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A Design of Droop Control for Multi terminal HVDC of Offshore Wind Farms with Three-Wire Bipolar Transmission

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Abstract: This paper presents a droop control design for multi terminal HVDC (MTDC) of offshore wind farm with three wire bipolar transmission lines. The MTDC (Multi Terminal HVDC) represents a suitable solution in solving wind farms interconnection problems. The interconnection of offshore wind farms is considered as a cost effective way by converting existing ac transmission lines to multi-terminal three wire bipolar HVDC system. In this paper it shows that converting existing ac transmission lines into extended multi-terminal HVDC transmission line to interconnect the offshore wind farm to onshore grid. The converters in multi terminal hvdc lines needs fast communication between them. But, by adopting the droop control techniques as effective means in multi terminal hvdc lines, there is no need of fast communication between them. This droop control techniques are mainly depends on line resistances. Droop control techniques have been proposed as a means to regulate the dc voltage. Different techniques have been proposed to select the droop gains to satisfy the performance of the system.
Keywords: MTDC, Three Wire Bipolar Transmission Lines, Droop Control Technique, HVDC.

I. INTRODUCTION

Electricity generation through wind plays a major role in the world's future renewable energy. Now a day's wind power integration is a challenging research area because of its special characteristics. And the electrical energy generation through offshore wind farm plays a significant role in the renewable energy generation due to the availability of vast potential energy [3]. The MTDC (Multi terminal HVDC) solution represents a suitable solution in solving wind farms interconnection problems. And it leads to automatically coordinate between different converters in wind farm without the need of fast communication between them. MTDC can be classified based on its connection into parallel (radial parallel or meshed parallel) and series connections. The Droop control design is mainly depends on line resistances. This line resistance of 3-wire bipolar systems changes based on its operational modes (two wire or three wire mode). The selection of proper mode will be depends upon the transmitted current level i.e. the two wire mode is operated when the transmitted current level is lower and three wire mode is operated when the transmitted current level is higher.

Droop control techniques are mainly depends on line resistances. Droop control techniques have been proposed as a means to regulate the dc voltage [2]. Different techniques have been proposed to select the droop gains to satisfy the performance of the system. The technical and economical benefits of HVDC via undersea cables are increasing in power transmission, reducing cost for long transmission lines, connecting asynchronous systems, reducing corona loss and interconnection of the offshore wind farms with the main power grid. Additionally, the contribution of HVDC system to the ac side faults is less, and also the controlling of HVDC systems is easier than HVAC systems. Integration of offshore energy into the existing power grid has brought in the utilization of HVDC transmission, which draws little capacitive current compared with the HVAC solution. Voltage source converter (VSC) can work as an interface between DC and AC networks. And the contribution of HVDC system in the AC side faults is small, and also the control of HVDC is easy than HVAC. To reduce the complexity of the system with dc values, instead of AC values [3]. But, park transformations have some disadvantages to like the PLL which causes the waveform to follow the grid voltage according to the angle (θ).Renewable energy is predicted to supply 15% of the total world's energy by 2020. The idea of droop control is based on frequency-power control in the traditional AC power systems. VSC HVDC provides a complete controllability of DC network, which allows a connection of number of converters to the same dc grid. This advantage is the realization of MTDC offshore wind farm for grid integration. Due to the need of extendibility in the future parallel (mesh or radial) connections are preferred. The increase in demand of electrical energy adds a burden to the transmission network to supply the demand in an effective way to the load point.

This shows that building up of new HVDC lines is expensive, due to the manufacturing of tower, erection and costs of converter. The control of VSC in MTDC system is mainly based on appropriate voltage-current characteristics is suitable for operating modes. Different control methods are available in the literature such as voltage margin, master slave, and DC voltage droop control.

Among all these DC voltage droop control methodology is preferred due to the no need of fast communication between them, which is a significant advantage over other control methods [1]. It is used to balance the power in DC grid considering dc line drops. And the main contribution of this paper is the effect of resistance change on the selection of the droop gain is to be investigated.

II. TRANSMISSION

There are two different types of transmissions HVAC and HVDC. By using HVAC it leads to dielectric loss due to the insulation size of the transmission cable is greater than conductor size. Whenever insulation size increases, concept of capacitance comes into picture and it leads to charging currents, then sending end power decreases. Hence, directly using of HVAC gives losses. Then there is another technique called LFAC (Low Frequency AC) transmission.

In LFAC systems, an intermediate frequency level 16.66 (50/3 Hz) or 20Hz is used [9], created by using a cyclo-converter, that lowers the grid frequency to a smaller value, normally to one-third its value. In general, the main advantage of the LFAC technology is the increase of power capacity and transmission distance for a given submarine cable compared to 50-Hz HVAC.

But, by using HVDC, there is no concept of frequency in HVDC. Hence HVDC gives vast economical advantages than HVAC and LFAC. HVDC system has two types of classifications, depending on the types of power-electronic devices used:

1) Line-Commutated Converter HVDC (LCC-HVDC) using thyristors and
2) Voltage-Source Converter HVDC (VSC-HVDC) using self-commutated devices.

The major advantage of HVDC technology is that it imposes effectively no limit on transmission distance because of the absence of reactive current in the transmission line. VSC provides superior operational advantages over LCC’s in HVDC applications for future grid expansion. Those superior operational advantages are of faster dynamic response, independent control of active and reactive powers and avoiding communication failure and no need of transformer as in case of LCC.

Instead of building new HVDC transmission lines, converting exiting HVAC systems into HVDC can solve many problems associated with new HVDC lines [2]. Firstly, HVAC is converted into a monopole HVDC but facing a problem in ground return. Then converted into a bipole HVDC but in this bipole hvdc the three wires are not fully utilized, only two wires are utilized and the third one is kept ideal. It leads to a limited transmission capacity. Using of third wire in a proper way can definitely increase in efficiency of transmission lines over the monopole and bipole without exceeding the thermal limits [8]. In order to increase transmission capacity, a tripole concept was proposed i.e. existing HVAC line is converted into a tripole HVDC. Which makes the fully utilization of three wires in the transmission lines and the transmission capacity also increased accordingly to the 1.3667 times than bipolar. But this type of HVDC system is difficult to integrate in tripole HVDC of MTDC grid.

Another three wire HVDC system is proposed. Here, it uses the third wire (intermediate wire) is used as a modulating pole. This intermediate wire is paralleled with the other two wires, then it connects to the one wire for certain time to create one pole and another wire with some time to create one (second) pole by using power electronic switches such as IGBT’s. And a series CRC (Current Regulation Controller) is connect to the intermediate wire to equalize the voltage between both the poles and a series resistance (Rc) is connected with a switch to limit the discharging currents during transient period. This way the transmission capacity of the three wire bipolar HVDC increases [7].

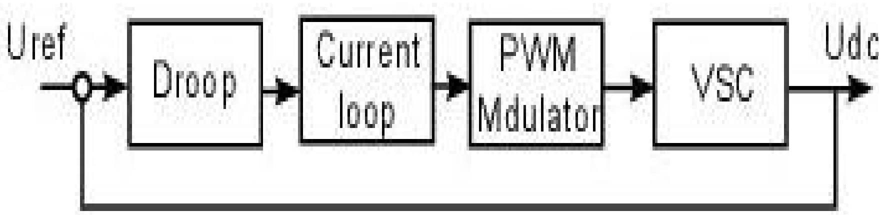

Fig.1. Droop Control Design Scheme

III. THREE WIRE BI POLAR HVDC

The benefits that behind the HVDC transmission and its transfer capabilities are well known in above section. In this paper the capacity of two operating wires dc transmission is used. In this three wire bipolar HVDC all the three wires are utilized using a transmission modulating process [5]. The structure of tripole HVDC is as shown below in Fig.2.

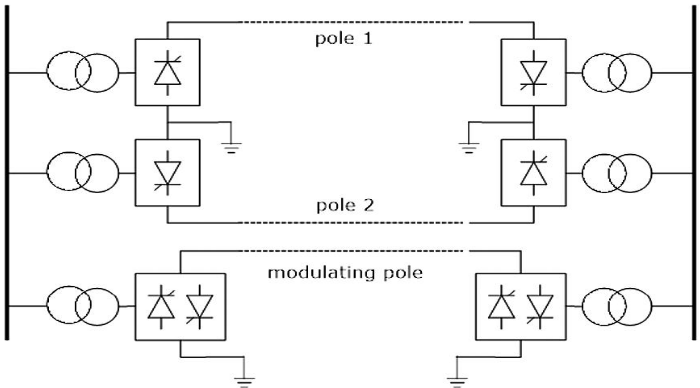

Fig. 2. Structure of the tripole HVDC.

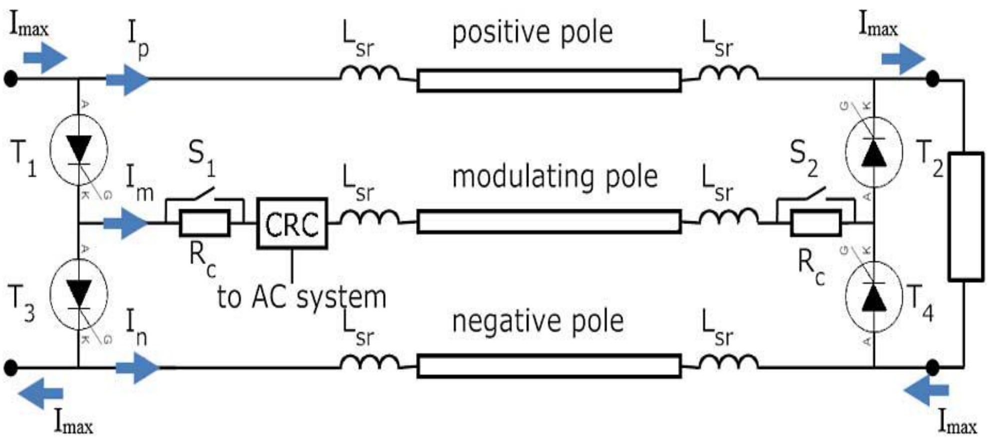

Fig.3. Three-wire bipolar HVDC system.

The respective outputs of the three wire bipolar HVDC system is as follows:

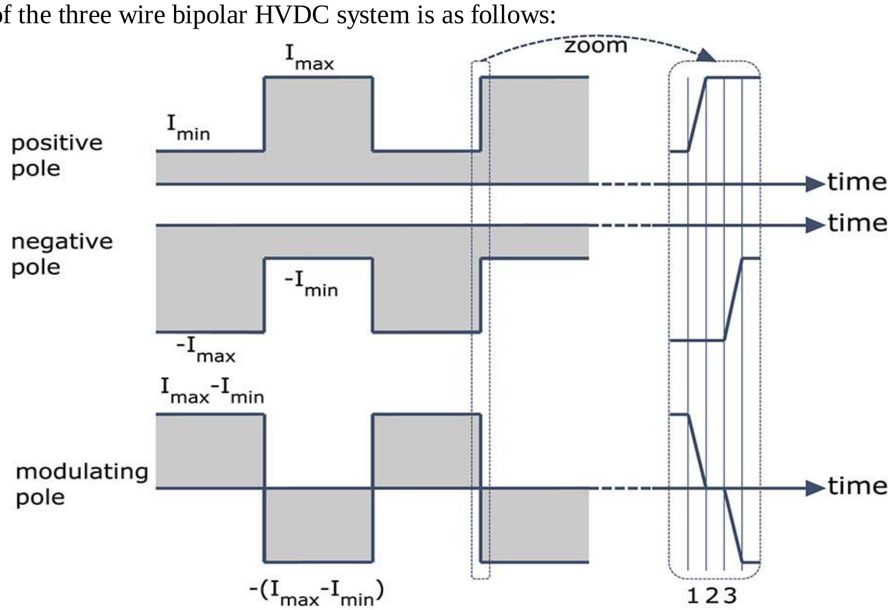

Fig.4. Current diagrams of three-wire bipolar HVDC system.

The third wire is used as a reversible monopole in both voltage and current to create tripole HVDC system create a third pole called modulation pole. Then the power transfer is increases by 36.67% compared with the bipolar HVDC[2]. The converters are complex to realize of the third pole because of periodic reversal of currents and voltages on the modulating pole[6].

$$I_{p(\text{rms})} = I_{n(\text{rms})} = \sqrt{\frac{1}{2}\left(I_{\max}^2 + I_{\min}^2\right)} = I_{\text{limit}} \quad (1)$$

where I_{limit} is the thermal limit of the cable.

The rms current of the modulating pole is also set equal to its thermal limit, as shown in

$$I_{m(\text{rms})} = I_{\max} - I_{\min} = I_{\text{limit}}. \quad (2)$$

Solving (1) and (2) results in

$$I_{\min} = (2 - \sqrt{3}) I_{\max}. \quad (3)$$

Hence, the rms current for the modulating current is given by

$$I_{m(\text{rms})} = (\sqrt{3} - 1) I_{\max} \quad (4)$$

and the corresponding limits are

$$I_{\max} = 1.366\, I_{\text{limit}} \quad (5)$$
$$I_{\min} = 0.366\, I_{\text{limit}}. \quad (6)$$

The power transferred using bipolar HVDC (P_{2w}) at the thermal limit of its two poles is calculated from

$$P_{2w} = 2V I_{\text{limit}} \quad (7)$$

The power transferred using the three-wire bipolar HVDC (P_{3w}) at the thermal limit of its three wires is calculated in

$$P_{3w} = 2V \times 1.366\, I_{\text{limit}} \quad (8)$$

Dividing (8) by (7), the ratio of the power transferred by the three-wire bipolar HVDC to the power transferred using conventional bipolar HVDC is 1.366. Thus, the power transfer of the three-wire bipolar structure can be increased by 36.6% over the regular bipolar structure without exceeding the system thermal limit.

IV. MULTI TERMINAL HVDC TRANSMISSION

In a multi-terminal configuration, the same control can be used. To reduce the need for communication even further, presents a two-stage DC voltage control. The main slack converter is still implemented as before with its voltage reference at V_{DC}(ref). The other converters will be implemented in two stages, as shown in Fig. 5. This increases the flexibility in two ways. First, the active power in all buses can be easily regulated by changing Pref. At the same time the active power limits Pmin and Pmax can be kept at the physical boundaries of the converter at all times. Second, it provides an easy way to give all buses a certain level of importance [3]. For example, if it is desired that one bus always keeps working at Pref, both the upper and lower voltage margin can be made sufficiently large. In that way, other buses will be assigned the role of slack bus first, when the main slack bus has reached its limits. A PI-controller is a straightforward choice to regulate VDC, since it will always control the DC voltage to its reference value. However, it should be noted that it is not feasible to control VDC at different places at the same time [4]. This could give rise to suboptimal operating points (statically) and hunting oscillations (dynamically).

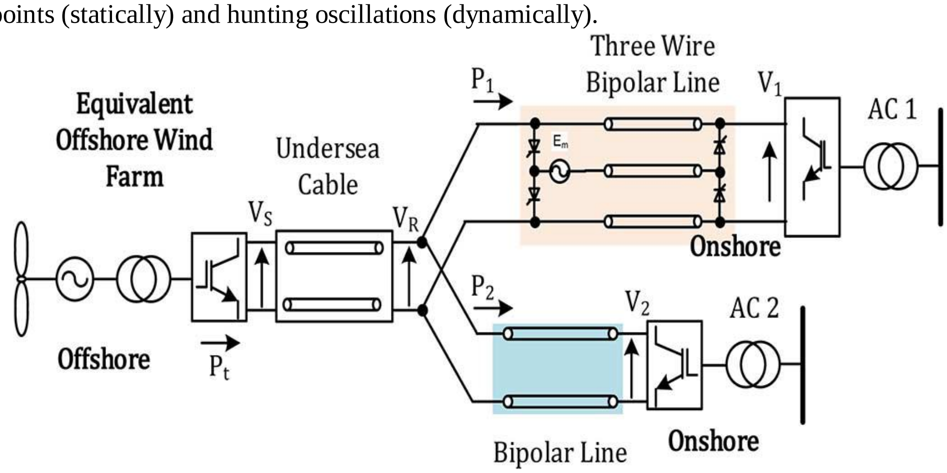

Fig.5. Offshore wind-farm grid-integration using a three terminal HVDC system.

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A. Voltage Droop Control

When voltage droop control is used in the absence of a PI controller, the voltage controller's active power P will change when the value of the DC bus voltage V_{DC} changes. This principle is shown in Fig. 5. When V_{DC} drops (e.g. due to large withdrawal of power someplace else in the DC network) the slack bus will increase the active power injection in the DC grid P until a new equilibrium point, at a lower DC voltage, is reached. The use of a proportional V_{DC}-controller allows multiple converters to regulate the voltage at the same time. This control can now be adapted by including a voltage margin. The voltage droop characteristic with a voltage margin is shown in Fig. 6. This characteristic can be horizontally transposed when Pref needs to be changed. Note however that there should always be one converter (the main slack converter) implemented with a voltage droop without this voltage margin, or with a PI-controller. This will give the best transient response since it allows a continuous regulation of V_{DC} around Vref [1].

When the main slack converter also uses droop control, the other converters join in regulating V_{DC}, once the voltage margin is exceeded. When the main slack converter is using a PI-controller to regulate V_{DC}, the droop on the other buses will only have effect in case of transients or in case the voltage drop across the DC cables is larger than the voltage margin [4]. This is obvious since the PI-controller will ensure there is no steady state error and therefore V_{DC} will stay within the voltage margin. A PI-controller on the main slack bus is preferable because it lowers the voltage rating of the converters.

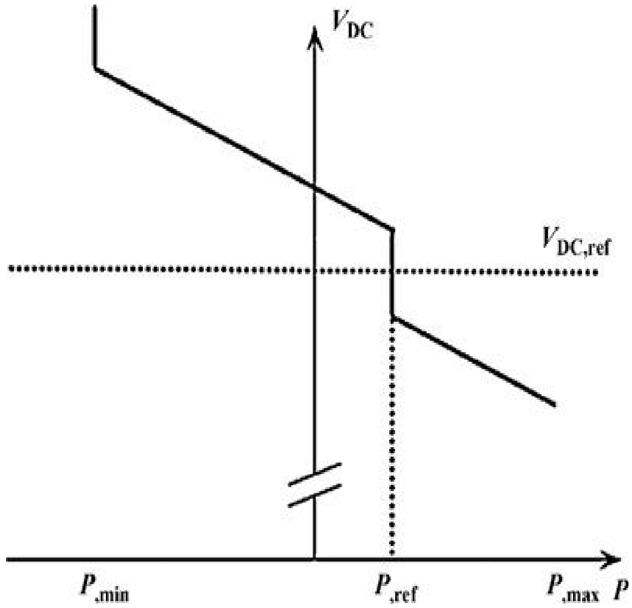

Fig.6. Voltage droop characteristic with voltage margin.

B. Problem Statement

As the MMC is used in high voltage and high power applications, the switching frequency must be limited for safe operation of IGBTs. At such sampling-to fundamental low frequency ratios, the dynamic performance of the control loops [6], i.e. AC side current control, becomes a challenge. Reduced switching frequency algorithms of current control should be used. The applied in HVDC system will be investigated in this thesis, so AC side current control of will also be studied and the control system mainly has two functions:

1) Independent active and reactive power control following the desired values.
2) Regulation of the dc-bus voltage at its nominal value.

Motivated by the promising future of the MMC and HVDC system for offshore wind power, as well as the technical challenges introduced above, this thesis will focus on the current control of MMC in HVDC systems especially on the wind farm side. The current control methods introduced in existing academic papers are reviewed first and some of the algorithms are simulated and compared. This paper mainly focuses on changes required for the droop gain converters connected to three wire bipolar HVDC systems. The power transferred using bipolar HVDC at the thermal limit is as

$$P = 2V \times 1.366\ I_{limits}$$

In power-sharing mode, the converters are operating with a dc voltage droop characteristic defined by the droop gains, provided that their currents are less than their maximum limits. Thus, the selected droop gains affect the power transferred by each converter.

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V. PROPOSED SYSTEM

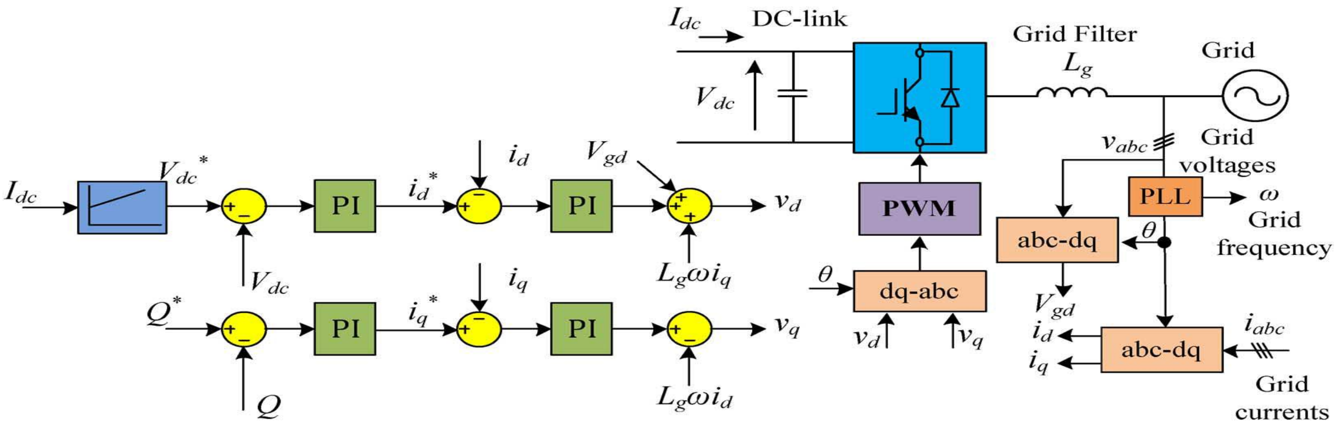

Fig.7. DC voltage control mode of grid-side converter.

In the following subsections, dc voltage current droop control is employed using a three-terminal radial parallel HVDC system. To verify the effect of terminal voltage on transmission loss and impact of droop control on the optimum transmission, simulations are carried out using Matlab Sim-Power System Tool. By keeping time factor only averaged models of the VSCs are considered for power converters to avoid long simulation time.

A. Simulation Goals

This paper is focused to offer an alternative way of connecting the offshore wind farm with two asynchronous grids. The solution comes with the Multi-terminal HVDC concept which gives this possibility of connection. The paper goals are summarized as follows:

1) Implementation of the entire system in MATLAB/Simulation Tool Box.
2) Overview of the possible transmission system that can be suitable for offshore wind farms.
3) Description of the VSC-HVDC transmission systems.
4) study of the multi terminal HVDC connecting possibility;
5) modeling of the offshore WF - including all the components of the wind turbine (generator, aerodynamic model, mechanical model), the wind model and the pitch controller;
6) Modeling of the HVDC system - including the PWM converters, the DC cables, the filters and the control structure for the converters, proper sizing of all of the system components, sending an efficient method of control of power sharing for the considered multi-terminal system;

VI. SIMULATION & EXPERIMENTAL RESULTS

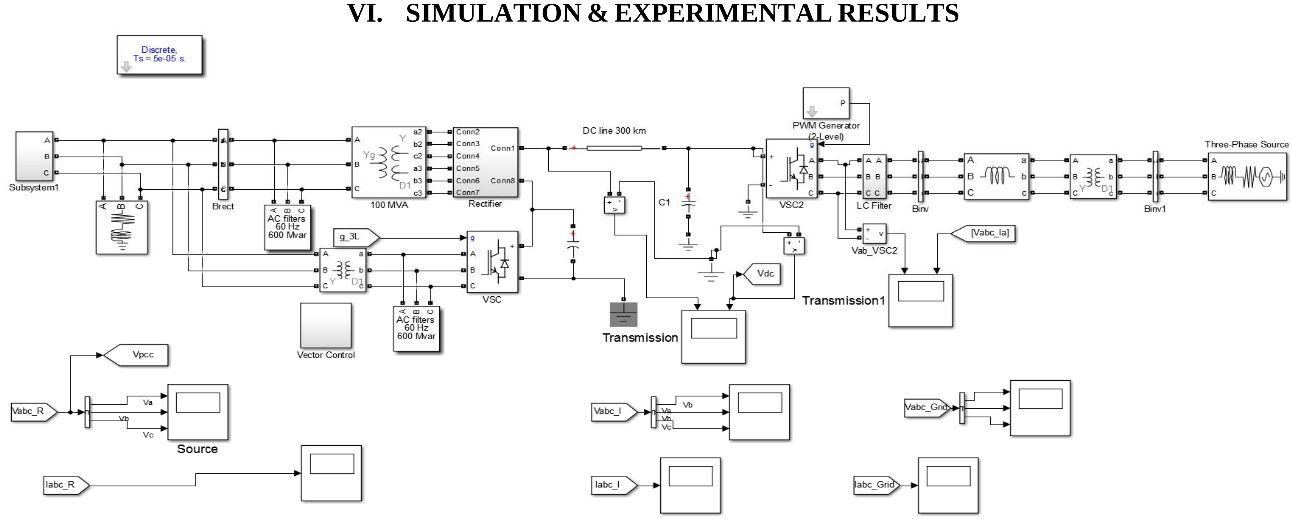

Fig. 8 Simulation Circuit

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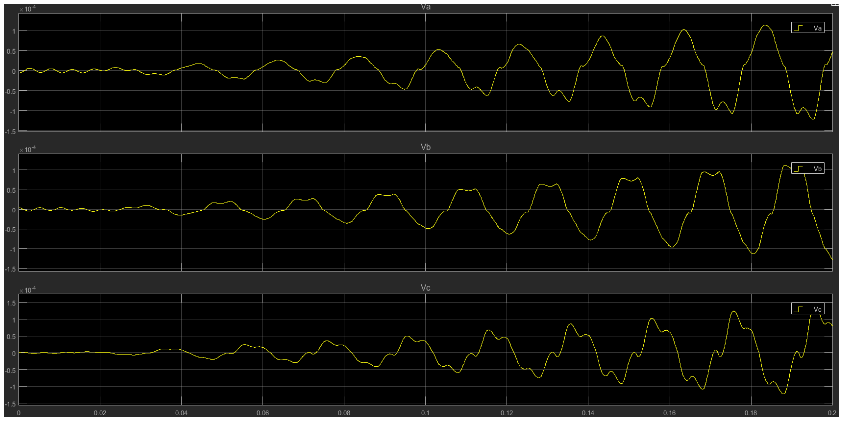
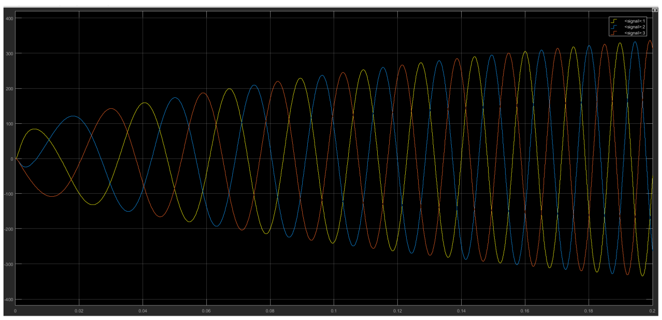
A. Results

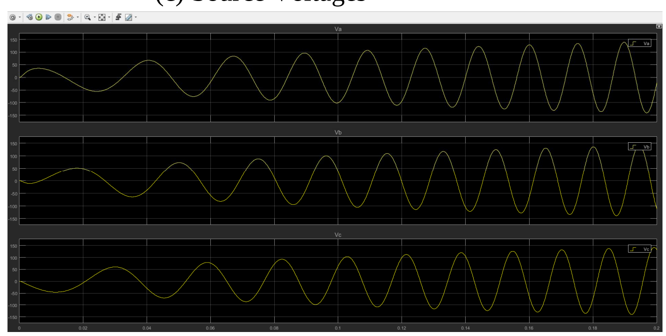
(a) Injected Voltage



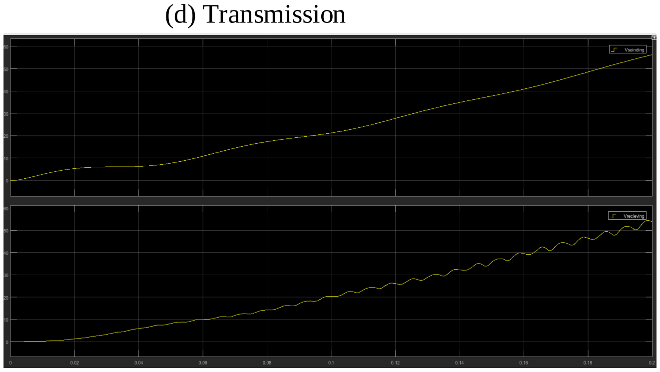
(b) Source Currents



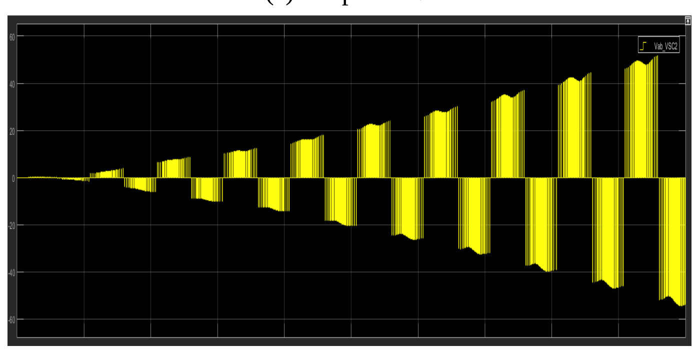
(c) Source Voltages



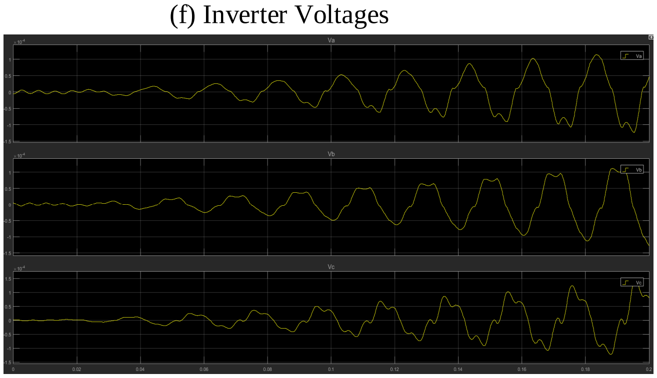
(d) Transmission



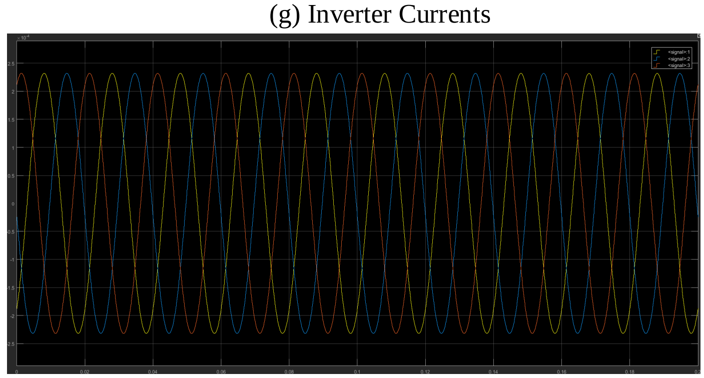
(e) Output of VSC



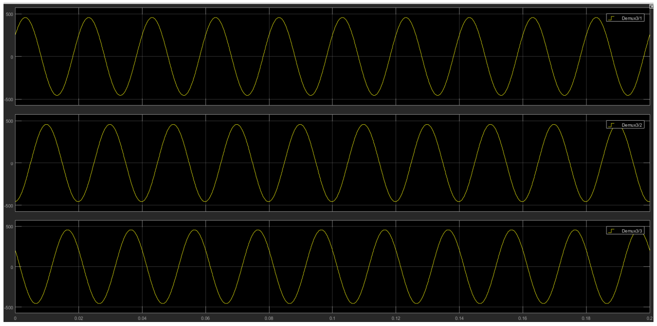
(f) Inverter Voltages



(g) Inverter Currents



(h) Grid Voltages



(i) Grid Currents

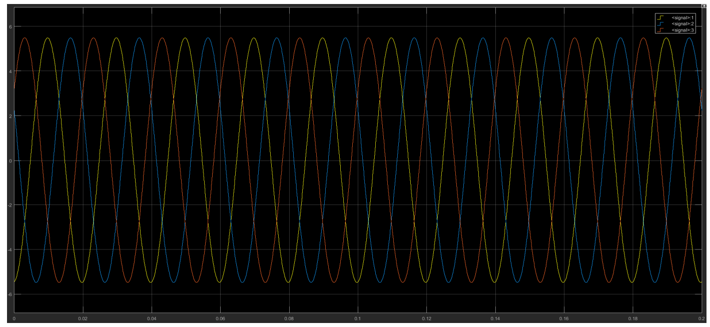


Fig.9. a,b,c,d,e,f,g,h,i, are the simulation results for the step variation in wind power in MTDC.

VII. CONCLUSIONS

The equivalent line resistance is approximately reduced by 36.6%. The droop gain design is carried out for both radial parallel and meshed parallel MTDC systems. This paper presents a methodology to design a voltage–current droop controller for an MTDC system with a three-wire bipolar HVDC transmission line. It has been shown that switching from two-wire mode to a three-wire mode of the three-wire bipolar line affects the equivalent line resistance. In case of radial MTDC systems, the line currents, mainly depend on the line resistance (in power-sharing mode), corresponding droop gains of the VSCs should be updated to ensure distributing of current with the desired sharing ratio. However, their values can be obtained offline. On the other hand, a meshed MTDC system necessitates an online algorithm to update the droop gain constants with any variation in input/output current magnitudes and/or line resistance variation.

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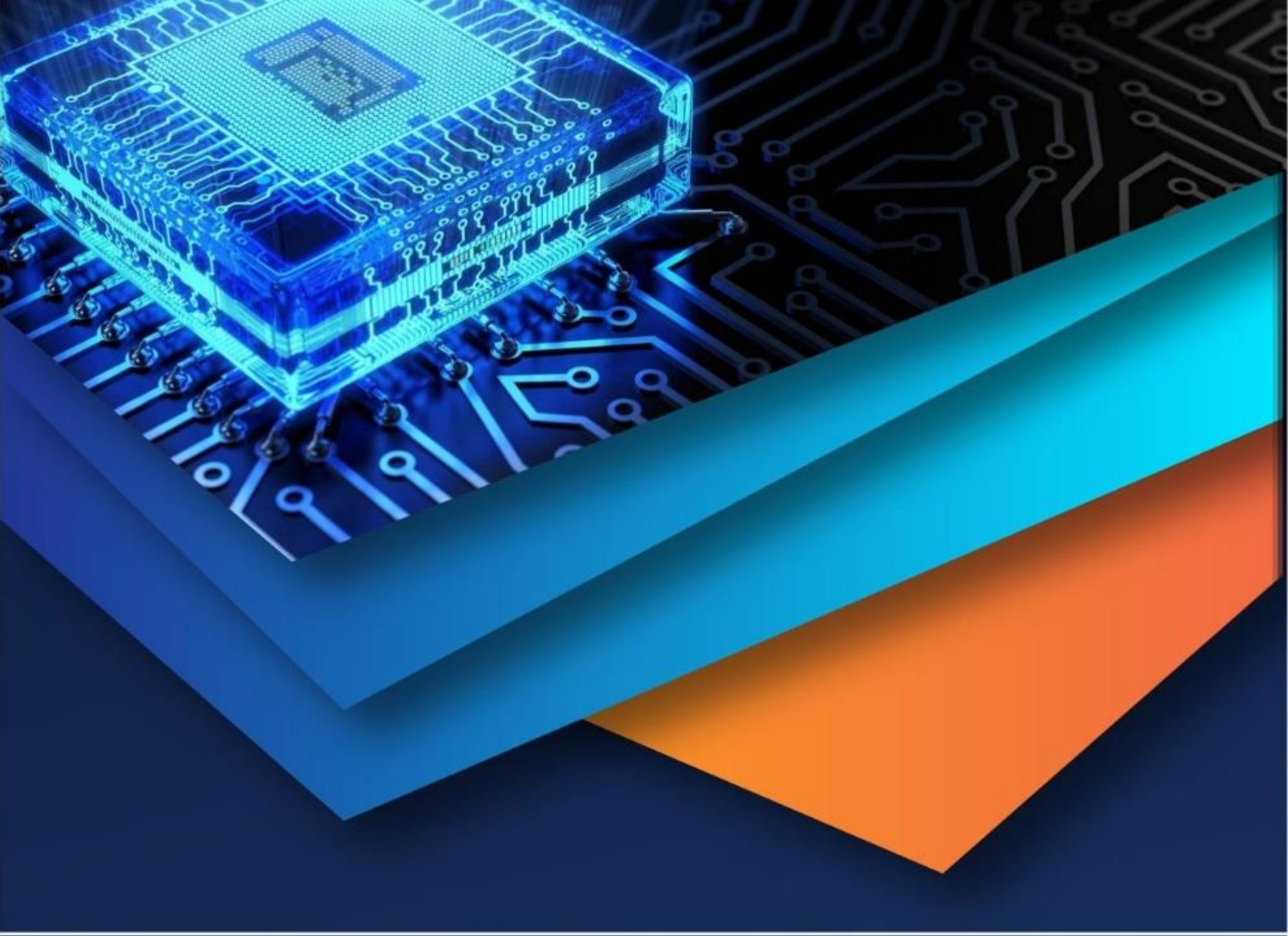

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