Reduce the Effect of Unbalanced Condition in a Distributed Generation Grid Using Advance VSS (Voltage Support Scheme)

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***Abstract*: Unbalanced voltages can be caused due to abnormal system operations such as a single-phase fault, trip of one or two phases, and unsymmetrical loads. Such phenomena occur frequently in power systems. Investigation of the impact on inverter-based energy delivery infrastructure can help provide feasible solutions and build a robust energy delivery infrastructure. Focuses on the impact of grid voltage unbalance on distorted AC current, while our research focuses on the DC-voltage which affects PV system power efficiency. Supporting the grid and improving its reliability have recently become major requirements for large distributed generation units. Under most grid faults, the accuracy of the traditional voltage support schemes (VSSs) is dramatically affected due to the existence of the over voltage. Also, the traditional VSSs have been used only in the STATCOM applications, where the active power is zero. An advanced VSS in the converter-interfaced units, called zero-sequence compensated voltage support (ZCVS).**

***Keywords*: System faults, photovoltaic system, grid simulation (MATLAB), unbalance grid voltages, voltage support schemes.**

1. Introduction

1.1 What is Voltage support?

Voltage support is provided by generating units or static equipment capable of producing or absorbing reactive power. This is done to maintain voltages on the system within Code limits. The principle of voltage support requirement under grid faults is depicted in Fig.1

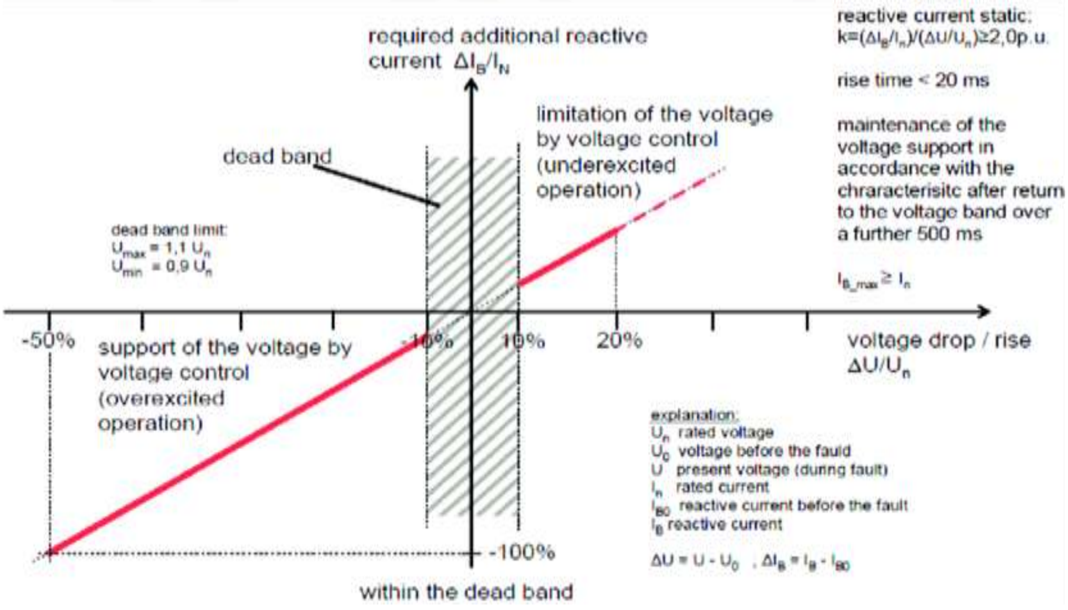


Fig.1. voltage support requirement under grid faults

1.2 Basic of Distributed Generation

Distributed generation, also distributed energy, on-site generation (OSG) or district/decentralized energy is electrical generation and storage performed by a variety of small, grid-connected devices referred to as distributed energy resources (DER).

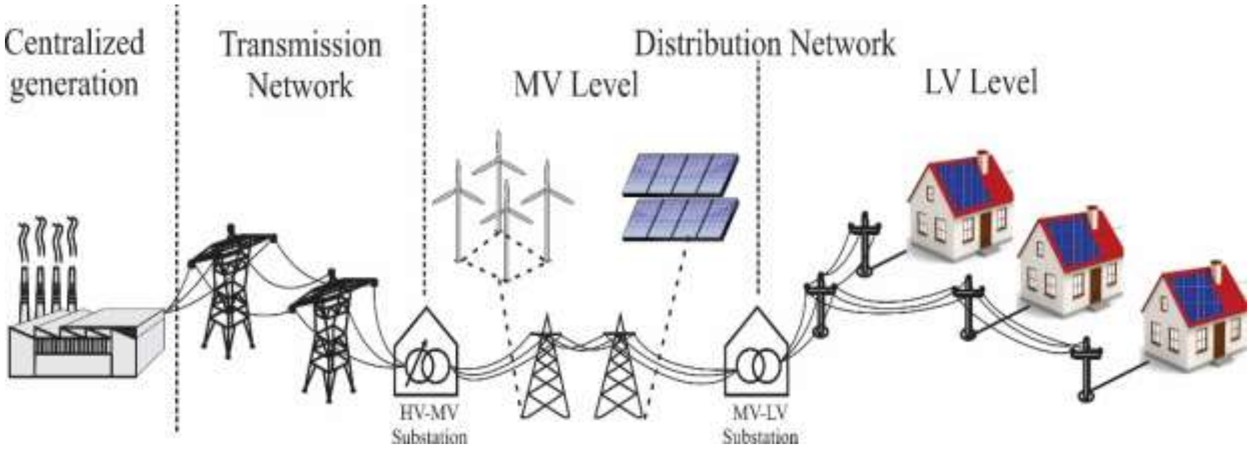


Fig.2. Simple Diagram for Distributed Generation

Conventional power stations, such as coal-fired, gas, and nuclear powered plants, as well as hydroelectric dams and large-scale solar power stations, are centralized and often require electric energy to be transmitted over long distances. By contrast, DER systems are decentralized, modular, and more flexible technologies, that are located close to the load they serve, albeit having capacities of only 10 megawatts (MW) or less. These systems can comprise multiple generation and storage components; in this instance they are referred to as hybrid power systems.

DER systems typically use renewable energy sources, including small hydro, biomass, biogas, solar power, wind power, and geothermal power, and increasingly play an important role for the electric power distribution system. A grid-connected device for electricity storage can also be classified as a DER system and is often called a distributed energy storage system (DESS). By means of an interface, DER systems can be managed and coordinated within a smart grid. Distributed generation and storage enable collection of energy from many sources and may lower environmental impacts and improve security of supply.

1.3 Unbalanced Conditions in Distributed Generation

Unbalanced voltages can be caused due to abnormal system operations such as a single-phase fault, trip of one or two phases, and unsymmetrical loads. Such phenomena occur frequently in power systems. Investigation of the impact on inverter-based energy delivery infrastructure can help provide feasible solutions and build a robust energy delivery infrastructure. Few existing literatures has addressed the impact of unbalance on PV systems. Focuses on the impact of grid voltage unbalance on distorted AC current, while our research focuses on the DC-voltage which affects PV system power efficiency.

1.4 Faults in AC side

In AC side two types of faults can be identified: total black out which measured as exterior fault for system, lighting and unbalanced voltage or grid outage for AC part defect such as weaker switch, over current or over voltage and etc. Meanwhile most PV inverters having transformers that could give good galvanic isolation between PV arrays and utility grids and perfect electrical protections. The AC output power will become low and DC output power remains the same, when there is a fault in the inverter. This detail confirms that there is no possibility that a wire between modules/strings and inverter was broken or a breakdown occurs in strings and/or modules. So, fault in the inverter is the reason for power loss.

2. MATLAB simulation

This Simulation given in MATLAB and shows a detailed model of a 100-kW array connected to a 25-kV grid via a DC-DC boost converter and a three-phase three-level VSC.

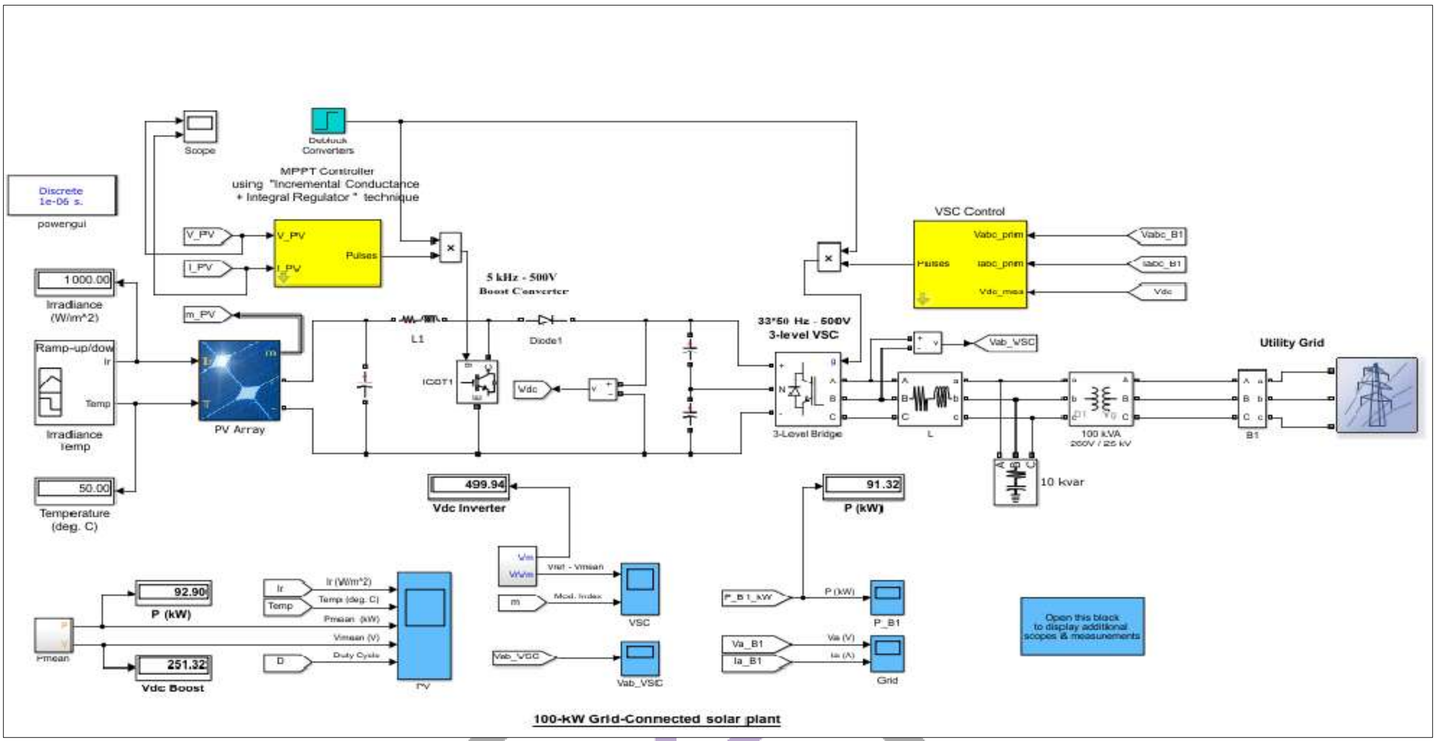


Fig.3 Simulation Diagram of 100kw Grid connected solar plant.

This Simulation Diagram will help to understand the working of Grid connected Solar power plant working

Components	Specification
PV array	100-kW capacity, 330 SunPower modules (SPR-305),
No. of Strings and no. of series strings per series	66 strings of 5 series connected modules, (66*5*305.2 W= 100.7 kW)
Single PV module	No. of series connected cells: 96, Open circuit voltage: Voc= 64.2 V, Short-circuit current: Isc = 5.96 A, Voltage and current at maximum power: Vamp =54.7 V, Imp= 5.58 A
Boost Converter	5-kHz, Increase 272 V DC to 500 V DC
MPPT	Incremental Conductance + Integral Regulator technique
VSC	1980-Hz (33*60) 3-level 3 phase VSC, converts 500 V DC to 260V AC and keeps unity power factor, 10-kvar capacitor bank filtering harmonics produced by VSC
Grid	100-kVA 260V/25kV 3 phase coupling transformer, 25 kV distribution feeder + 120 kV equivalent transmission system

Table.1. Simulation parameters.

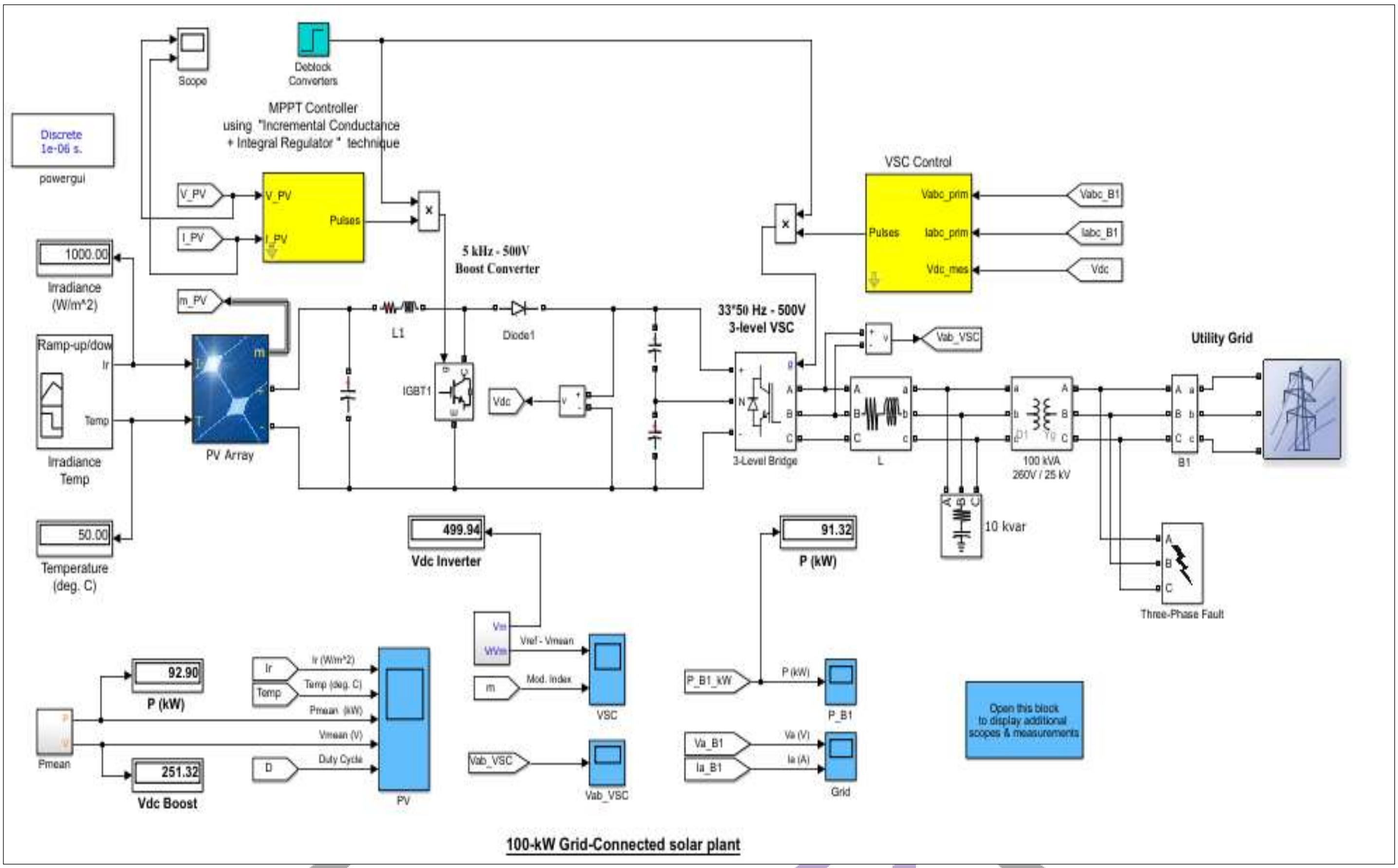


Fig.4. simulation diagram with Three-Phase Faults

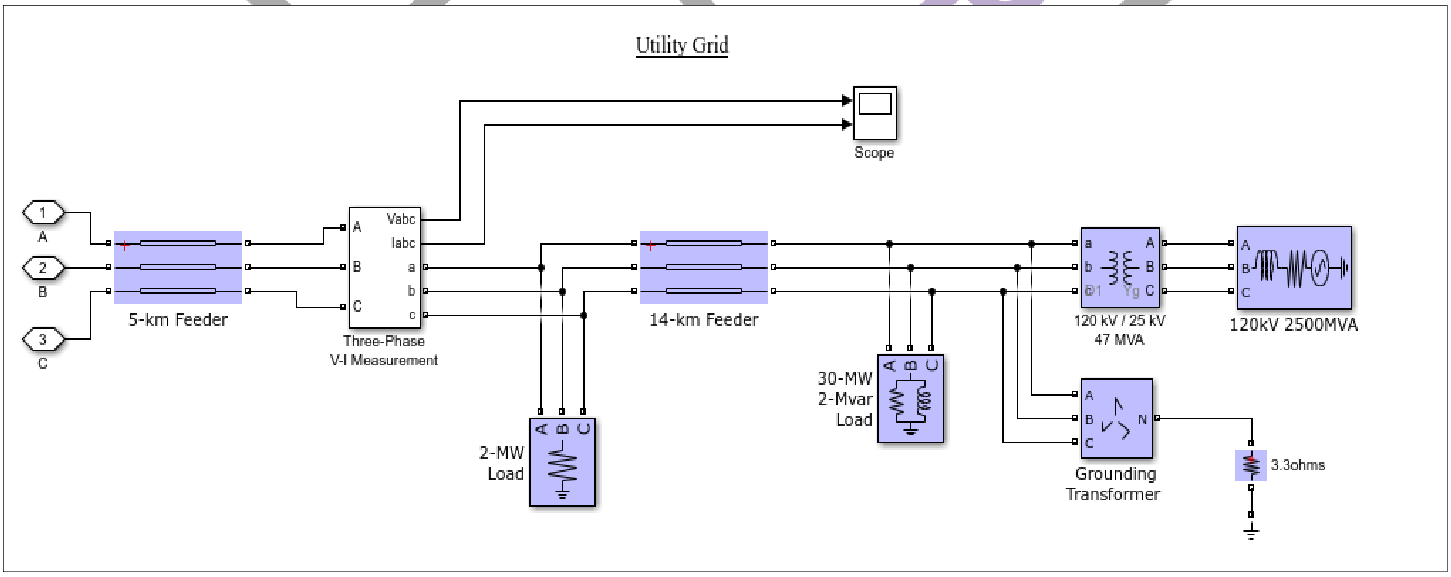


Fig.5. Simulation circuit of utility Grid at 5km Distance

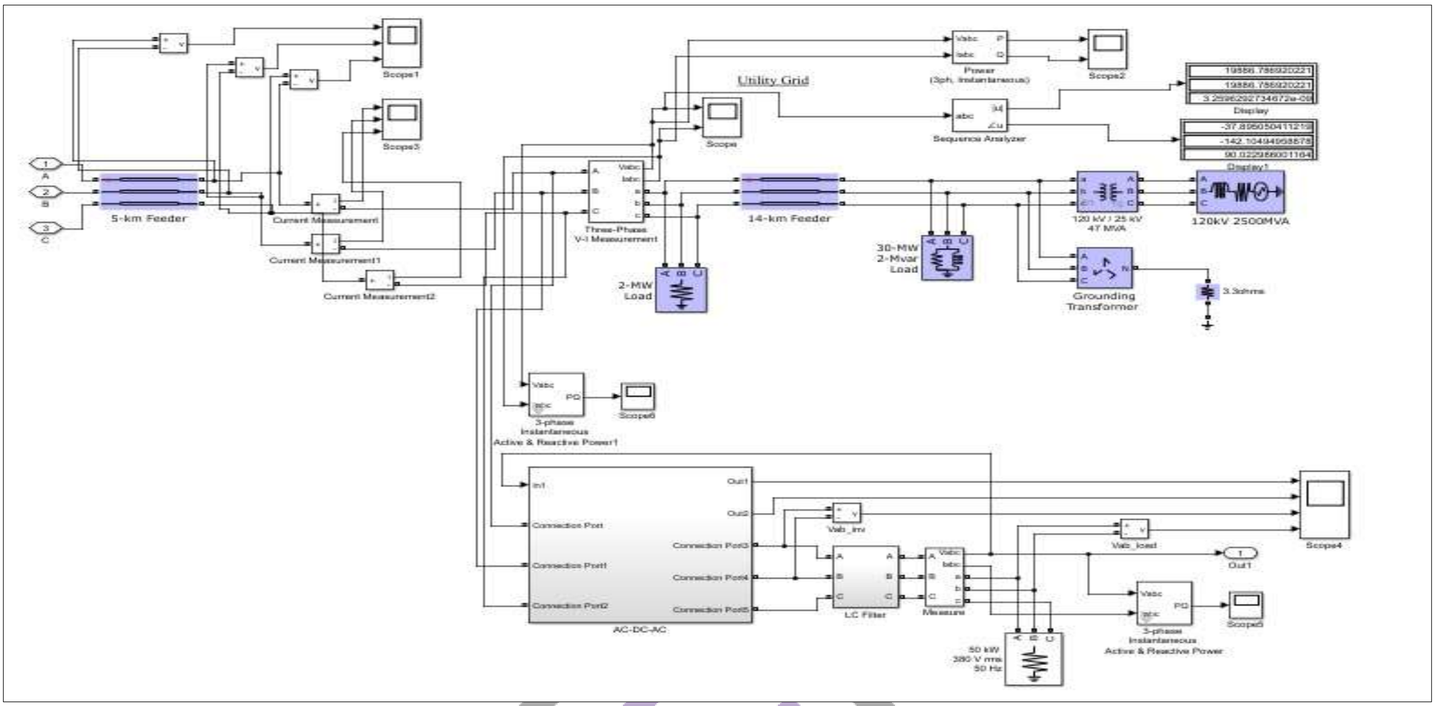


Fig.6. simulation circuit with unitality grid and zcvs (statcom)

2.1 simulation Description

A 100-kW PV array is connected to a 25-kV grid via a DC-DC boost converter and a three-phase three-level Voltage Source Converter (VSC). Maximum Power Point Tracking (MPPT) is implemented in the boost converter by means of a Simulink® model using the 'Incremental Conductance + Integral Regulator' technique.

The detailed model contains the following components:

- **PV array** delivering a maximum of 100 kW at 1000 W/m^2 sun irradiance.
- **5-kHz DC-DC boost converter** increasing voltage from PV natural voltage (273 V DC at maximum power) to 500 V DC. Switching duty cycle is optimized by a MPPT controller that uses the 'Incremental Conductance + Integral Regulator' technique. This MPPT system automatically varies the duty cycle in order to generate the required voltage to extract maximum power.
- **1980-Hz 3-level 3-phase VSC**. The VSC converts the 500 V DC link voltage to 260 V AC and keeps unity power factor. The VSC control system uses two control loops: an external control loop which regulates DC link voltage to +/- 250 V and an internal control loop which regulates Id and Iq grid currents (active and reactive current components). Id current reference is the output of the DC voltage external controller. Iq current reference is set to zero in order to maintain unity power factor. Vd and Vq voltage outputs of the current controller are converted to three modulating signals Uabc_ref used by the PWM Generator. The control system uses a sample time of 100 microseconds for voltage and current controllers as well as for the PLL synchronization unit. Pulse generators of Boost and VSC converters use a fast sample time of 1 microsecond in order to get an appropriate resolution of PWM waveforms.
- **10-kvar capacitor bank** filtering harmonics produced by VSC.
- **100-kVA 260V/25kV three-phase coupling transformer**.
- **Utility grid** (25-kV distribution feeder + 120 kV equivalent transmission system).

The 100-kW PV array uses 330 SunPower modules (SPR-305E-WHT-D). The array consists of 66 strings of 5 series-connected modules connected in parallel (66*5*305.2 W= 100.7 kW).

The manufacturer specifications for one module are:

- Number of series-connected cells : 96
- Open-circuit voltage: Voc= 64.2 V
- Short-circuit current: Isc = 5.96 A
- Voltage and current at maximum power : Vmp =54.7 V, Imp= 5.58 A

2.2 simulation waveforms

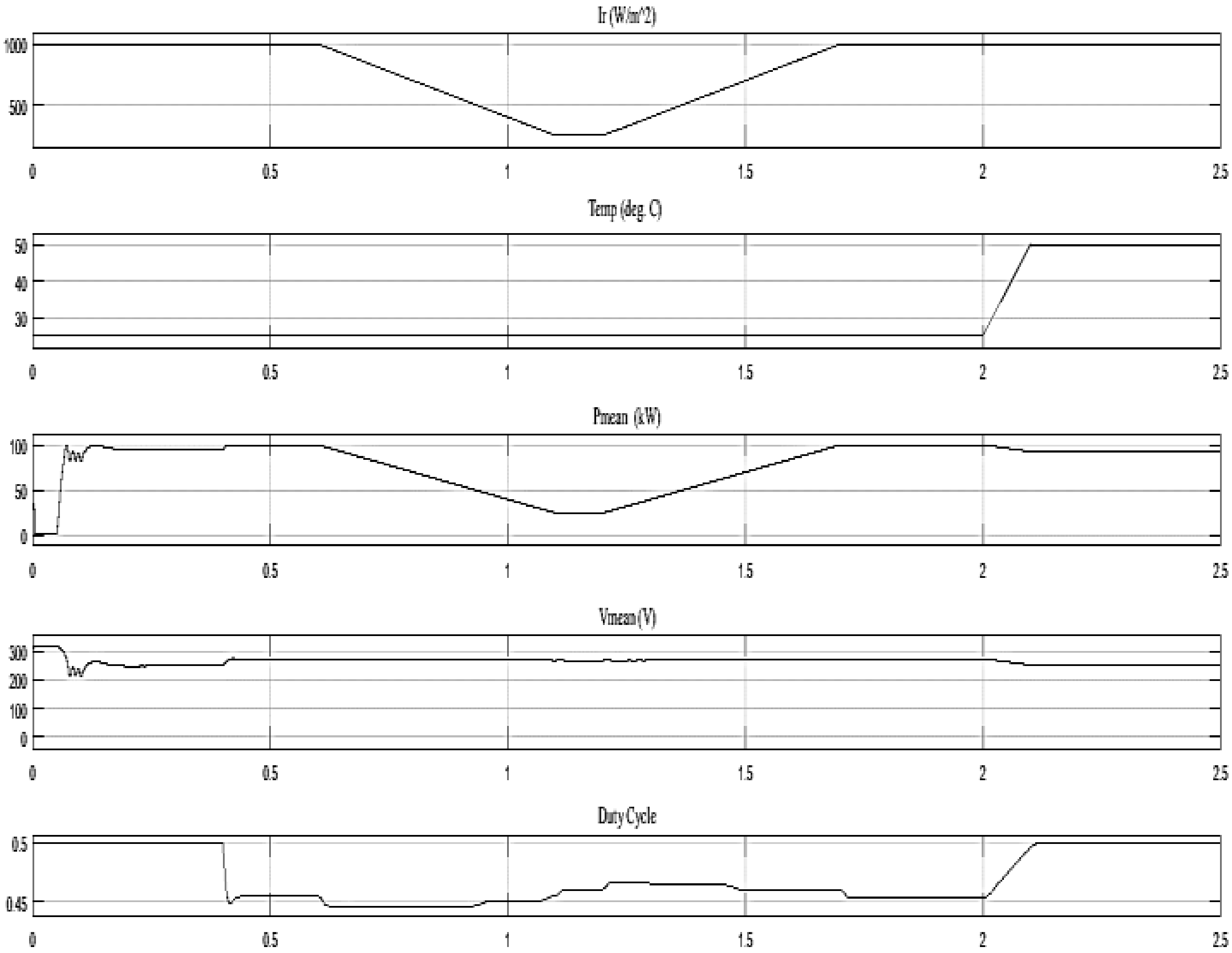
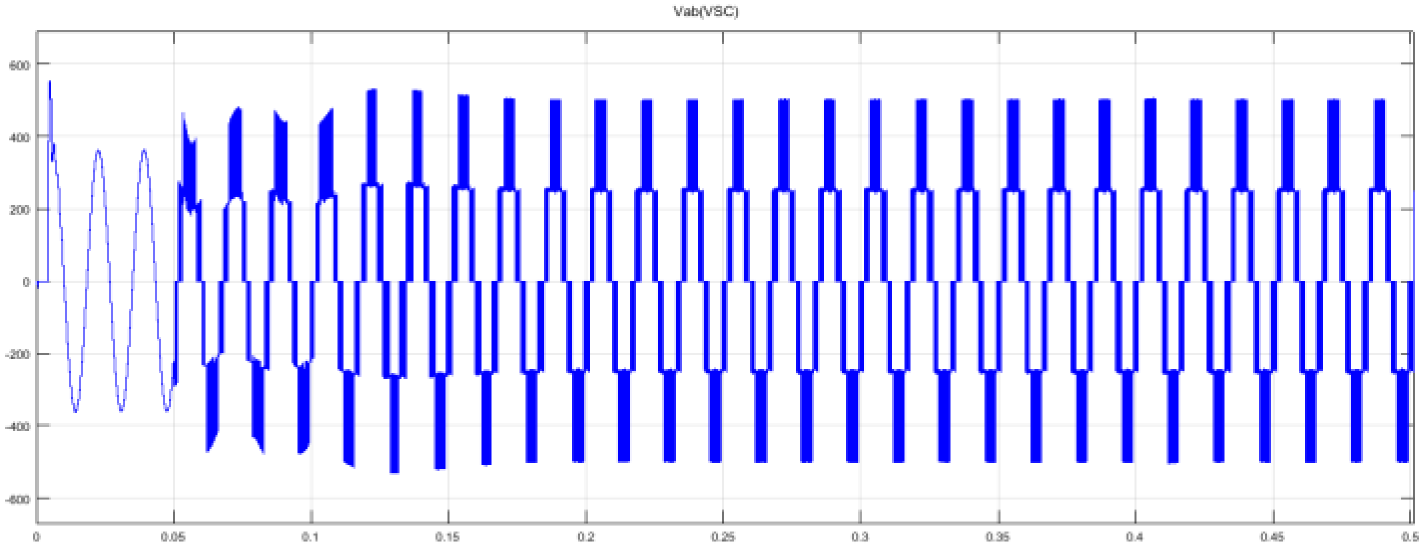


Fig.7.output wave form PV module



Fig,8. waveform of Vac- VSC (Voltage source converter)

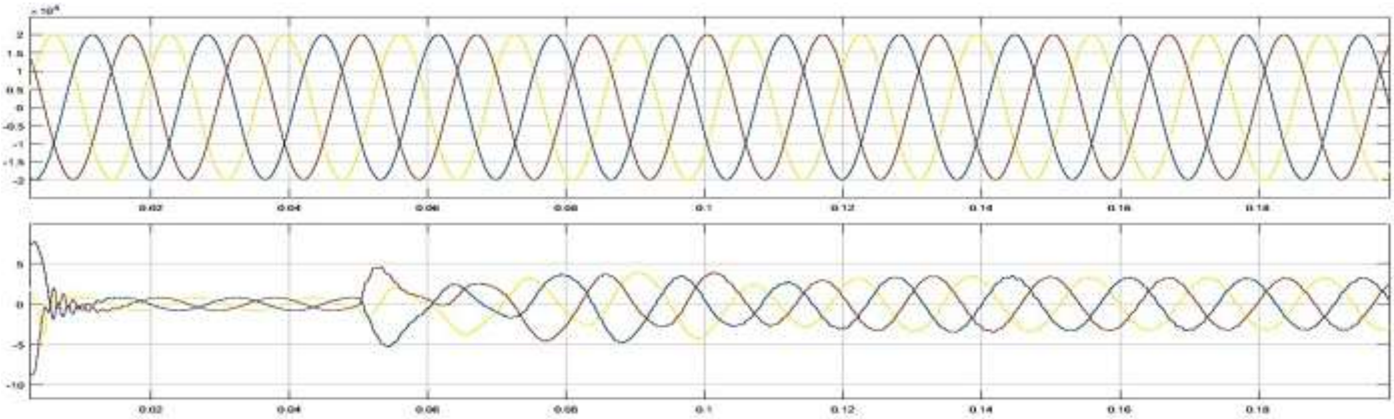


Fig.9 Triple line to ground Fault without ZCVS

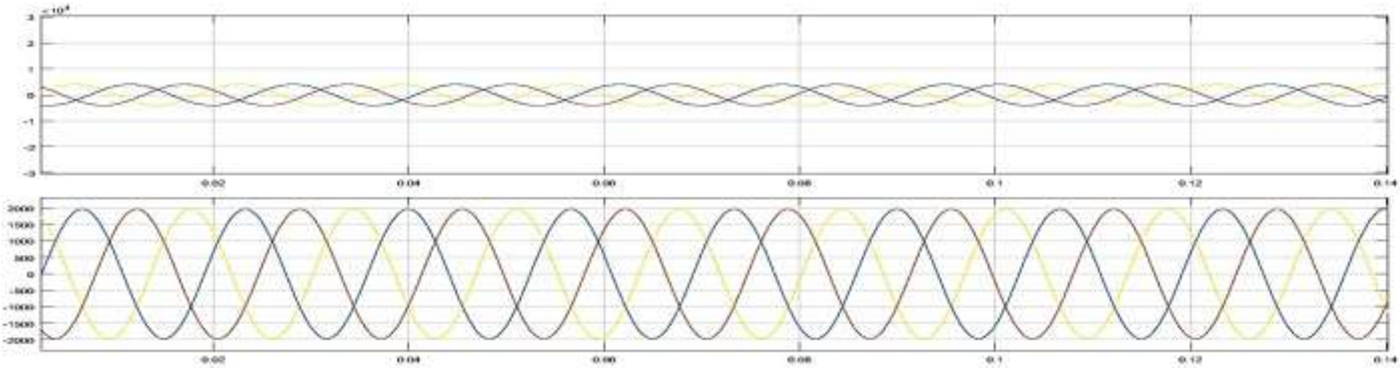


Fig.10 Triple line to ground Fault wZCVS

3. Simulation Results.

Type of short circuit fault	Distance of PCC (km)	PCC of the three-phase grid-connected PV system								VSC	PV array		
		Effective voltages (kV)			Effective currents (A)			Active power (kW)	Frequency (Hz)	Dc-link voltage (V)	Voltage (V)	Current (A)	P_{max} (kW)
		V_a	V_b	V_c	I_a	I_b	I_c						
Normal operating conditions		19.42	19.42	19.42	2.91	2.92	2.95	98.62	50	500.12	275.60	365.27	100.70
Single line-to-ground	19	21.53	31.92	1.47	39.69	36.36	35.95	93.79	50.21	505.25	278.49	377.18	100.52
	5	0.26	22.86	25.69	69.04	73.56	65.08	93.69	50.05	508.02	279.01	375.75	100.54
	0 (in PCC)	0	23.14	25.35	41.47	43.46	39.17	93.67	50.05	508.08	278.87	379.29	100.43
Line-to-line	19	19.45	9	9.74	5.72	4.24	4.89	73.46	50.11	708.65	287.26	379.90	99.76
	5	9.71	9.18	19.44	4.22	4.88	5.71	72.01	50.11	708.49	288.88	384.17	98.95
	0 (in PCC	9.72	9.04	19.44	4.22	4.88	5.71	72.09	50.11	709.02	287.33	381.27	99.52
Line-to-line-to-ground	19	26.84	0.88	0.93	28.88	25.96	31.32	69.84	50.11	779.56	284.23	377.52	100.24
	5	0.18	0.19	24.72	17.85	23.68	20.82	62.87	50.17	939.04	289.77	382.91	98.52
	0 (in PCC)	0	0	24.77	18.23	24.02	21.12	62.43	50.18	943.29	286.67	379.57	99.79
Three phase	19	0.06	0.09	0.13	7.73	11.05	12.26	0	49.41	1090	306.25	225.02	74.80
	5	0.27	0.24	0.11	9.91	12.17	7.11	0	49.32	998.10	305.93	228.13	75.92
	0 (in PCC)	0	0	0	8.19	11.32	10.96	0	49.26	1016	306.35	223.96	74.70

CONCLUSION

This paper presents a study on three-phase grid-connected PV systems under grid faults. PV array, PV inverter and PCC of the grid-connected PV system are perturbed by grid fault events. The impact of grid faults on PV systems depends on the fault type and less on the fault distance. An advanced VSS to precisely regulate the phase voltages of a three-phase GCC within the preset safety limits. The proposed VSS strategies bring significant advantages to emerging distributed generation units. The successful results of the proposed schemes are verified using simulation.

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