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STUDY OF A DC NANO GRID SYSTEM INTEGRATED WITH SOLAR PV GENERATION

[1]Rajesh Kumar, [2]Prof. Balram Yadav, [3]Prof. Namrata Sahu
[1]Research Scholar, [2]Professors
SCOPE College of Engineering, Bhopal (M.P.)

Abstract: - The power electronic interface has two stage conversions, with a DC-DC boost converter and a DC-AC voltage source inverter for grid integration. The dc-dc boost converter takes the Maximum Power Point (MPP) operation of the solar panel and VSI controls the dc link voltage and the power injected into the grid. The Maximum Power Point Tracker (MPPT) algorithm is applied to the boost dc-dc converter to ascertain the solar array operation always at its Maximum Power Point (MPP) on P-V characteristics.

This work proposes grid connected SPV for power quality improvement by suppling load. The THD of grid current. For the analysis of Total Harmonic Distortion, Fast Fourier Transform (FFT) analysis is done which provides the total harmonic distortion in percentage. The Nano-grid is taken as a future of electrical power system as the wide use of DC characterized load is increasing and is much reliable as per safety considerations. It will be much easier to construct an efficient DC Nano-grid based on the existing low AC power system. The complete system has been verified using simulation for 1000W/m2 insolation and respective reference track by controller.

1. OVERVIEW

The use of renewable resources has led to a paradigm shift in the way electrical power is generated, transmitted and consumed. Since the renewable resources are dispersed in nature, the concept of DG has emerged, which reduces the power losses by supplying the load locally. Further, it improves voltage profile, reliability, productivity, and security for critical loads. It also helps in load management, peak load shaving, flexibility in installation, reduction in emission, and effective energy pricing. DG has come up as a promising solution to meet the growing energy demand. In the initial stage of development, DG were primarily used as a backup source and stand-alone power supply. With technological advancement, the role of DG has changed from backup to primary energy supply. Eventually, the evolution of DG has gained significant attention and led interest of researchers on smart grid,.

Nanogrids are small microgrids, typically serving a single load which is smaller in size, up to 50 kW and it is extremely suitable for remote systems not interconnected with a regular utility grid.

1.1 MICROGRID

Microgrid is an integration of distributed generation and loads that has been observed as a potential solution to the problems faced in distributed systems. Microgrids provide a flexible, yet controllable interface between microgrid and a power system which isolates both sides electrically and yet connects them economically. Microgrid is emerging as a means to solve many power system problems in developed countries and has been shown to improve power supply reliability and ease up pressure on energy conservation and environmental protection.

1.2 NANOGRID

According to Sercan Teleke, Black & Veatch, nanogrids are subgroup of microgrids and it is characteristically serving as a microgrid but it is smaller in size with the capacity in the range of 2-50 kW. Since its niche application is likely to be for the remote area power supplies where no electricity grids and habitually it cannot be connected with a regular utility grid. Typically, renewable energy sources are used and are directly interfaced to a nanogrid to obtain higher efficiency and reliability. The nanogrids are pertinent for the locations that have a great renewable energy potential. The solar PV cell, fuel cell, wind turbine and diesel generator with PWM inverter are mostly used to generate power. The bidirectional converters, storage batteries, smart meters and control systems are needed to design the nanogrid for rural area.
In addition, the developing countries households may formulate a nanogrid with local generation and battery storage.

1.3 MICROGRID Vs NANOGRID

The capacity of the nanogrid for standalone system will be up to 20 kW and for grid connected system it can go up to 100 kW but the microgrid integrated up to 1 MW capacity. Furthermore, a nanogrid operates at DC as opposed to 50/60 Hz and relies on power electronic converters to interface both sources and loads to the system. The key potential for nanogrid are the rustic areas where no electricity grids, military installation station, developing countries with limited electricity access, tall buildings in inner city area, the areas where electricity is expensive and locations that have high renewable energy potential. Three key features of the nanogrids are

1. Its fiscal design for the total system energy requirements.
2. Its provision of extraordinary level of power quality and reliability to end users.

3. Its presentation to a single controlled entity

1.3.1 DC NANOGRIDS

A DC nanogrid typically used for smaller power converters with larger overall efficiency and easier interface of renewable energy sources to a DC system. The electronic appliances such as electronic ballasts, CFL, LED light and variable speed motor drives can be more suitably powered by DC nanogrid

1.3.2 AC NANOGRIDS

The AC nanogrids incorporate smart appliances, lighting and heating/ventilation/air conditioning with onsite power generation.

2. SYSTEMS BLOCK DIAGRAM

The main components for the modeling of maximum power point tracker algorithm are presented in Fig., for performance evaluation.

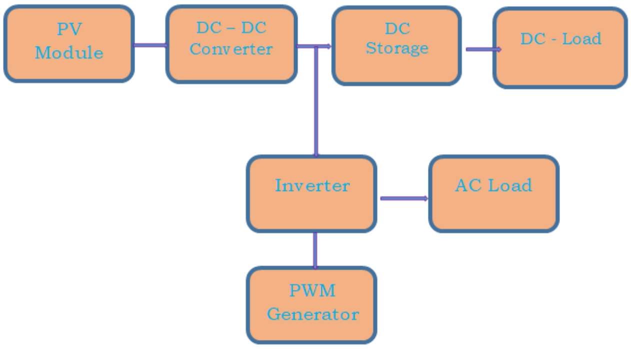


Figure 1: Systems block diagram

Let's discuss each block one by one

2.1 PV MODULE

Solar photovoltaic (SPV) cell consists of a p-n junction semiconductor fabricated in a thin layer. An equivalent circuit of solar photovoltaic (SPV) cell can be given as a current source connected with parallel diode. It generates current when light is illuminated otherwise acts as a conventional diode. When exposed to light, photons with energy greater than the band gap energy of the semiconductor are absorbed and generate an electron-hole pair. In depletion region, carriers are swept under the influence of the internal electric fields of the p-n junction and generate a current directly proportional to the incident light. The V-I characteristics of the solar photovoltaic cell is exponential which is similar to the conventional diode. When current flows in the external load, SPV is short circuited and when current is internally shunted in p-n diode, it is open circuited [9].

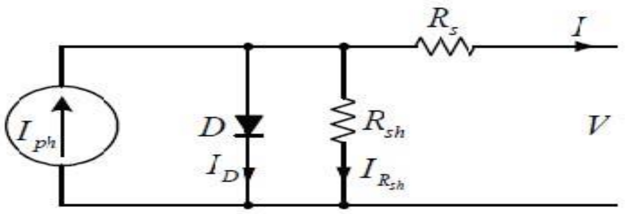


Figure 2: Single diode model of a solar photovoltaic cell

2.2 DC – DC CONVERTER

The DC-DC converters are main voltage controlling component of DC Nano-grid system integrated with solar PV generation which states that the DC-DC converters are used for voltage control for maintaining power quality of the system and also to meet the load demand. As the load increases the pressure onto the system increases due to which the required voltage of the system is controlled by these converters. It varies the voltage levels. It may also be termed as DC to DC converter be an electronics device or electromechanicals device that exchanges a DC source voltage from a voltage to another level.

2.3 INVERTER

Inverter is a power electronic device which converts DC to AC power. In the early decades inverter was limited to two level inverter, which implements only few semiconductor switches. However, with rapid growth in the industry the conventional two level inverter is not capable of handling high power application. Due to this reason, the need for introducing the high power application equipment such as Multi Level Inverter (MLI) become essential to overcome the short comings of conventional two level inverter and efficiently handling high power loads.

MLI is aimed to replace conventional two level inverter to achieve high power quality, voltage capability and low switching losses. The concept of MLI is to produce multilevel output voltage with less power switching loss and harmonic distortion. This power electronic inverter is an important element in the grid connected PV system. Several power conversion circuits have been proposed and studied, out of which the most popular topologies considered are centralized, string, multi-string and AC- module topology. Usually, the first three configurations present two power stages. In particular, the front stage is boost DC-DC converter, which obtains proper DC bus voltage and /or a wider tracking range, while the second stage is an inverter to generate the desired AC grid voltage. Instead of a DC-DC boost converter, a step up transformer can also be used to meet the grid voltage requirement. These latter solutions can also be used in AC module topology for individual PV panel application. The conventional approaches have high volume, weight, cost and reduced efficiency, thus being not convenient in distributed DC-AC conversion.

2.3 PWM GENERATOR

The control principle of sinusoidal PWM is to use several triangular carrier signals and keeping only one modulating sinusoidal signal. The m-level inverter requires (m –1) triangular carriers. The carriers have the same frequency fc and the same peak-to-peak amplitude Ac . The modulating signal is a sinusoid of frequency fm and amplitude Am. At every instant, each carrier is compared with the modulating signal. Each comparison switches get switched-on, if the modulating signal is greater than the triangular carrier assigned to that switch. The main parameters of the modulation process are

- The frequency ratio, k = fc / fm, where fc is the frequency of the carrier and fm is the frequency of a modulating signal.
- The modulation index, m = Am / (m * Ac), where Am is the amplitude of the modulating signal, Ac is the peak-to-peak amplitude of the carriers and m = (m - 1) / 2, where m is a number of level (which is odd).

The typical voltage generated by one cell for the inverter by comparing a sinusoidal reference with triangular carrier signal is shown in figure 4.3. A number of cascaded cells in one phase with their carriers shifted by an angle and using the same control voltage produce a load voltage with smallest distortion.

Advantages of SPWM

- Low power consumption
- High power energy efficiency up to 90%
- High power handling capability
- No temperature variation – and ageing – caused drifting or degradation in linearity
- Easy to implement and control
- Compatible with today's digital microprocessors

Disadvantages of SPWM

- Attenuation of the wanted fundamental component of a waveform
- Drastically increased switching frequencies that leads to greater stress on the associated switching devices and therefore derating of those devices.

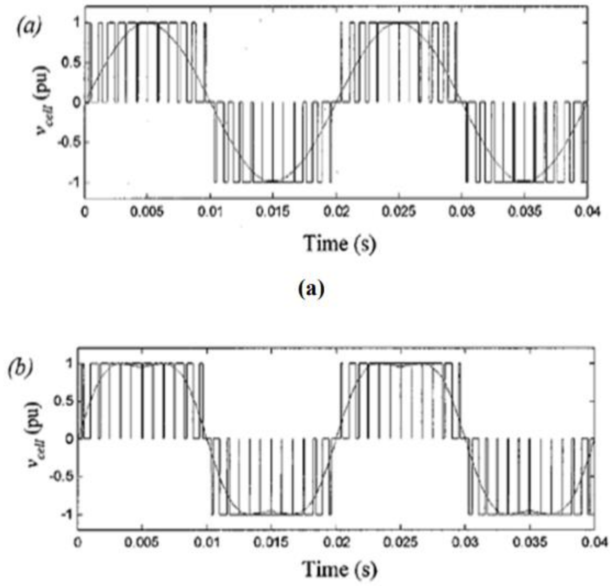


Figure 3 (a) Inverter cell voltages - Output voltage and reference with SPWM (b) Inverter cell voltages - Output voltage and reference with injection of sinusoidal third harmonic

2.4 STORAGE/BATTERY

The battery system must be sized correctly to minimize the system's total cost. The battery must be chosen by its ampere hour rating, voltage, daily watt hour requirement and depth of charge. Modeling and battery simulation within a nanogrid design had been studied according to their performance and the energy storage device to enable optimization of size of the batteries to minimize the overall operating cost. Modeling of batteries is challenging because of the State of Charge (SoC), various voltages, internal resistances, charge resistance, battery capacitance and discharge resistance. These are difficult to measure and predict within a system where charging/discharging cycles are often unpredictable and system temperature is not constant with most Renewable Energy Systems (RES). Sizing should be done carefully as over sizing has a detrimental effect on generated power price while under sizing reduces reliability of energy supply. Success of a system depends on balancing the maximum reliability and minimum cost. System sizing needs knowledge of solar radiation data at site, load profile, and supply of continuity. For 25 kW nanogrid power system, the 12 V and 200 Ah batteries of 52 numbers is implemented.

3. RESULTS AND DISCUSSION

The simulation of DC Nano-grid system is done with various types of DC-DC Converters. The results of the SIMULINK models are acquired for output waveform of DC and AC loads but the FFT's are analysed is for AC output of different loads. The FFT's Analysis is done through the solver power GUI block and the THD is obtained in percentage. The FFT results for THD (Total Harmonic Distortion) are discussed in three load different loading condition in three category of DC – DC Converter i.e. Boost Converter, Buck Converter and Buck – Boost Converter.

The results are analyzed in two parts
1. The results of the system in Buck-Boost Mode.
2. Comparison of the THD's in different loading conditions.

RESULT's FOR BUCK - BOOST CONVERTER

Figure. 5.1 shows the subsystem for the Buck-Boost converter.. The output voltage is calculated by

$$V_{out} = (D*V_{in})/(1-D) \quad 5.1$$

Where V_{out} is output voltage of the converter, V_{in} is input voltage of the converter and D is the duty cycle of the pulses. When 0<D<0.5, the converter operates as buck mode and when 0.5<D<1, the converter operates in boost mode. When D=0.5 converter is in an ideal mode. The result is seen in scope 1 for the output of both AC and DC but the FFT analysis is done for AC voltage since DC do not have frequency i.e. cyclic output. Hence FFT analysis of AC output is done.

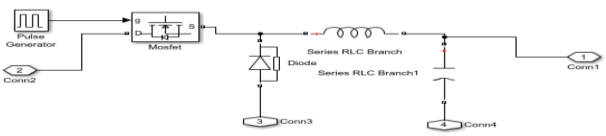


Figure 5: Subsystem of Buck-Boost Converter

The results in this subsystem model are shows in the figures 5 to 7.

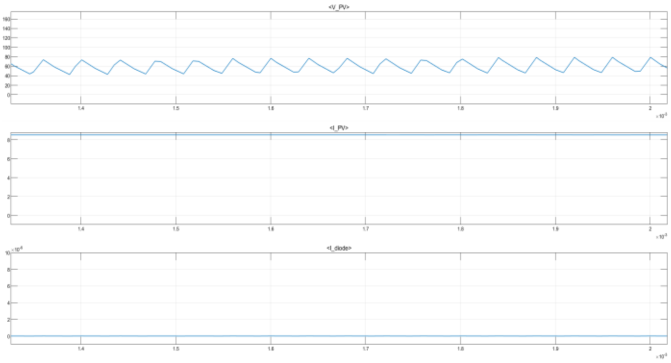


Figure 6: Output Voltage, Current and Diode current of the system

The output voltage, current and diode current is shown in the figure 6, the Voltage is kept constant at 70 V in the system and it has some disturbances. The current is kept at 9 A which is higher than compared work.

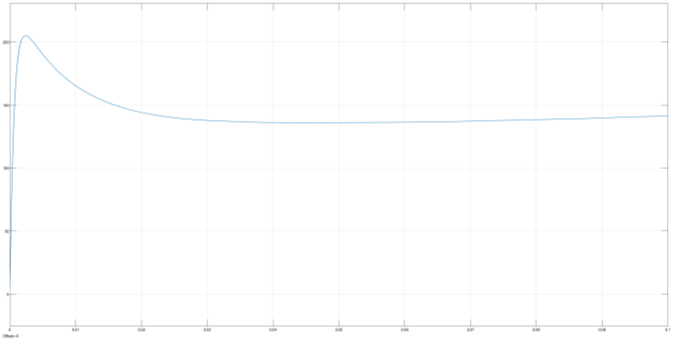


Figure 7: Output DC Voltage of the system

Figure 7 shows the output DC Voltage of the system, the voltage initially grows substantially and attains more than 200 V and then comes to settle down at 150 V.

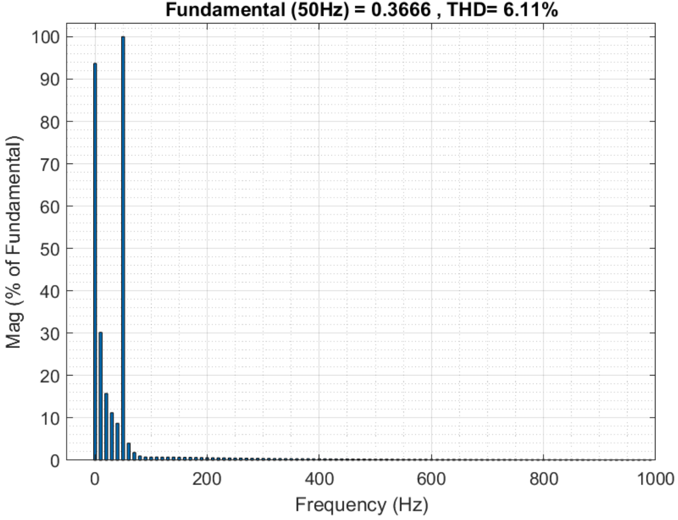


Figure 8: The Systems THD in Buck – Boost Controller

Results For load R=10Ω and L=0.5H

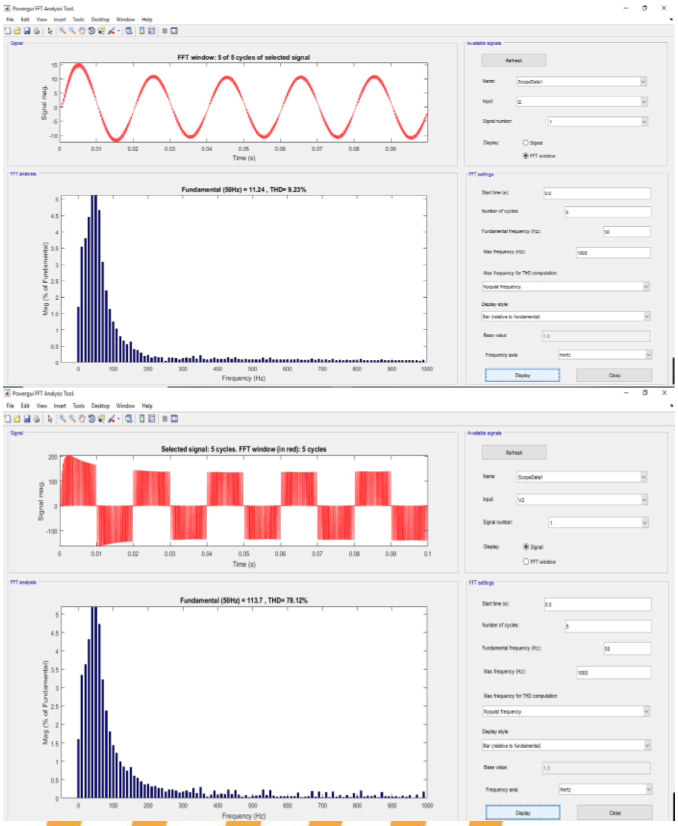


Figure 9: Current and Voltage FFT Analysis for R=10Ω and L=0.5H

Figure. 9 shows the FFT analysis of the boost converter at load R=10Ω and L=0.5H. The above curve is showing the current and below shows voltage curve. The THD obtained for current is 9.23% and for voltage is 78.12%.

Results for R=10Ω and L=1H

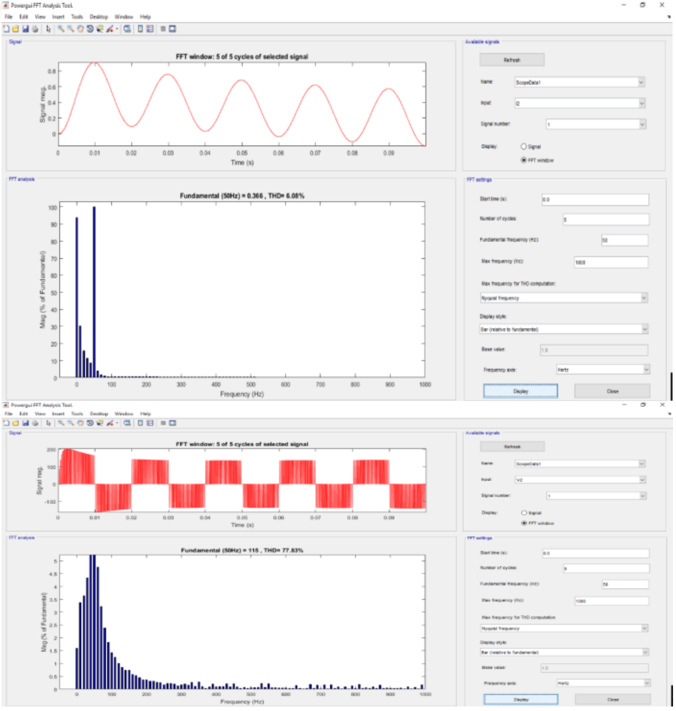
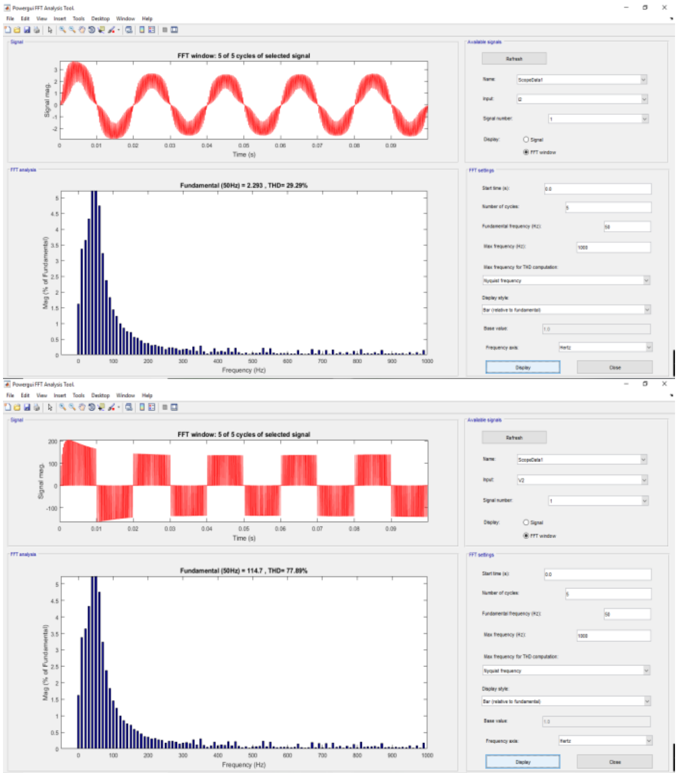


Figure 10: Current and Voltage FFT analysis for load R=10Ω, L=1H

Figure. 10 shows the FFT analysis of the boost converter at load R=10Ω and L=1H. The above curve is showing the current and below shows voltage curve. The THD obtained for current is 6.08% and for voltage is 77.83%.

Results For load R=50Ω and L=0.5H



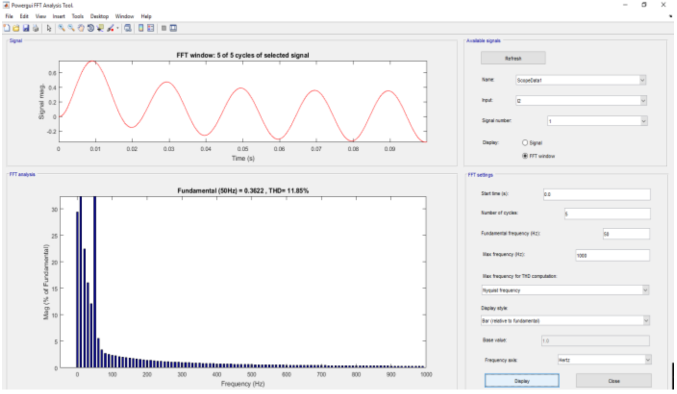
Name: ScopeData1
Input: I2
Signal number: 1
Display: ○ Signal ● FFT window
Start time (s): 0.0
Number of cycles: 5
Fundamental frequency (Hz): 50
Max frequency (Hz): 1000
Max frequency for THD computation: Nyquist frequency
Display style: Bar (relative to fundamental)
Base value: 1.0
Frequency axis: Hertz

Name: ScopeData1
Input: V2
Signal number: 1
Display: ○ Signal ● FFT window
Start time (s): 0.0
Number of cycles: 5
Fundamental frequency (Hz): 50
Max frequency (Hz): 1000
Max frequency for THD computation: Nyquist frequency
Display style: Bar (relative to fundamental)
Base value: 1.0
Frequency axis: Hertz

Figure 11: Current and Voltage FFT analysis for load R=50Ω and L=0.5H

Figure. 11 shows the FFT analysis of the boost converter at load R=50Ω and L=0.5H. The above curve is showing the current and below shows voltage curve. The THD obtained for current is 29.29% and for voltage is 77.89%.

Results For Load R=50Ω and L=1H



Name: ScopeData1
Input: I2
Signal number: 1
Display: ○ Signal ● FFT window
Start time (s): 0.0
Number of cycles: 5
Fundamental frequency (Hz): 50
Max frequency (Hz): 1000
Max frequency for THD computation: Nyquist frequency
Display style: Bar (relative to fundamental)
Base value: 1.0
Frequency axis: Hertz

Name: ScopeData1
Input: V2
Signal number: 1
Display: ○ Signal ● FFT window
Start time (s): 0.0
Number of cycles: 5
Fundamental frequency (Hz): 50
Max frequency (Hz): 1000
Max frequency for THD computation: Nyquist frequency
Display style: Bar (relative to fundamental)
Base value: 1.0
Frequency axis: Hertz

Figure 12: Current and Voltage FFT Analysis for load R=50Ω and L=1H

Figure. 12 shows the FFT analysis of the boost converter at load R=50Ω and L=1H. The above curve is showing the current and below shows voltage curve. The THD obtained for current is 11.85% and for voltage is 77.83%.

Table - 1: Result and Comparison of Total Harmonic Distortion from FFT Analysis

Load	Boost Converter Voltage THD (in %)	Boost Converter Current THD (in %)	Buck Converter Voltage THD (in %)	Buck Converter Current THD (in %)	Buck-Boost Converter Voltage (pulse width above 50%) THD (in %)	Buck-Boost Converter Current (pulse width above 50%) THD (in %)	Buck-Boost Converter Voltage (pulse width below 50%) THD (in %)	Buck-Boost Converter Current (pulse width below 50%) THD (in %)
R=10? and L=0.5H	78.12	9.23	77.39	6.42	77.36	6.42	77.30	6.42
R=50? and L=0.5H	77.89	29.29	77.40	28.32	77.40	28.32	77.40	28.32
R=100? and L=0.5H	77.86	46.39	77.31	45.73	77.31	45.73	77.31	45.73
R=10? and L=1H	77.83	6.08	77.43	8.70	77.29	8.73	77.29	8.73
R=50? and L=1H	77.83	11.85	77.43	13.50	77.29	13.40	77.29	13.40
R=100? and L=1H	77.83	11.39	77.43	12.95	77.29	12.85	77.29	12.85

Table – 1 shows the overall Total Harmonic Distortion (in %) for different load and converters for their load voltage and load current using FFT analysis process. The above result shows that the least Total Harmonic Distortion for load current is in Boost Converter and for load voltage is in Buck-Boost converter. As the resistance increases the distortion increases but if inductance increases the number of levels in output voltage for inverter output decreases and for lower inductive load the number of levels of the output voltage for inverter output increases. Thus Boost converter gives least distorted output.

5. CONCLUSION

Selection of any energy source (available in world), is primarily based on its reliability, robustness and distribution when subjected to various load demands. The key objective of this research work has been to improve the dynamic performance of the grid interfaced solar photovoltaic (SPV) system based on reduction of the total harmonic distortion (THD) of grid connected inverter by modifying the DC to DC Converter. A detailed investigation has been carried out to observe the improvement in the dynamic performance of the DC Nano grid interfaced with inverter. It can be concluded that the Boost Converter is providing less harmonic distortion than Buck Converter and Buck-Boost Converter. A solar PV module provides low voltage therefore Boost converter is mostly used to maintain the DC bus voltage for a DC Nano-grid system for higher DC loads. Less distortion due to converter provides efficient power supply and less loss in the system which makes the system economical as well as more efficient system. Less harmonic distortion leads to smooth functioning and therefore for DC Nano-grid system such converters are required which provides less distortion and maintain the bus voltage.

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