit the optimal voltage transformation. The present winding arrangement blocks tripplen harmonics produced by the converter. The transformer tap changer or saturation are not simulated. The tap position is rather at a fixed position determined by a multiplication factor applied to the primary nominal voltage of the converter transformers The multiplication factors are chosen to have a modulation index around 0.85 (transformer ratios of 0.915 on the rectifier side and 1.015 on the inverter side).

The converter reactor and the transformer leakage reactance permit the VSC output voltage to shift in phase and amplitude with respect to the AC system, and allows control of converter active and reactive power output. To meet AC system harmonic specifications, AC filters form an essential part of the scheme. They can be connected as shunt elements on the AC system side or the converter side of the converter transformer. Since there are only high frequency harmonics, shunt filtering is therefore relatively small compared to the converter rating. It is sufficient with a high pass-filter and no tuned filters are needed. The later arrangement is used in our model and a converter reactor, an air cored device, separates the fundamental frequency (filter bus) from the raw PWM waveform (converter bus).

The reservoir DC capacitors are connected to the VSC terminals. They have an influence on the system dynamics and the voltage ripple on the DC side. The size of the capacitor is defined by the time constant τ corresponding to the time it takes to charge the capacitor to the base voltage (100 kV) if it is charged with the base current (1 kA). This yields $\tau = C \cdot Zbase = 70e\text{-}6 \cdot 100 = 7$ ms with Zbase = 100kV/1 kA.

The DC side filters blocking high-frequency are tuned to the 3rd harmonic, i.e., the main harmonic present in the positive and negative pole voltages. It is shown that a reactive converter current generate a relatively large third harmonic in both the positive and negative pole voltages but not in the total DC voltage. The DC harmonics can also

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be zero-sequence harmonics (odd multiples of 3) transferred to the DC side (e.g., through the grounded AC filters). A smoothing reactor is connected in series at each pole terminal. To keep the DC side balanced, the level of the difference between the pole voltages has to be controlled and kept to zero (see the DC Voltage Balance Control block in the VSC Controller block). The rectifier and the inverter are interconnected through a 75 km cable (2 pi sections). The use of underground cable is typical for VSC-HVDC links. A circuit breaker is used to apply a three-phase to ground fault on the inverter AC side. A Three-Phase Programmable Voltage Source block is used in station 1 system to apply voltage sags.

Power can be controlled by changing the phase angle of the converter ac voltage with respect to the filter bus voltage, whereas the reactive power can be controlled by changing the magnitude of the fundamental component of the converter ac voltage with respect to the filter bus voltage. By controlling these two aspects of the converter voltage, operation in all four quadrants is possible. This means that the converter can be operated in the middle of its reactive power range near unity power factor to maintain dynamic reactive power reserve for contingency voltage support similar to a static var compensator. It also means that the real power transfer can be changed rapidly without altering the reactive power exchange with the ac network or waiting for switching of shunt compensation. Fig. shows the characteristic ac voltage waveforms before and after the ac filters along with the controlled items Ud, Id, Q and Uac.

IV. CONTROL OF THE HYBRID MTDC SYSTEM

In this section, the article will propose and present in detail a novel control strategy for the hybrid MTDC system in this control is named active voltage feedback control. A qualified control strategy for MTDC system should consider the dc grid’s energy balance as well as the connected ac grid’s energy balance. I.e., both dc bus voltage and ac grid’s frequency should stabilize at its rated value. Besides achieving energy balance, active voltage feedback control proposed by this paper features that: When integrating volatile and intermittent renewable energies, or experiencing various disturbances, the hybrid MTDC system can run normally without high speed communication system. In the following part, the active voltage feedback control will be introduced in details. First, local control strategies of three VSC stations in the offshore grid are introduced. Then, back on land, local controls of GSINV and GSREC are elaborately explained. After that, we can have a complete picture of the active voltage feedback control. Broadly speaking, in the dc grid, the offshore grid part is seen as a current source, GSREC plays the role of a slack bus, and dc voltage is maintained through the cooperation between GSREC and GSINV with no reliance on high speed communication system.

Controls of different electric components in the offshore grid in total, the offshore grid part can be regarded as a load node in the dc grid. Regardless of line losses, per unit value of the active power which flows from onshore grid to offshore grid is represented as in power of voltage source converter.

In brief, the control target of GSINV and GSREC is that GSINV can extract a specified amount of dc current from the hybrid MTDC system, GSREC can serve as a slack bus in the dc grid, and dc voltage can be maintained at a desirable value.

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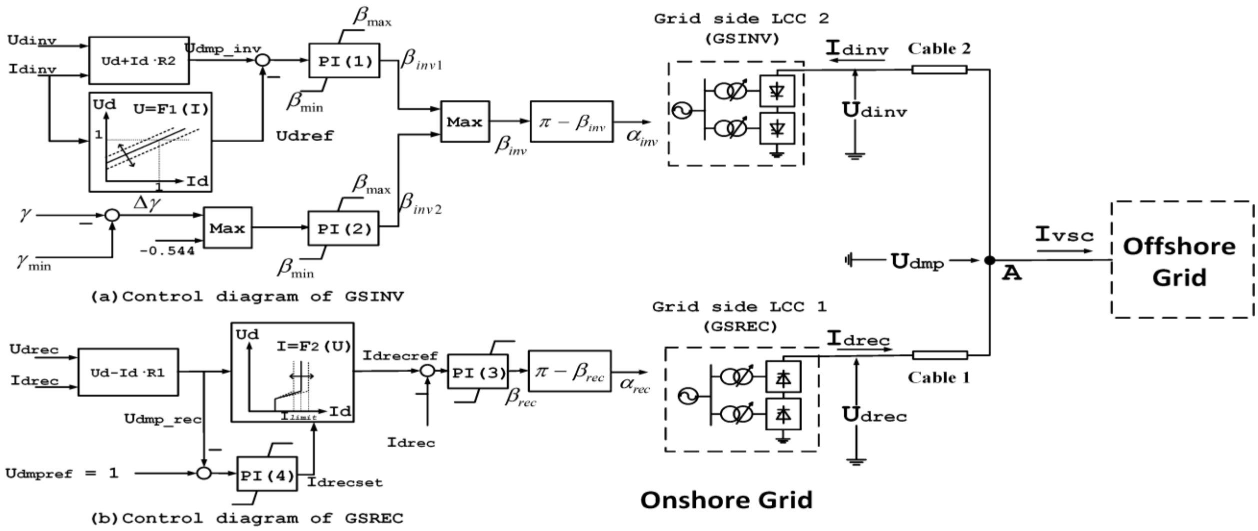

Fig. 3 Control diagrams of GSINV and GSREC

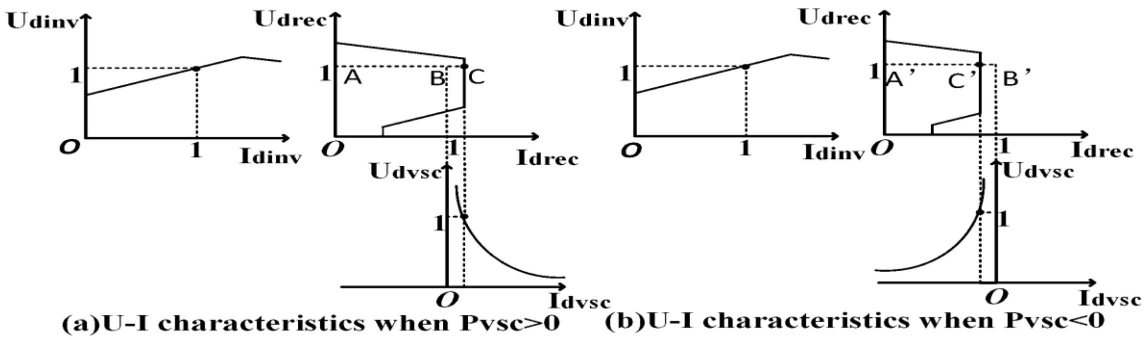

Fig. 4 Current voltage characteristics of the hybrid MTDC system

When the whole system starts up, these steps can be followed: (i) the point-to-point HVDC system including GSINV and GSREC starts up with the aid of telecommunication system, then the system switches to *active voltage feedback control*; (ii) in Island 1, VSC1 is unblocked and connected to the dc grid, but its active power output is set to 0; (iii) Plant1 reduces its active power output to 0 slowly, meanwhile VSC1 gradually injects more active power into the AC Grid 1; (iv) VSC2 is unblocked and connected to the dc grid, then the wind turbines at sea are synchronized to the grid group after group to minimize the impact; (v) after the offshore wind farm has been connected to the dc grid, VSC3 is unblocked to power the Island 2; (vi) the PV station can be connected to the AC Grid 2.

V. RESULTS AND RESPONSE

In this sections, the dynamic performance of the transmission system is verified by simulating and observing the Dynamic response to step changes applied to the principal regulator references, like active/reactive power and DC voltage Recovery from minor and severe perturbations in the AC system For a comprehensive explanation of the procedure followed obtaining these results and more, refer to the Model Information block.Different waveform which show the relation of both side of dc line is obtained. The hybrid MTDC system and its control was modelled in PSCAD/EMTDC, In this the whole hybrid MTDC system was tested under various disturbances, e.g., wind speed variations, solar radiation changes, load fluctuations and even faults, to verify the *active voltage feedback control*'s feasibility. The hybrid MTDC system can operate normally without high speed communication system during the whole process.

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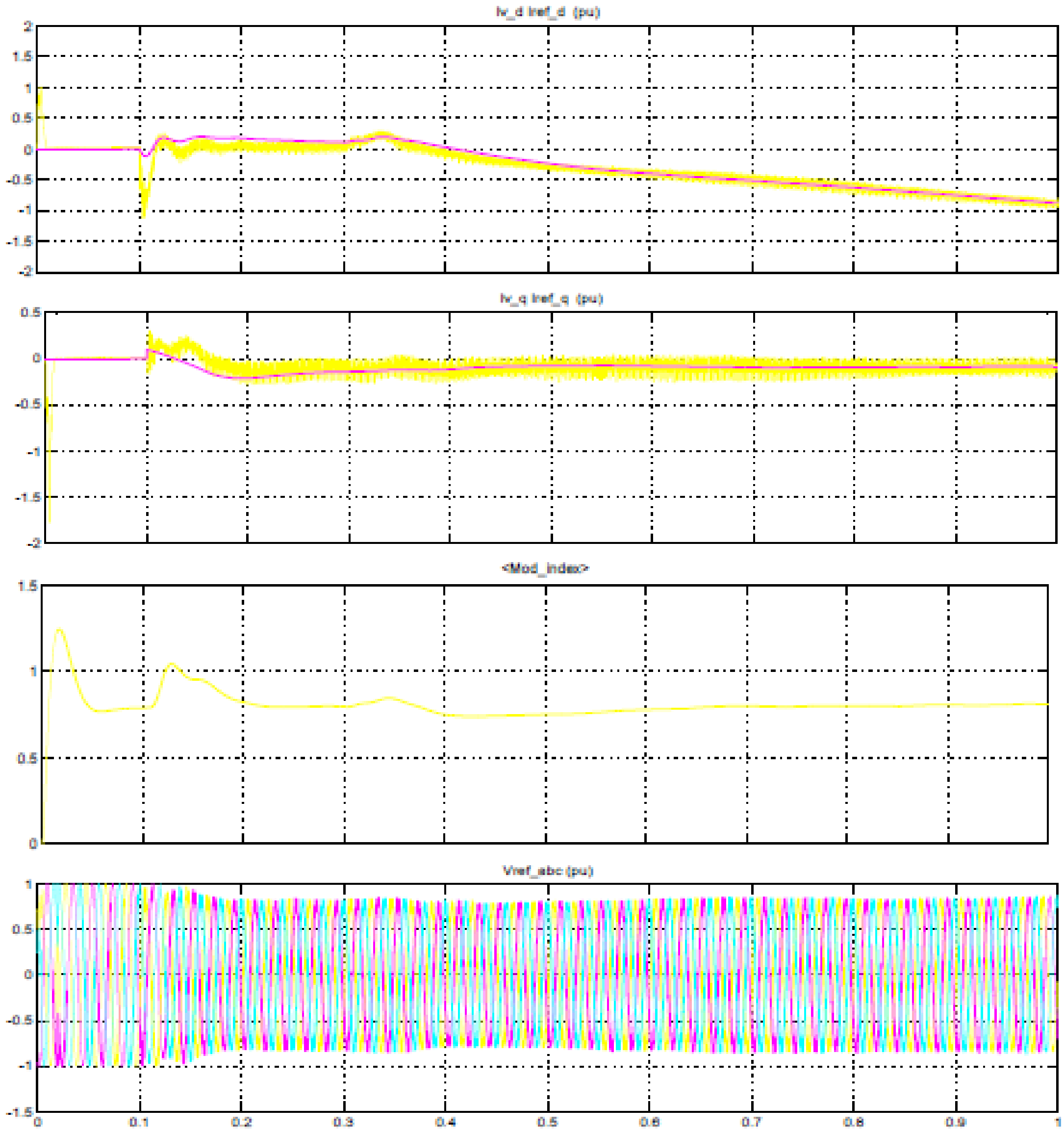

Fig. 5 Control signal of station output

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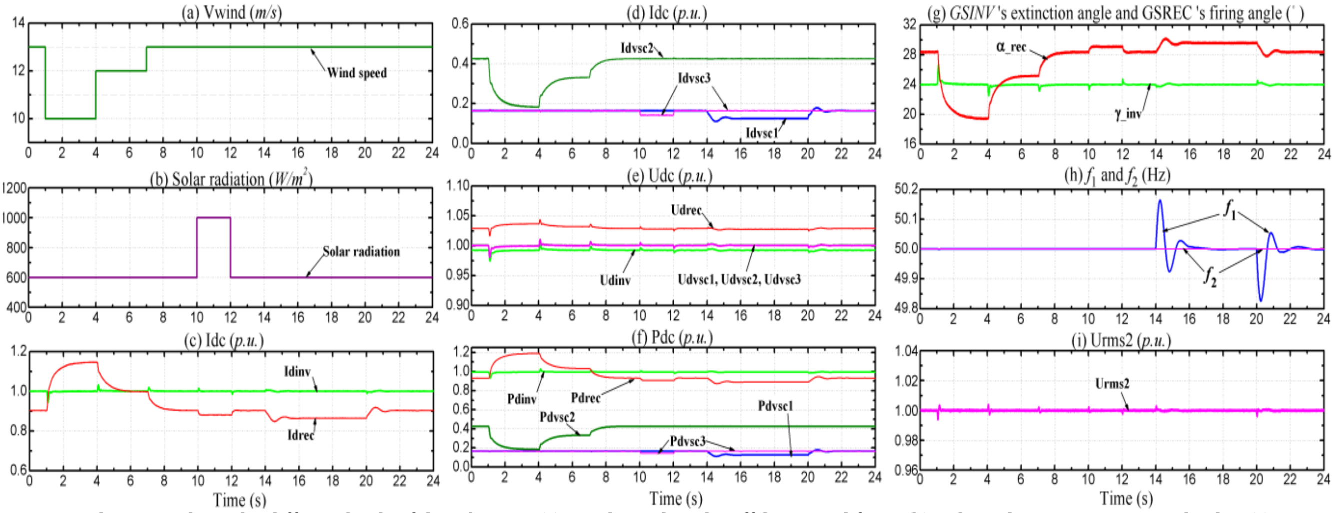

Fig. 6 Simulation results under different kinds of disturbances. (a) Wind speed on the offshore wind farm. (b) Solar radiation intensity in Island 2. (c) DC currents of GSINV and GSREC. (d) DC currents of VSC1, VSC2 and VSC3. (e) DC voltage. (f) DC power. (g) GSINV's extinction angle and GSREC's firing angle. (h) Grid frequencies in Island 1 and Island 2. (i) AC voltage in Island 2.

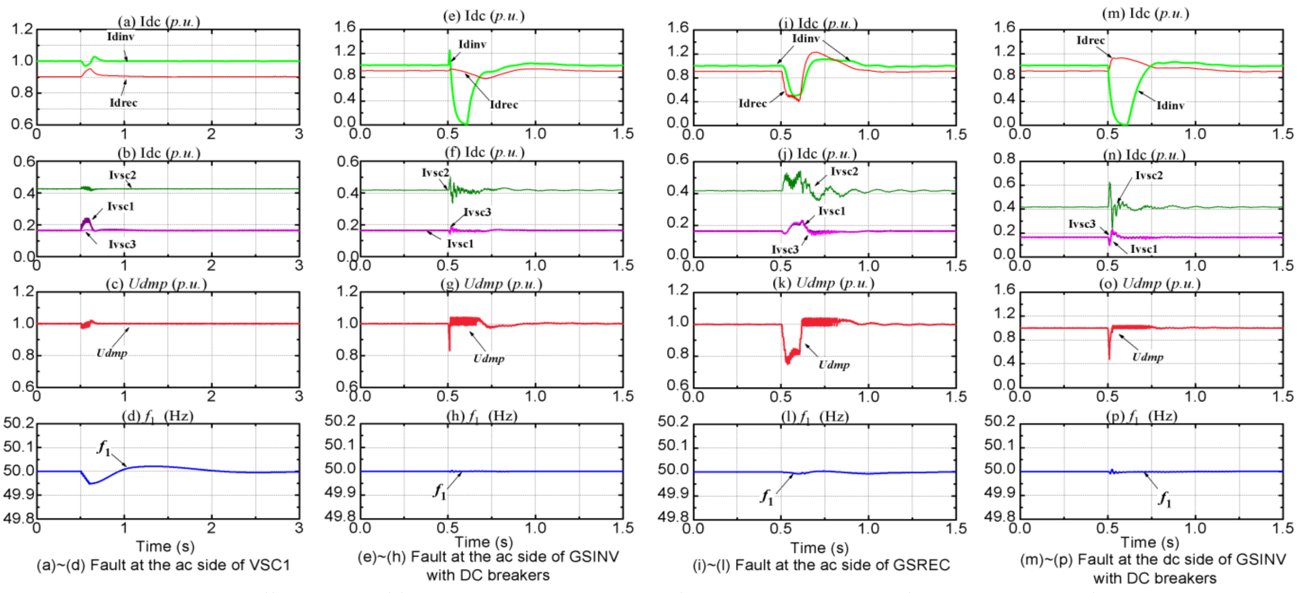

Fig. 7 Simulation results under different kinds of faults. (a)(e)(i)(m) DC currents of GSINV and GSREC. (b)(f)(j)(n) DC currents of VSC1, VSC2 and VSC3. (c)(g)(k)(o) DC voltage at point A in Fig. 1. (d)(h)(l)(p) Grid frequency in Island 1.

VI. CONCLUSION AND FUTURE WORKS

In this paper mainly an idea proposed to intigarte the system to achive reliable supply and regulate their grid frequencies at the same time, to improve the traditional control system , voltage source converter based multi terminal direct current system in high voltage system is proposed, result of both station show the better quality then previous papers performance. In near future due to digital signal technology and fast growing protection and control equipments high voltage dc system beat extra high voltage ac system in each and every performance. The proposed active voltage feedback control: (i) makes the system integrate more renewable energy, and offer reliable power supply for remote islands. (ii) During normal operation, it can make the hybrid MTDC system work at a desirable operating point independent of telecommunication system. (iii) With dc breakers and dc damping resistor, the hybrid MTDC system can ride through various faults. In India several HVDC project based on new digital technology running in progress, thanks

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to power industries which help to develop DC system more accurately to better future of renewable energy and to maintain quality of supply to people.

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