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The hybrid solar energized back-to-back high voltage direct current modular converter for distributed networks

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ABSTRACT

High voltage direct current (HVDC) transmission is flexible towards the power control (produced by solar or wind) and can be transported over thousands of kilo meters with minimal losses over the high voltage alternative current (HVAC). It allows solar power to be integrated into the current power grid on a large scale. The author view in this article aims at providing an overview of methods used to integrate HVDC and solar systems. MATLAB/Simulink is used to simulate the solar power integration with HVDC transmission link. This article emphaises solar energy and grid integration, which results in quality and controlled electricity to the grid. Further the simulation studies are compared with real time data between the stations Pugalur AC grid (high solar energy region) and Thrissur AC grid (low solar energy region). Obtained results from the simulation, voltage and currents and power quality stresses the superiority towards the solar integration. The comparison studies enumerate the need to go situation for HVDC technology during the penetration of solar voltaic penetration into the utility network.

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1. INTRODUCTION

The electric power demand in India has traditionally increased due to economic growth [1], [2]. As a result of burning fossil fuels, there are several instantaneous negative effects on the environment, including the emission of large quantities of greenhouse gases (GHG). Power plant efficiency can be improved, and other fuel sources, like renewable energy, can be used in place of coal [3]–[8]. As discussed by [9], renewable energy is having a significant impact on the Indian electricity market. Climate-related concerns have led to a rapid expansion of large photovoltaic (PV) plants throughout industrialized countries [10]–[12]. For India to attain its energy targets soon, solar energy plays a crucial role. A solar power plant installation is one solution to increase the role of solar energy in the nation's energy mix. Depends on plant size and availability of land, high generating capacity solar plants are constructed in locations that are far from the load centers.

The theft of electricity and line losses are significant issues in many developing countries [13]. According to official estimates, transmission and distribution (T&D) losses in India account for 23% of the electrical power generated. In some cases, these losses could be up to 50%, according to studies performed by independent agencies including the energy and resources institute (TERI) [14]. According to Raikar and Jagtap in [15], in India, CO_2 emissions would be reduced by 6% by reducing the transmission and distribution losses of electricity and the electrical efficiency of power plants would be improved by 9% by doing so. It is estimated that India's economy loses 1.5% of its gross domestic product (GDP) each year due to T&D losses, which have aggravated chronic power shortages and strained the financial position of the country's public electricity providers [16]. Transmission losses are reduced by high voltage DC systems. Hempelt concept of ultra high voltage direct current (UHVDC) for long distances mentioned in [17]. Multi terminal concept to interconnecting the DC grid mentioned in [18]. Swetapadma *et al.* [19] relaying scheme for short bipolar HVDC system is mentioned. For renewable power generations, HVDC converters significance is mentioned in several research [20]–[23].

Traditional PV modules are arranged in string form, with a centralized inverter to convert the voltage. The low efficiency of this string architecture hampers the system's efficiency. The use of PV modules in strings, or even substrings are coupled with the existing grid by different converters i.e., a DC/DC converter and a centralized inverter is a most adoptable concept [24], [25]. The current ripples in DC-DC boost converter as a guide for designing the battery charger is presented in [26]. The method is designed to reduce ripples in converter output current. The study examined and compared with conventional DC-DC converters and DC-DC converters with diode assist in wide range power converters from lens of silicon devices [27]. Battery storage and related accessories may not be needed for PV systems connected to the grid [28].

The PV module configuration and several types of phase-changing structures were proposed. We present a new method of connecting panels with technologies and same current rating. For long distance transmission, this new panel concept converts low voltage levels to HVDC levels. Later, the simulation studies are conducted with solar fed AC grid Simulink model linking Pugalur AC grid and Thrissur AC grid. The simulation studies enumerate the need to go situation for HVDC technology with penetration of solar PV into the utility network.

2. SOLAR ENERGY PENETRATION INTO THE HVDC SYSTEM

Since the 1950s, HVDC has become a viable transmission technology. There are currently 3000 to 6400 MW of high-capacity projects with high DC voltages are preferrable. The following applications demonstrate the value of HVDC as a bulk power transmission alternative: i) connecting two asynchronous networks; ii) when an energy transmission line crosses more than 600 km, either to carry energy from a specific generation site to a specific load centre or to connect two connected regions; and iii) for underground transmission. It is possible for asynchronous networks to be interconnected with long-distance networks in a way that is particularly effective, both economically and from the perspective of transmission system performance. The basic HVDC system interconnection is illustrated in Figures 1(a) and (b).

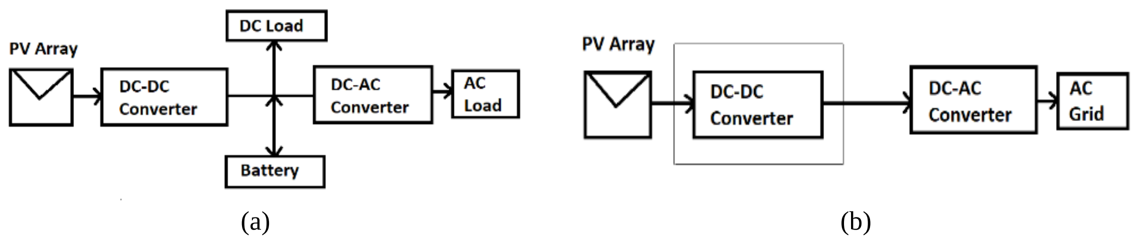


Figure 1. Scheme for collecting and connecting PV power plants to the grid: (a) AC load and (b) AC grid

By using HVDC to connect different PV technologies, transmission and distribution losses can be minimized when transmitting power over great distances [20]–[23]. In this case, DC-DC boost converter topology utilized to increase the panel low voltage to the high voltage DC level. Figure 2 illustrates the proposed concept. This concept provides different PV panel technology and similar current ratings to be connected, but with different voltages. The same current rating in all blocks using the different panel combinations, PV cells from various appropriate technologies can be used in the same solar power plant.

The Pugalur is the area where we have high abundance of solar energy. Hence the present study focuses on the installation of solar plant in hybridization with conventional AC grid of Thrissur (low solar energy location) connected via HVDC link. The specifications of such system are as shown in Table 1. The literature survey emphasizes on robust converter stations backed by connected long DC transmission links for reducing power loss and reliable operation with penetration of renewable into utility grid. The different architectures of this converter stations and its control strategies are discussed in next section.

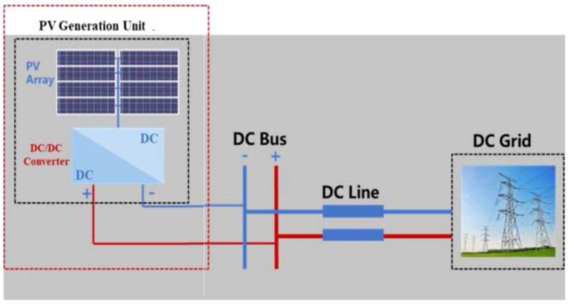


Figure 2. Solar PV DC grid integration

Table 1. HVDC parameters

S. No	Parameter	Ratings/topology
1	Rated power flow	1000 MW
2	MMC levels	331
3	Sub-module	Half bridge
4	Rated pole voltage [U_{dc}] (positive to negative)	640 KV
5	Pugalur AC grid	50 Hz, 400 kV, 36.4 GVA, X/R=10
6	Thrissur AC grid	50 Hz, 400 kV, 36.4 GVA, X/R=10
7	Converter transformer	400/380 kV, 367 MVA
8	Leakage impedance	17.5%
9	Neutral grounding reactor	Lg=6 kH, Rg=2.5 kΩ
	MMC sub-module parameters	
10	Nominal switching frequency	100 Hz
11	Capacitor	8.5 ± 2% mF
12	Peak turn-off current	3300 A
13	DC reactor per arm	90 mH
	Power transmission parameters	
14	Conductor size	2500 mm^2
15	Conductor	Copper
16	Insulation	XLPE insulation
17	OHL length	143 km
18	Cable length	32 km
19	OHL DC resistance	23.27 mΩ/km
20	Cable DC resistance	mΩ/km

3. HVDC CONVERTER STATIONS

Line-commutated converters (LCCs) are a very common HVDC technology. Minimum AC system strength is required for efficient operation of such converters. Semiconductors made it possible to apply thyristor valves instead in the 1970s, marking a milestone in the development of HVDC. In the field of power transmission, voltage-sourced converter (VSC) systems complement LCCs today. The two-level and three-level topologies in modular multilevel converters (MMCs) was a major boost in the system terminology. In addition, there are several voltage sources which can be used to adjust the sinusoidal system voltage wave shapes very accurately, so no harmonics are generated practically. Thus, harmonic filtering is no longer necessary. For bulk power transmission, a bipolar link is typically used (see Figure 3). Such a configuration consists of two converters connected in series with one grounded or floating close to ground potential. High-voltage potential with opposite polarity is applied to two pole conductors. There are three possible return paths between the two terminals: an additional conductor (generally medium voltage) or sea or ground electrodes. During normal operation, converters of each pole should be powered at the same level, to avoid an unbalanced current in the return path. This will minimize transmission losses.

There are some advantages to bipolar configurations. They include redundancy-at least for power ratings of 50%. Outages of one converter or transmission line do not affect the remaining converters or DC lines. The configuration of a bipolar link may need further modifications for large power ratings and DC voltage levels. Power rating with voltage profile enhancement and current profile enhancement where later reduces the current handling rating of the devices by 50%. Despite focusing mainly on long DC cable connections, we have included one more configuration for completeness: the rigid bipole. DC circuits consist of only two high voltage conductors. Due to the absence of a return path, the project costs are further reduced. Unfortunately, there is a disadvantage in that if there is a fault in one of the converters, the entire link will be interrupted for a few seconds. Once faults were cleared and DC cables were reconfigured, power was restored to the link with 50% current rating. The entire link must be shut down permanently if the cable is permanently faulty in one system.

In general, the simplest HVDC configuration is the symmetrical monopole (SMP). Monopoly refers to one converter as an operating unit. DC voltages of both polarities are symmetrical in the DC circuit and neither pole conductor is solidly grounded. The voltages can be balanced by using different concepts, such as installing star-point reactors as shown in Figure 3. Monopoles are suitable for cable connections since there are no unbalance effects, such as those caused by pollution, on the DC circuit. Especially in cases where overhead lines are involved, special attention must be given to avoid adverse effects. Typically, a SMP's maximum rating depends on the voltage and current capacity of the single converter. Standard SMP designs are typically limited to 400 kV. In the case of two kilo Amps, approximately 1.25 kW is the maximum rating. This is equivalent to 1400 to 1600 MW. It is possible to connect two (or more) SMPs in parallel on the AC side of a system when the power rating is higher and/or there is a need for redundancy. The simulation is performed on this real time data. Figure 4 illustrates the modelling of Pugalur and Thrissur AC grid stations. Figure 4 illustrates solar grid connection at Pugalur station and AC grid connection at Thrussur station. This concept gives the grid connecting model at Pugalur station and Thrissur station in Figures 4(a) and (b) respectively.

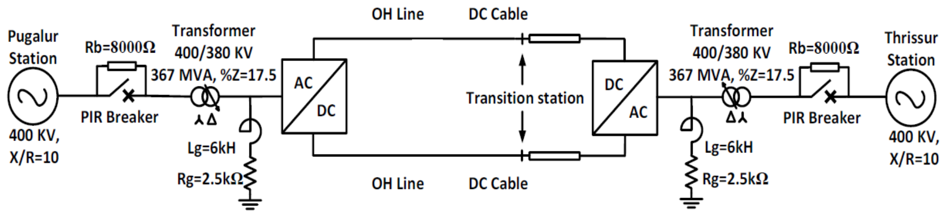
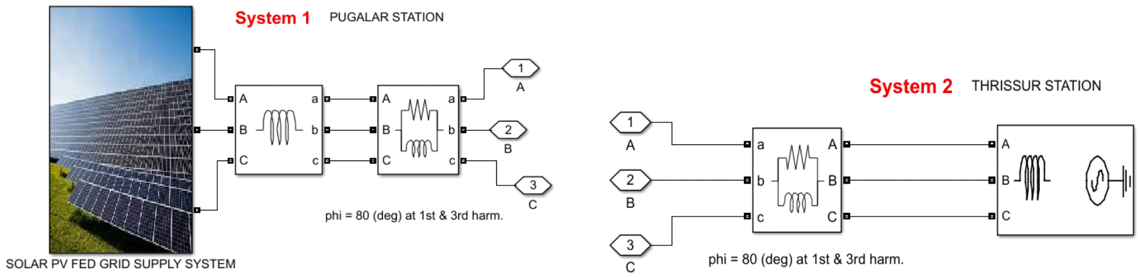


Figure 3. Single line representation of VSC HVDC transmission link



(a) (b)

Figure 4. Modeling of: (a) solar energy fed Pugalur station (system 1) and (b) conventional AC grid connected Thrissur station (system 2)

4. SIMULATION RESULTS DISCUSSION

The author view focuses the real-time data modelling of the first renewable source penetration between Pugalur and Thrissur AC grids as per the specifications given in Table 1. The MATLAB/Simulink is the base simulation platform for the dynamic simulation is shown in Figure 5. Figure 6 illustrates solar fed Pugalur grid supply station with its control schema and energy conversion subsystem modelling.

a. The solar fed Pugalur grid station supply after conversion which is an AC grid fed supply is illustrated in Figure 7, which is on par with real time data. Thus, the overall input power available from Pugalur supply station is shown in Figure 8.
b. The solar PV converter module (station-1: Pugalur HVDC station) output will act as the input to the HVDC link. The input per unit voltage and per unit power input is represented in Figure 9.
c. The conventional AC grid station module (station-2: Thrissur HVDC station) output will act as the input to the HVDC link from the other side of the HVDC link. The input per unit voltage and the equivalent input per unit DC power is shown in Figure 10.
d. The solar converter module (station-1: Pugalur HVDC station) control station responses are illustrated in Figure 11. The controlled input voltage, active and reactive power, three phase-controlled voltages and currents in per units are shown in Figure 11.

e. The conventional AC grid station module (station-2: Thrissur HVDC station) control station responses are shown in Figure 12. The input control voltage, active and reactive powers, three phase control voltages and currents in per units are shown in Figure 12.
f. The solar PV converter module (station-1: Pugalur HVDC station) performance of the filter is shown in Figure 13. The direct axis and quadrature axis currents, modulation index and the reference voltage generated for VSC gating respectively are shown in Figure 13.
g. The conventional AC grid station (station-2: Thrissur HVDC station) filter performance is shown in Figure 14. The currents of direct axis and quadrature axis, modulation index (MI) and the reference of generated voltage for VSC gate switching respectively are shown in Figure 14.
h. The solar connected grid converter module (station-1: Pugalur HVDC station) controlled voltages of DC link, compensation voltage, improved profile of station-1 and three phase voltages respectively are represented in Figure 15.
i. The conventional AC grid station module (station-2: Thrissur HVDC station) compensation voltage, improved profile of station-1, controlled DC link voltage and three phase voltages respectively are represented in Figure 16.

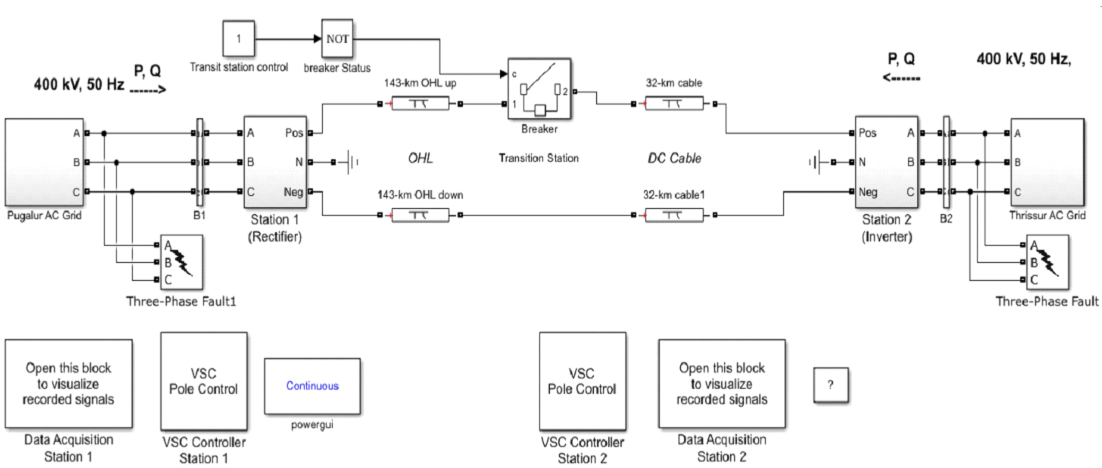


Figure 5. Equivalent simulation model for the VSC HVDC transmission link

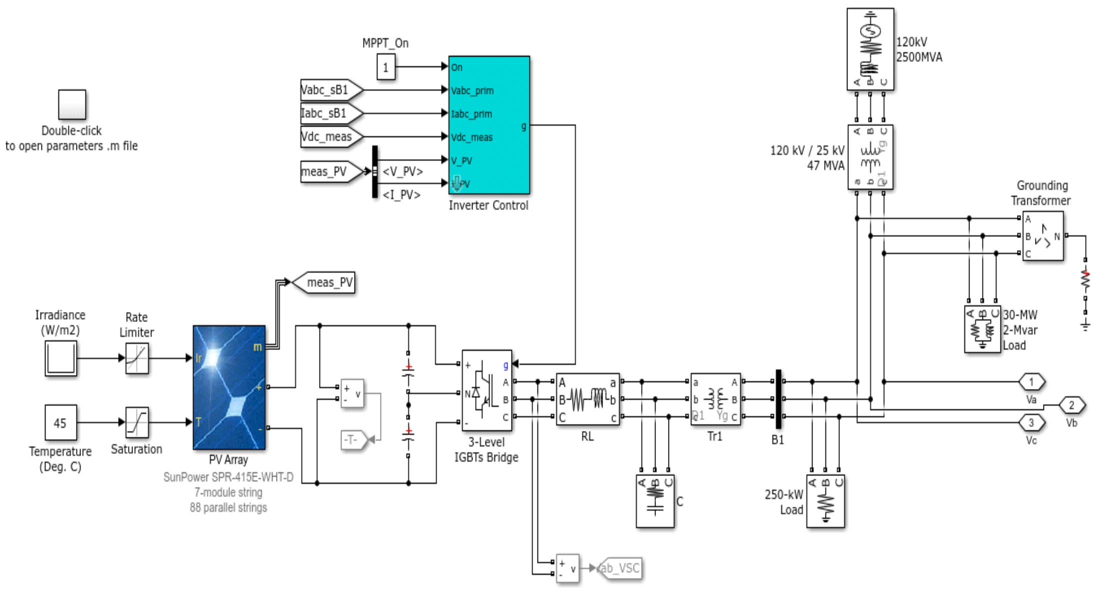


Figure 6. Equivalent simulation model for the solar fed Pugalur AC grid

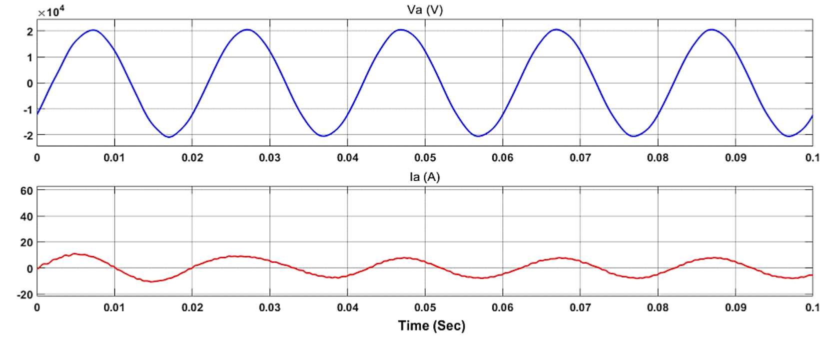


Figure 7. Solar fed Pugalur AC grid voltage and current illustration

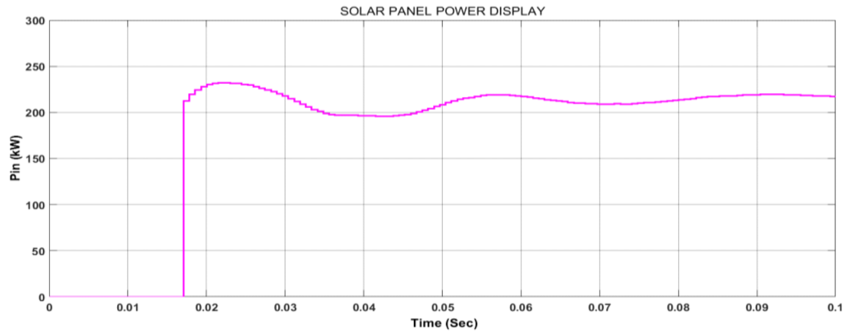


Figure 8. Solar fed grid Pugalur supply station power inflow illustration

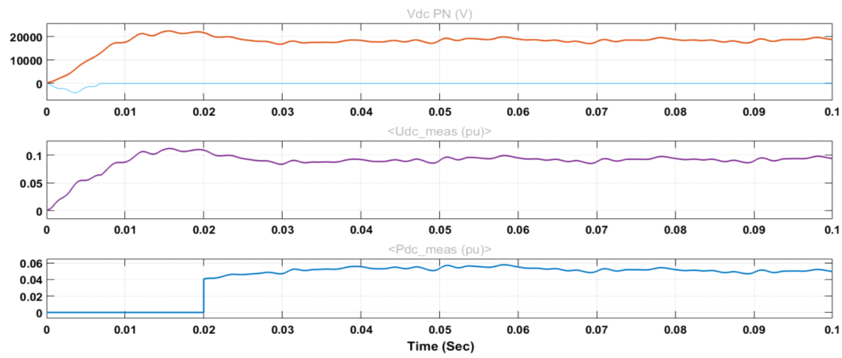


Figure 9. Station-1 DC voltage and DC power

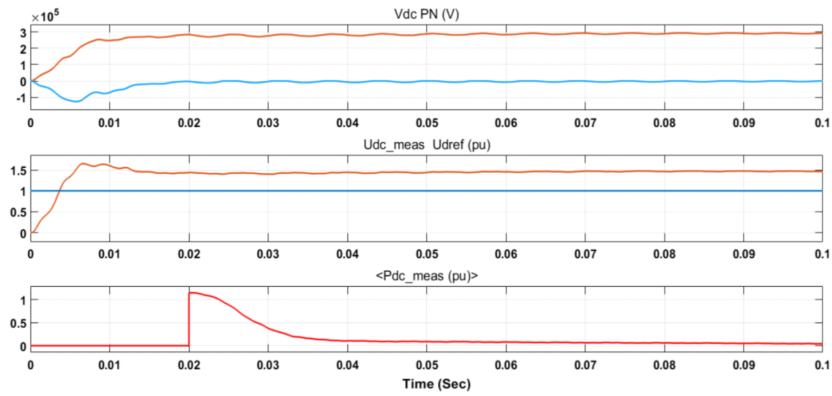


Figure 10. Station-2 DC voltage and DC power

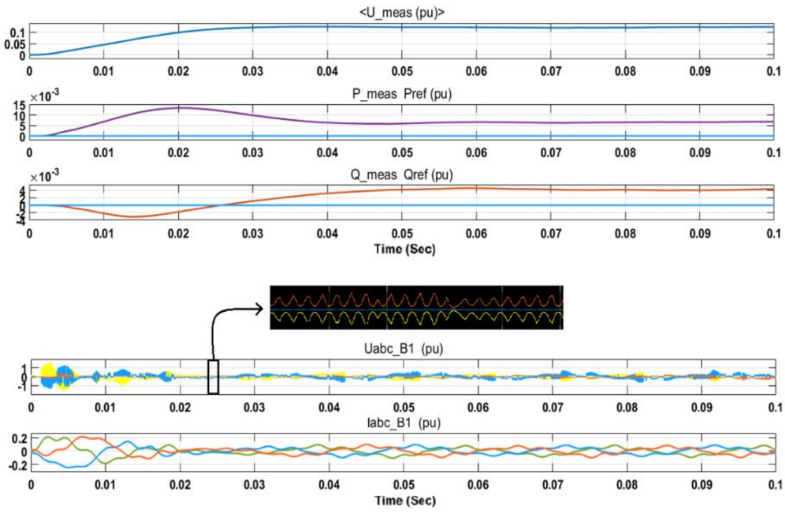


Figure 11. Station-1 voltage source converter station performance illustration

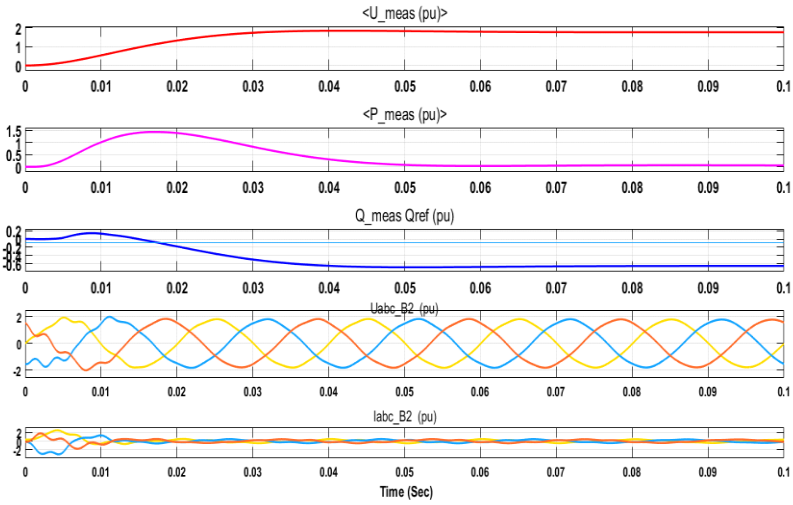


Figure 12. Station-2 voltage source converter station performance illustration

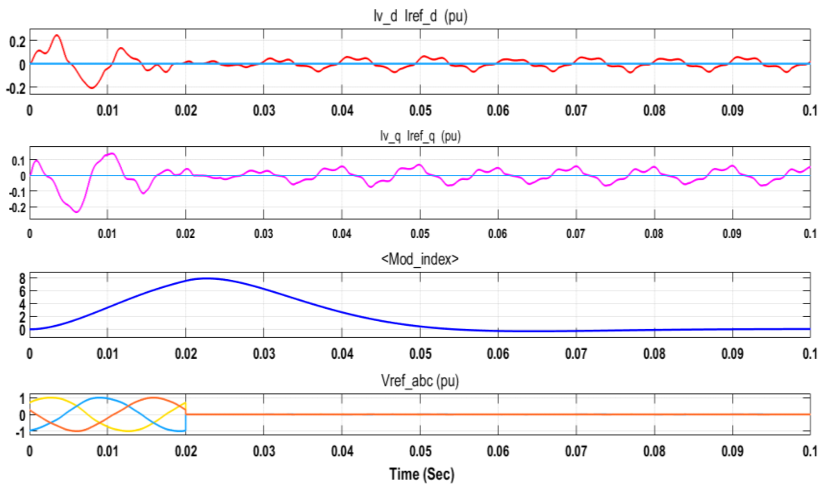


Figure 13. Station-1 VSC control filter performance

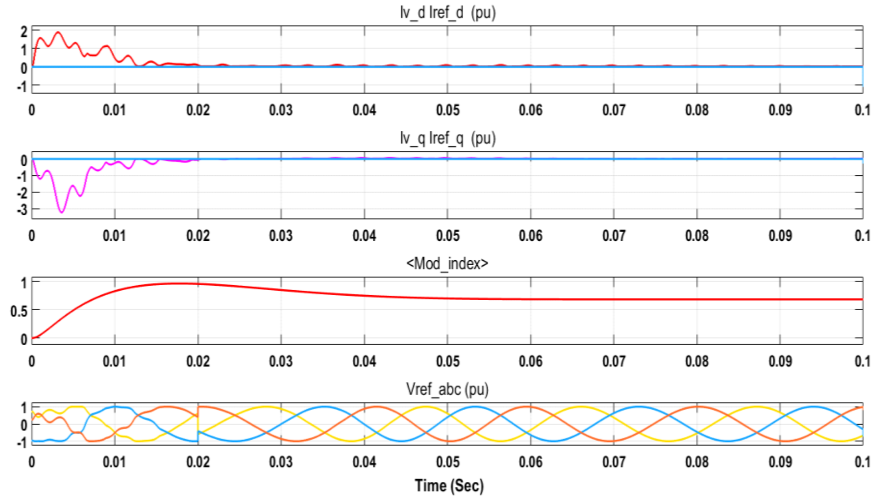


Figure 14. Station-2 VSC control filter performance

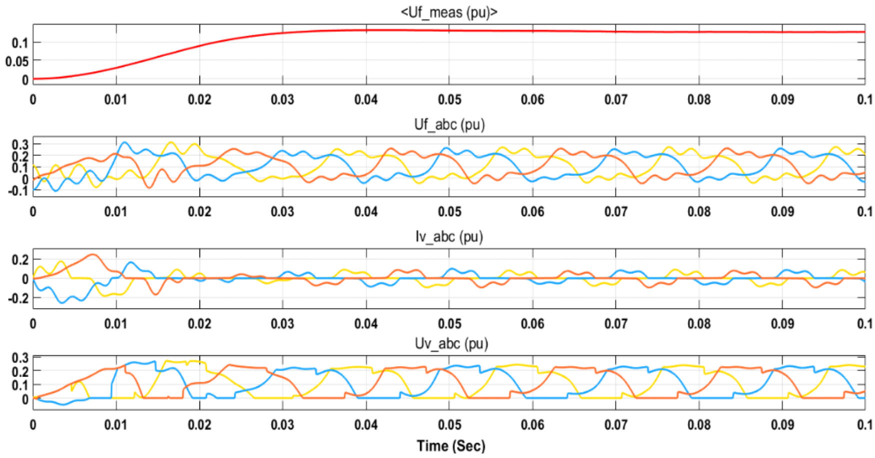


Figure 15. Station-1 VSC converter control parameters

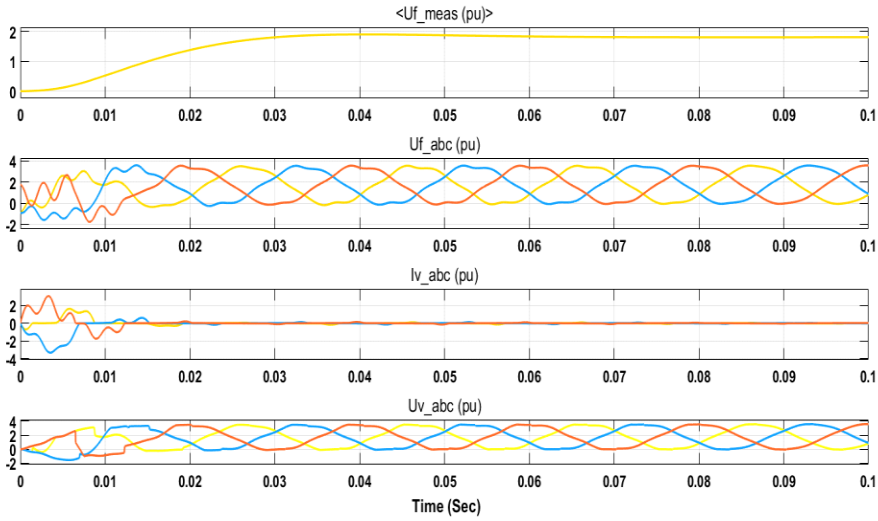


Figure 16. Station-2 VSC converter control parameters

5. CONCLUSION

The transmission grid today is able to integrate renewable energy seamlessly due to available technologies in HVD. Hybrid HVDC operation with LCC and VSC technologies, back-to-back transmission links and longer distribution network links can give sustainable power from renewable energy resources such as wind and solar. AC power infrastructures can be enhanced with DC links over long distances. Latest HVDC technology is proved around the world in sustainable power transmission, making it an important step forward in ensuring power is sustainable and environmentally friendly. The dynamic simulation studies discuss the probable options for PV energy penetration into the existing grid with HVDC system. Further the advantages and proficiency in power system is discussed and compared with conventional systems. The simulation studies show the efficacy of the performance of the system with renewable source penetration.

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