

Power Quality Improvement Using Voltage Controlled Distributed Energy Resources (VC-DER)

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ABSTRACT: This paper presents voltage control scheme by using directly voltage-controlled distributed energy resource units (VC-DERs) of an islanded microgrid to provide overcurrent, voltage sag and harmonics protection. The overcurrent protection scheme detects the fault, limits the output current magnitude of the DER unit, and restores the microgrid to its normal operating conditions subsequent to fault clearance. The overload protection scheme limits the output power of the VC-DER unit. VC-DER unit maintains voltage profile by injecting voltage in the system it controls voltage sag occurred due to uncertain conditions & it controlled harmonics further improves power quality of the system. Off-line digital time-domain simulation studies, in the MATLAB software environment, demonstrate the feasibility and desirable performance. Real-time case studies verify performance of the hardware.

KEYWORDS: Autonomous Microgrid, Decentralized Control, Protection, VC-DER Unit, Harmonics, Power Quality, Robust Control.

I. INTRODUCTION

The existing microgrid control approaches for electronically coupled DER units can be divided into droop based [1]-[6] and non-droop-based methods [7]-[12]. One of the microgrid control objectives, particularly in the islanded mode of operation, is to control the voltage of prespecified DER units to guarantee an overall acceptable voltage profile. The voltage control of an electronically coupled DER unit can be realized either directly or through an inner current controller. The advantage of the inner current controller [1], [8], [9], [13] is that the DER unit is protected against fault currents since the reference set point of the current controller restricts the phase currents to permissible values. Thus, the DER unit can ride through faults without trip-out or damage to the unit. Likewise, the inner current controller can limit the DER output power and prevent overloading conditions. A direct voltage control method [10], [11], [14], without the inner current control loop, can provide a faster and more robust performance; however, it is unable to limit the current in the DER unit during abnormal conditions. Thus, a fault condition can either trip out the DER unit or damage its power electronic components. A voltage-controlled distributed energy resource (VC-DER) unit is also prone to dynamic overload conditions since it inherently lacks the ability to transiently limit the output power. This paper introduces following control actions with VC-DER unit to overcome power quality issues.

- overcurrent protection
- voltage sag control
- power balance
- harmonics compensation

A set of comprehensive digital time-domain simulation studies, in the MATLAB platform, are performed to demonstrate performance of the proposed overcurrent and overload protection schemes under various system transient scenarios. To verify the feasibility of proposed strategies, the corresponding algorithms are digitally implemented in an industrial hardware.

II. POWER QUALITY ISSUES IN POWER SYSTEM

power quality problem can be defined as “Any power problem manifested in voltage/current or leading to frequency deviations that results in failure or misoperation of customer equipment”. This definition means that the decisive measurement of power quality is taken from the performance and productivity of end user equipment (customer). If the electric power is inadequate for those needs, the quality is said to be “lacking”.

- **Voltage sags(dips):**

A voltage sag, sometimes known as a voltage dip, is a short term reduction in the rms voltage. voltage sag is defined as, “sudden reduction of the voltage at a point in the electrical system, followed by voltage recovery after a short period of time, from half a cycle to a few seconds”. Voltage sags are characterized by their duration and depth. Duration is the length of time for which the voltage remains below a threshold.

- **Voltage swells:**

Voltage Swell is defined by IEEE 1159 as the increase in the RMS voltage level to 110% - 180% of nominal, at the power frequency for durations of ½ cycle to one (1) minute. It is classified as a short duration voltage variation phenomena, which is one of the general categories of power quality problems. A swell is defined as an increase to between 1.1 and 1.8 p.u. in rms voltage at the network fundamental frequency with duration from 0.5 cycles to one minute. The term momentary overvoltage is also used as a synonym for swell. Switching off a large inductive load or energizing a large capacitor bank are typical system maneuvers that cause swells.

- **harmonics:**

Main cause to crises power quality is presented harmonics in the system. A harmonic is a part of an occasional wave having a recurrence that is an essential different of the principal power line recurrence. Sounds are the various of the basic recurrence, and while all out consonant mutilation is the commitment of all the harmonic recurrence streams to the major. Sounds are the by-results of current gadgets. They occur frequently when there are large numbers of personal computers (single phase loads), uninterruptible power supplies (UPSs), variable frequency drives (AC and DC) or any electronic device using solid state power switching supplies to convert incoming AC to DC. Non-linear loads create harmonics by drawing current in abrupt short pulses, rather than in a smooth sinusoidal manner.

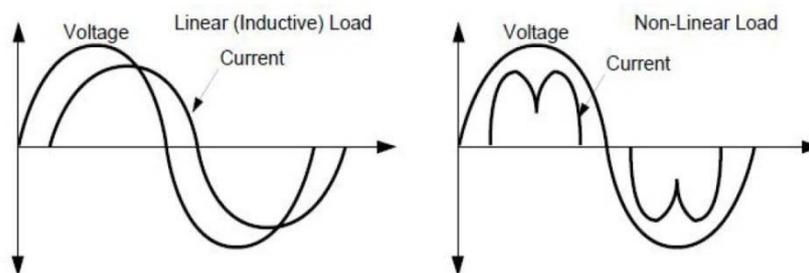


Fig.1. Difference between Linear and Non-Linear Loads

The terms “linear” and “non-linear” define the relationship of current to the voltage waveform. A linear relationship exists between the voltage and current, which is typical of an across-the-line load. A non-linear load has a discontinuous current relationship that does not correspond to the applied voltage waveform. All variable frequency drives cause harmonics because of the nature of the frontend rectifier.

THD (Total harmonic distortion) is the summation of all harmonic components of the voltage or current waveform compared against the fundamental component of the voltage or current wave. The formula above shows the calculation for THD on a voltage signal.

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and the THD equation for current harmonics is given by:

$$\%THD (V) = \frac{\sqrt{V_2^2 + V_3^2 + \dots + V_n^2}}{V_1} * 100$$

$$\%THD (I) = \frac{\sqrt{I_2^2 + I_3^2 + \dots + I_n^2}}{I_1} * 100$$

Power sources act as non-linear loads, drawing a distorted waveform that contains harmonics. These harmonics can cause problems ranging from telephone transmission interference to degradation of conductors and insulating material in motors and transformers. Therefore it is important to gauge the total effect of these harmonics. As indicated by standard the Total Symphonious Distortion quality ought to be under 5%. However, keeping low THD values on a system will further ensure proper operation of equipment and a longer equipment life span.

III. VOLTAGE CONTROL SCHEME

Fig. 2 illustrates a VC-DER unit, represented by a dc voltage source, a VSC, and a series RL filter. The unit is interfaced to the microgrid at the point of connection (PC) in Fig.1 through a step-up transformer. The block denoted by "Remainder of Microgrid" in Fig. 2 includes current- and/or power-controlled DER units and other components, e.g., distribution lines, loads, and capacitor banks.

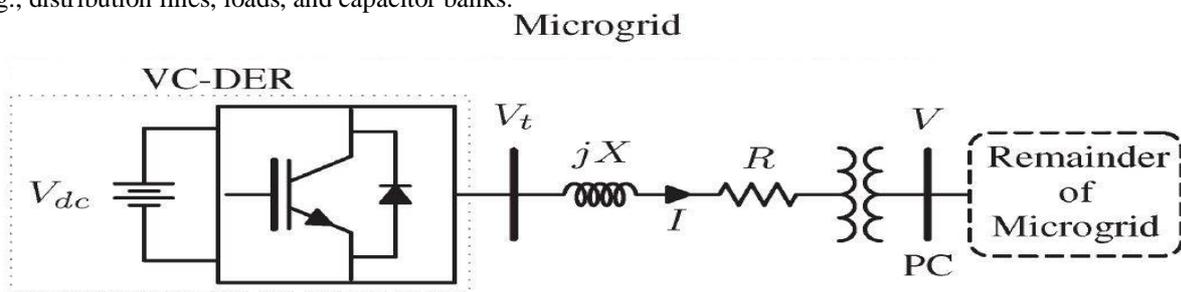


Fig. 2. Schematic diagram of a VC-DER unit that controls the voltage at PC.

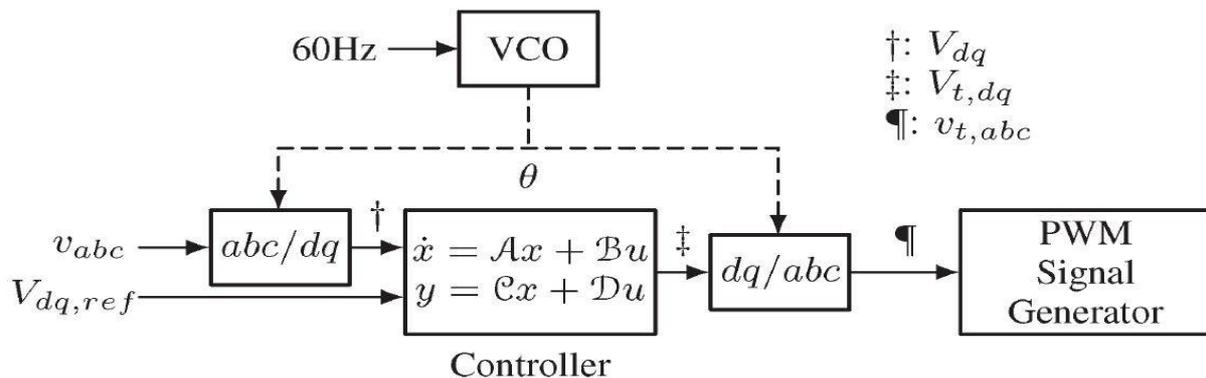


Fig. 3. Block diagram of a VC- DER voltage control scheme.

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A block diagram of a general direct voltage control scheme is illustrated in Fig. 3. The control objective is to maintain the PC voltage at its set point, with zero steady-state error. The control function is performed in the dq frame. Three-phase instantaneous voltages of the PC bus, v_{abc} , are measured and transformed to a dq frame of reference, V_{dq} , and provided to the control block. The controller outputs, $V_{t,dq}$, are transformed to abc frame of reference taking into account the turns ratio and phase shift of the interface transformer. Then, the PWM signals are generated based on the controller outputs, $v_{t,abc}$, to synthesize the voltage at the terminal of the interface VSC. Since the control scheme includes no inner current control loop, the VC-DER unit is subject to overcurrent and overload during system abnormal conditions, e.g., faults.

IV. PROTECTION SCHEME FOR MICROGRID WITH A MULTIPLE VC-DER UNIT

This section generalizes the proposed overcurrent protection scheme for a microgrid with multiple VC-DER units.

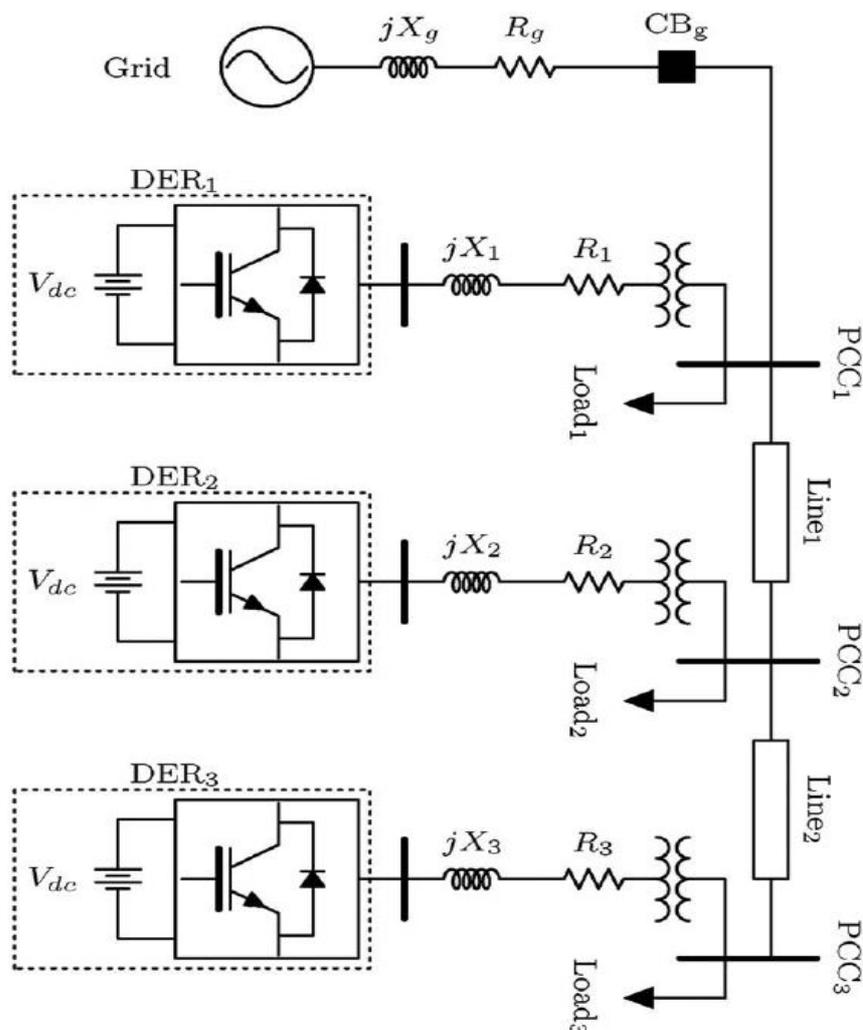


Fig. 4. Schematic diagram multiple- DER unit that controls the voltage at PC.

A schematic diagram of the three-phase studied microgrid system is illustrated in Fig.4. The microgrid includes three dispatchable VC-DER units, three local loads, and two distribution line segments. The primary source of each DER

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unit is represented by a dc voltage source, which is interfaced to the microgrid through a VSC, an inductive filter, and a step-up transformer (with the same power rating as the corresponding DER unit). The main grid is represented by a three-phase ac voltage source behind series R and L elements. The status of circuit breaker *CBg* determines the microgrid mode of operation.

In a microgrid with multiple VC-DER units, PC voltages can significantly drift from their set point values during a fault, and thus voltage controllers need additional time to restore the PC voltages to the prefault set points. Meantime, current magnitude can transiently exceed the permissible value. To avoid an inadvertent fault detection as a result of current overshoots, subsequent to a fault clearance, the voltage controllers should be gradually restored to minimize current transients. The following describes the fault clearance determination and smooth controller restoration for multiple VC-DER units.

- 1) *Fault Clearance Determination*: Fault clearance instant is determined based on the PC voltage magnitude V_{mag} .

$$V_{mag} = \sqrt{V_d^2 + V_q^2}$$

which drops during the fault and starts increasing immediately after the fault clearance. Fault clearance is acknowledged when V_{mag} has increased to a predefined level. It should be noted that the instantaneous voltage magnitude, calculated based on above formula, is subject to oscillatory components during unbalanced faults. Therefore, the lower envelope of V_{mag} is monitored, and the fault clearance is acknowledged when this envelope has increased to a predefined value.

- 2) *Voltage Control Restoration*: Restoration procedure begins after the fault clearance. This procedure is an integral part of the overcurrent protection scheme for a microgrid with multiple VC-DER units to ensure the controllers are smoothly restored and current transients are limited within the permissible range. The procedure depends on the relative difference between the prefault and postfault operating points of the VC-DER unit, which depends on the VC-DER apparent output power, S .

$A_1) S_{pre} \approx S_{post}$. In this case, the prefault and postfault operating points are approximately the same. This is the case when the fault 1) is temporary and clears itself without any line or generation outage, i.e., 80–90% of the faults in distribution systems [15], 2) is permanent but its clearance does not significantly change the DER unit output power.

$A_2) S_{pre} \neq S_{post}$. In this case, the postfault operating point significantly deviates from the prefault operating point. This is the case when the fault clearance entails a significant change in the DER unit output power.

V. SIMULATION RESULTS

A. RESULT WITHOUT VC-DER MODEL

• MODEL-

This is a simulation model without considering VC-DER unit .this model system operates at frequency of 50 Hz and voltage of 11kv is given through 3 phase source.following figure indicates its result on Matlab software.

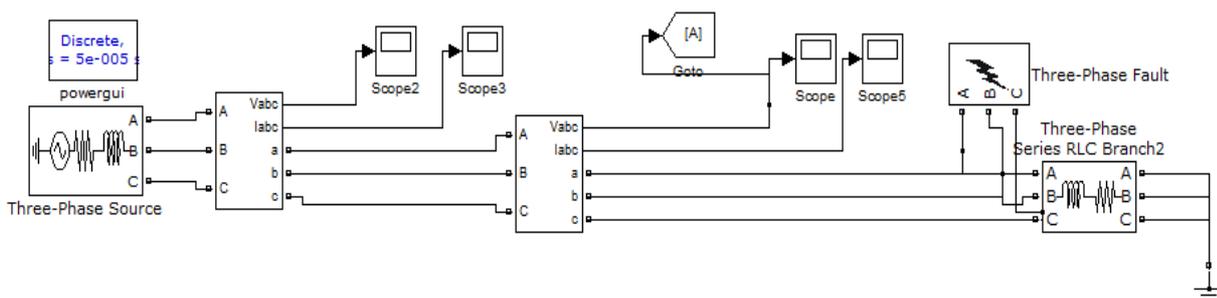


Fig. 5. Model without VC-DER unit

• **SIMULATION RESULT-**

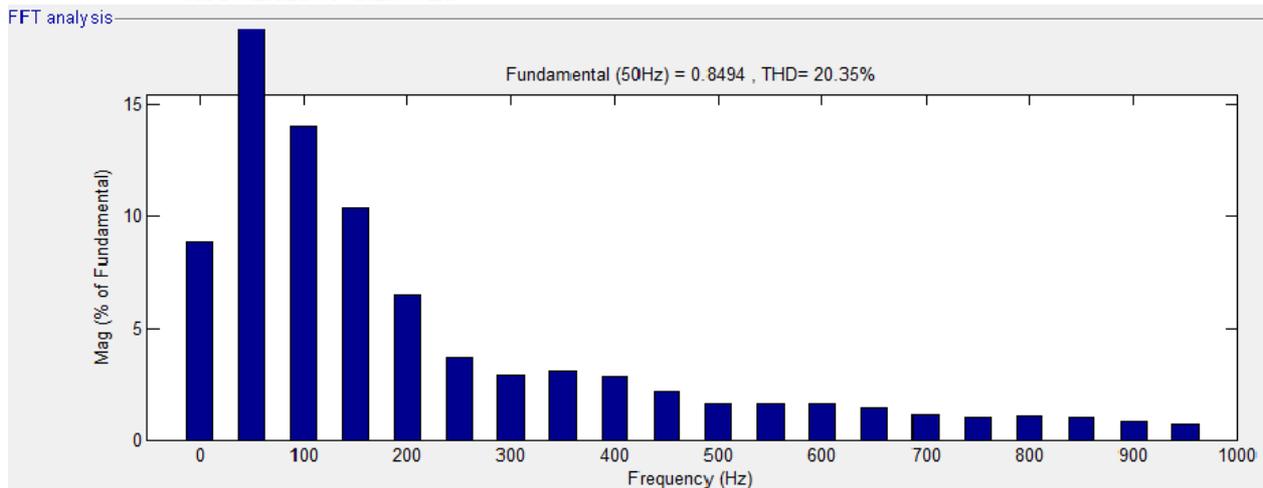


Fig. 6. THD without VC-DER unit

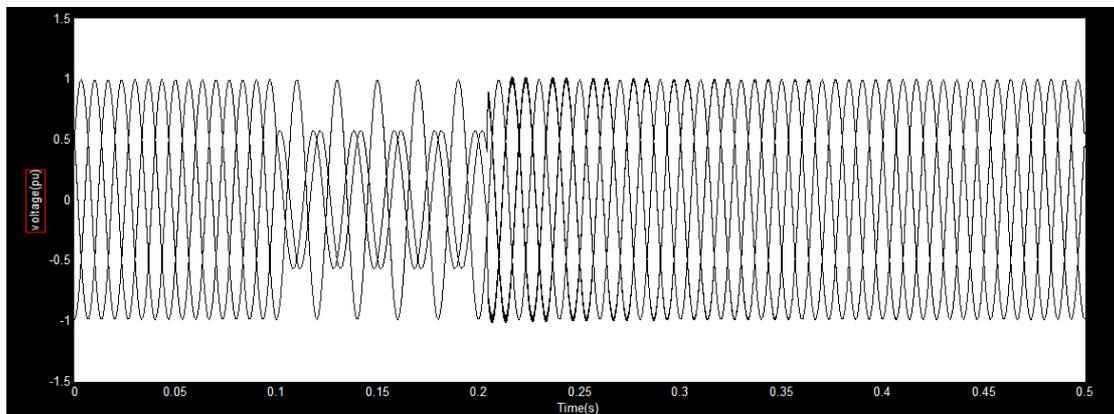


Fig. 7. Voltage sag during faulty condition

B. RESULT WITH VC-DER MODEL

• **MODEL-**

This is a simulation model with VC-DER unit .this model system operates at frequency of 50 Hz and voltage of 11kv is given through 3 phase source.following figure indicates its result on Matlab software.

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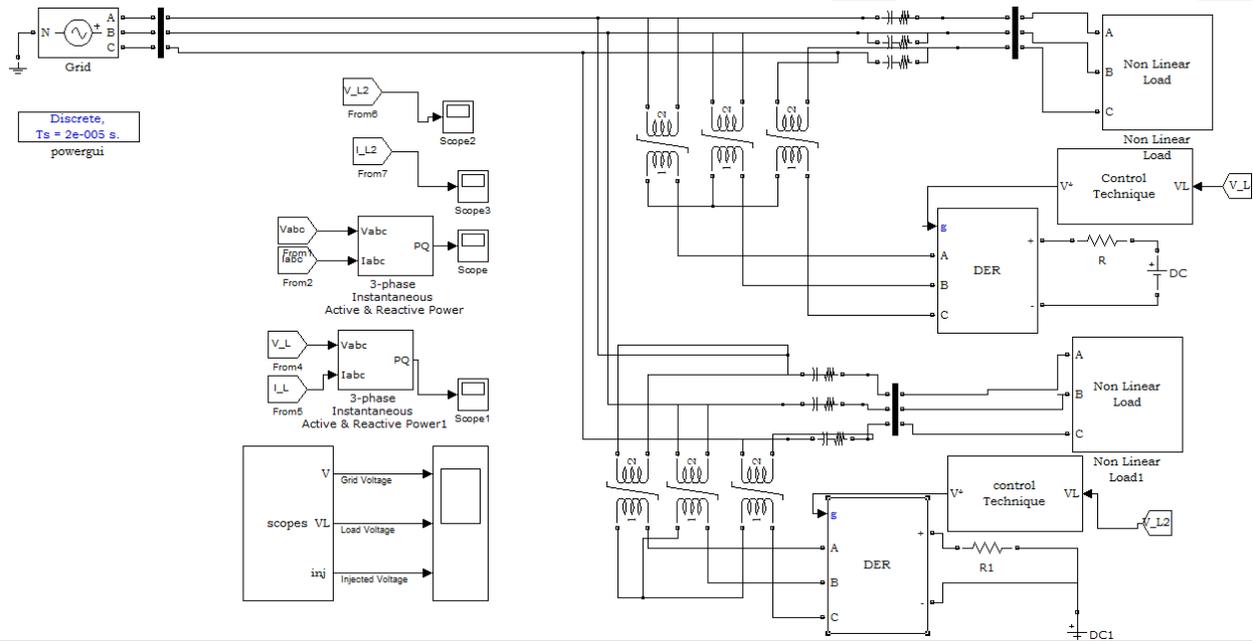


Fig.8. Model with VC-DER unit

• **SIMULATION RESULT-**

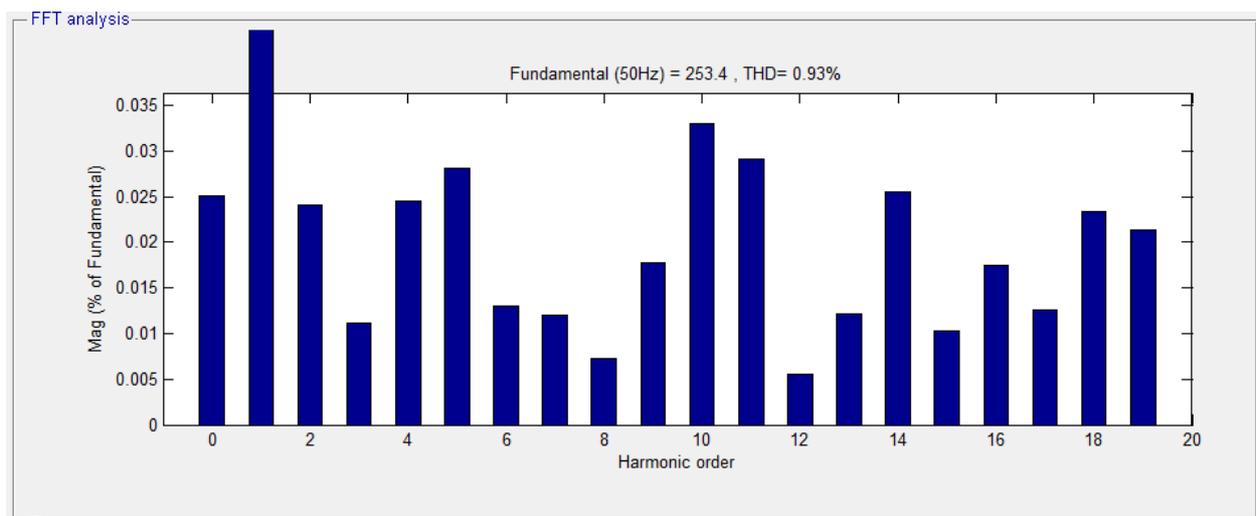


Fig. 9. THD with VC-DER unit

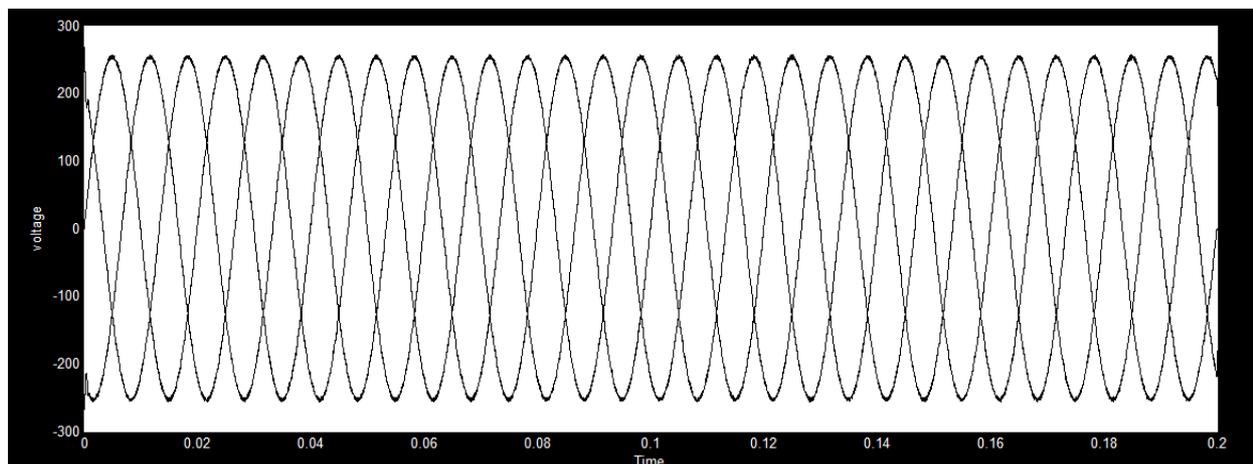


Fig. 10. Voltage with VC-DER unit

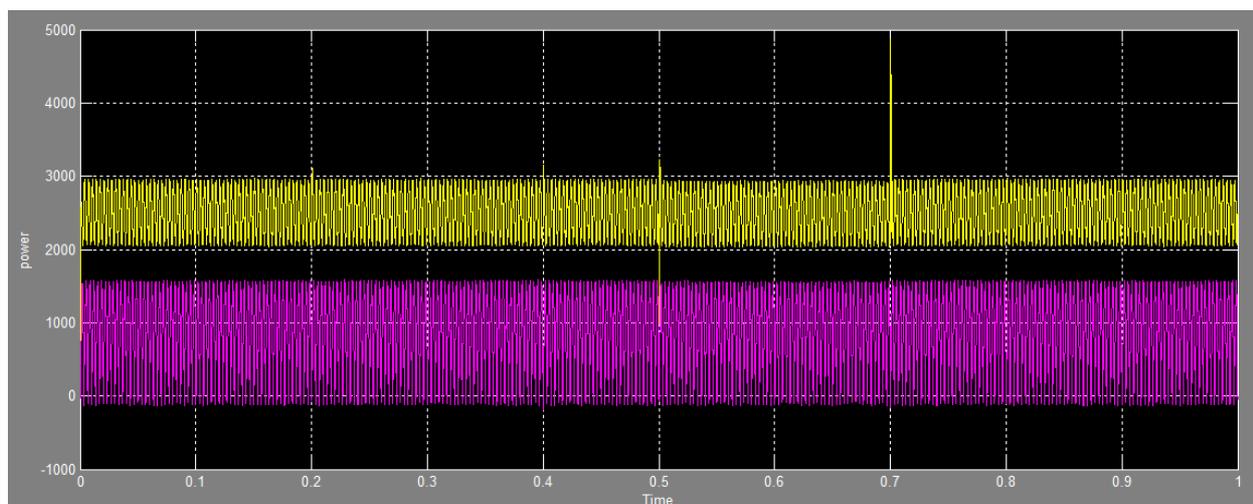


Fig 11 .power balance using VC-DER unit

VI. CONCLUSION

This paper has presented new concepts for overcurrent, overload & protection against harmonics to enable direct voltage control of electronically coupled DER units in an islanded microgrid. The overcurrent protection scheme detects the fault, limits the DER unit output current magnitude within its permissible range, and restores the microgrid to its normal operating condition subsequent to the fault clearance. The overload protection scheme limits the output power of the DER unit when excessive power demand is imposed on the DER unit & controls harmonics.

The study results demonstrate the desired performance of the add-on features when the microgrid is subject to various types of faults and the subsequent fault overcurrent/overload conditions. The results also imply that the voltage-based scheme has a predictive feature that can estimate the magnitude of DER unit output current in the next sampling period, and in case of a fault, it can limit the output current well in advance of reaching the maximum permissible value and further improves power quality of the system.

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