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Comparative Study and Classification of Solar fed Microgrids based on THD, DC component and Sub-harmonics

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***Abstract*—** In this paper, a solar based average model microgrid system has been demonstrated and behaviour of current signals under non identical load conditions have been analyzed. Inverters of various configuarations have been used here to monitor and analysis the performance during rated load, over-load and under- load conditions. First Fourier Transformation (FFT) technique has been applied to assess the nature of inverter output currents. The magnitude of DC components, Total Harmonic Distorsion (THD) and Sub-harmonic components have been evaluated from three phase inverter secondery side currents. Then parameter based comparetive study of microgrid have been carried out at varrying load conditions. Different definite relations have been obtained for a range of no-load to over-load conditions with THD values, magnitude of DC component and sub harmonic frequencies and have been presented.

***Keywords*—**FFT, Load, Micro grid, DC component, Inverter, PV array, Sub harmonics, Total Harmonics Distortion (THD)

I. INTRODUCTION

A solar photovoltaic energy system has been designed to transform the energy from the sun into electricity by means of photovoltaic effect. As because the sun provides more energy than its' required, electricity from solar power is very important energy resource in the move towards clean energy production. The solar PV system has better safety, low-maintenance and provides green energy without on-site pollution or emissions. Nowadays, solar photo voltaic array based microgrid systems have popularly been installed and adapted all across the globe. Lots of research works are going on solar power generation. Advancement of optimization technique based performance analysis has been used to minimise the effect of different physical conditions over the output of a photo voltaic cell [1]-[5].

Ivan Garcia et al (2014) introduced a whole new technique for optimization of multifunction solar cells using indoor energy yield measurements [1]. A new distribution maximum power point tracking based system for solar photo voltaic module [2] has been presented by pooja sharma et al (2014). Diego Alonso-Alvarez et al (2014) studied and proposed a new procedure of external thermalization of carriers for lower operating solar cell temperature with luminescent down shifting [3]. Thermography-based temperature distribution technique for identifying PV module mismatch faults [4] has been invented by Yihua Hu et al (2014). Katherine A. Kim et al (2015) have developed and proposed photovoltaic hot-spot based detection tools for solar panel substrings by utilizing AC parameter characterization [5]. Ambient-temperature dependence and implications for solar cell performance has been investigated by Johannes P. Seif et al (2015) using amorphous-crystalline silicon interface passivation method [6]. Hong Tak Kim et al (2015) have commenced a new study on conversion efficiency of $CuInGaSe_2$ solar cells by operating AC analysis of temperature effects [7]. R. PonVengatesh et al (2015) have investigated the effects of homogeneous and heterogeneous solar irradiations on multicrystal solar PV module under various configurations [8]. Where, proposed diagnostic process has been developed by using various computer simulation and laboratory experiment. A novel scheme for thermal design of photovoltaic/microwave conversion hybrid panel[9] have been introduced by Daisuke Sato et al (2016) for space solar power. R. Hariharan et al (2016) established a method to detect photovoltaic array faults and partial shading in PV systems [10]. Artificial neural network-based modeling of compensated multi-crystalline solar-grade silicon under wide temperature variations [11] has been proposed and presented by Jagdish Chandra Patra et al (2016). Xingshu Sun et al (2016) proposed an illumination- and temperature-dependent analytical model for copper indium gallium diselenide (CIGS) solar cells [12]. A whole new temperature-induced degradation technique of thin-film solar cells for space applications [13] has been suggested by Rosalinda H. Van Leest et al (2017). Seyed Ali Arefifar et al (2017) have developed and demonstrated a new multivariate design optimization for improving solar power PV plants [14]. Efficiency improvement tools for non-uniformly aged PV arrays [15] have been proposed by Yihua Hu et al (2017). Mohammad Aminul Islam et al (2018) analyzed the effect of different factors on the leakage current behavior of silicon photovoltaic modules at high voltage stress [16] by different simulation techniques and experiments. Reduction of PV module temperature using thermally conductive back sheets [17] has been developed by Jaewon Oh et al (2018).

Authors in their previous work [19]-[21], made an effort to use FFT based assessments in order to classify different inverter configurations on accordance to nature of sub-harmonics, THD and DC components. However, the work dealt with only the rated load conditions.

This has motivated the authors to extend the work with other load conditions with respect to THD, DC component and Sub harmonic components.

In this work, an effort has been made to build up a specific relation between load and those parameters for different inverter configuration. Based on the observation, classifications of inverters have been made.

II. SCHEMATIC DESIGN OF MICRO GRID

A 400 KW microgrid system has been modelled with 48 numbers of parallel connected strings in each array. In each string five series connected modules are connected. Solar PV module having -0.26 % per ˚C temperature co-efficient, maximum power output of 310 watt, the diode ideality factor of 0.95 and capable to deliver an open circuit voltage of about 60 V have been used. PV array has series and shunt resistances of 0.42 ohms and 420 ohms respectively. Each string is specified by short circuit current of 5.5 A. The output of the parallel connected PV arrays has been connected to the input side of three phase inverter as shown in Fig.1. Three bridge arms have been applied in inverter which offers a frequency of 50 Hz. The inverter output is first fed to high-voltage BUS and then connected with 200KVA, 260/25KV, and 50 Hz star-delta transformer. In this microgrid model, the generation units and loads have also been connected with conventional grid system by tie line through various load BUSes.

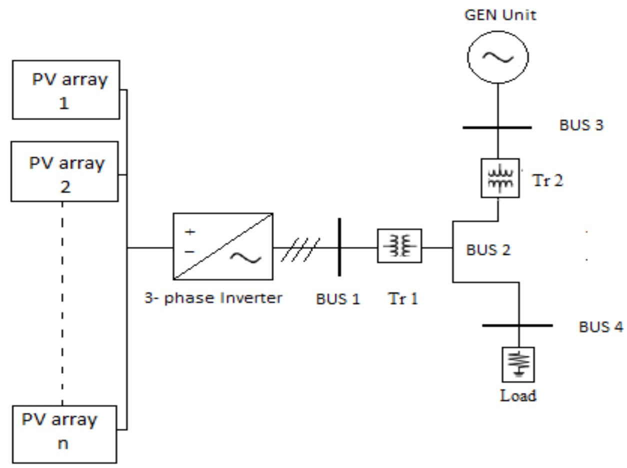


Figure 1. Schematic design of 400 KW micro grids

III. FFT BASED STUDY OF INVERTER SECONDARY CURRENTS

The Fast Fourier transformation (FFT) is an effective mathematical tool which efficiently calculates the frequency components of time-varying signals [18]. In this work, an average model based voltage source converter based microgrid has been taken into consideration, where various three phase inverter configurations (IGBT Diodes, MOSFET Diodes, GTO Diodes, Ideal Switches, Switching function based VSC, Thyristor, Diodes and Average model based VSC) have been employed subsequently at different load conditions i.e. over-load, rated-load and partial load to study the inverter output currents.

DC Component, THD, and Sub-Harmonics of inverters secondary currents at different percentage of loading i.e. 0% to 200% have been assessed using FFT.

IV. FACTORS CONSIDERED DURING ANALYSIS

The different factors have been considered during analysis are as follows:

- Variable load conditions i.e. 25% to 200% load.
- Normal temperature and irradiance
- Equal number of string
- Different inverter configurations.

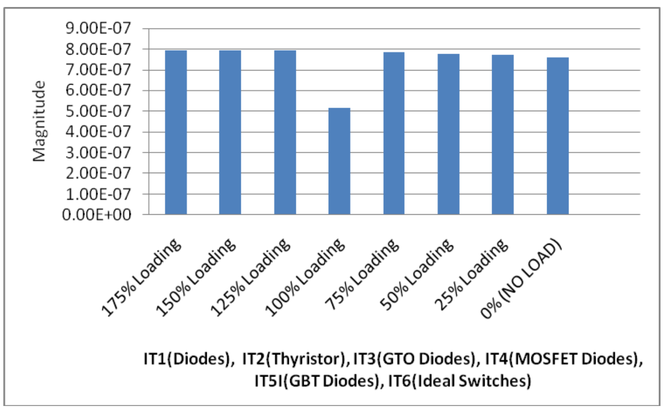
V. EVALUATION OF DC COMPONENT

The DC component values for different inverter configuration under varying load have been measured. Based on the analysis of nature of dc component the different Inverter configuration has been categorized and presented in Table 1. Total eight numbers of inverter types have been considered as follows: Diode (IT1), Thyristor (IT2), GTO Diodes (IT3), MOSFET Diodes (IT4), IGBT Diodes (IT5), Ideal Switches (IT6), Switching VSC (IT7) and Average VSC (IT8).

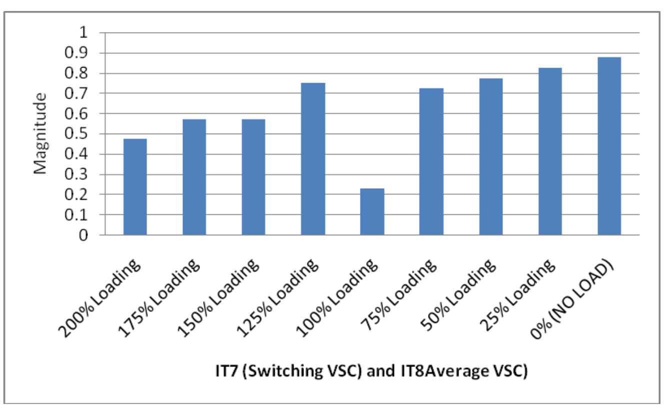
Table: 1 DC component values for different inverter configuration under varying load.

DC component values in Amperes										
Inverter Type (IT)	Under Load				Rated Load	Over Load				Remarks
	0% no load	25% Loading	50% Loading	75% Loading	100% Loading	125% Loading	150% Loading	175% Loading	200% Loading	
IT1	7.61x10^{-07}	7.61x10^{-07}	7.61x10^{-07}	7.61x10^{-07}	7.61x10^{-07}	7.61x10^{-07}	7.61x10^{-07}	7.61x10^{-07}	7.61x10^{-07}	IT1 to IT6 shows same nature
IT2	7.61x10^{-07}	7.61x10^{-07}	7.61x10^{-07}	7.61x10^{-07}	7.61x10^{-07}	7.61x10^{-07}	7.61x10^{-07}	7.61x10^{-07}	7.61x10^{-07}	
IT3	7.61x10^{-07}	7.61x10^{-07}	7.61x10^{-07}	7.61x10^{-07}	7.61x10^{-07}	7.61x10^{-07}	7.61x10^{-07}	7.61x10^{-07}	7.61x10^{-07}	
IT4	7.61x10^{-07}	7.61x10^{-07}	7.61x10^{-07}	7.61x10^{-07}	7.61x10^{-07}	7.61x10^{-07}	7.61x10^{-07}	7.61x10^{-07}	7.61x10^{-07}	
IT5	7.61x10^{-07}	7.61x10^{-07}	7.61x10^{-07}	7.61x10^{-07}	7.61x10^{-07}	7.61x10^{-07}	7.61x10^{-07}	7.61x10^{-07}	7.61x10^{-07}	
IT6	7.61x10^{-07}	7.61x10^{-07}	7.61x10^{-07}	7.61x10^{-07}	7.61x10^{-07}	7.61x10^{-07}	7.61x10^{-07}	7.61x10^{-07}	7.61x10^{-07}	
IT7	0.8755	0.8257	0.7737	0.7234	0.2285	0.7498	0.5711	0.5711	0.4721	IT7 to IT8 shows same nature
IT8	0.8755	0.8257	0.7737	0.7234	0.2285	0.6217	0.5711	0.5711	0.4721	

The inverter secondary current as presented in Table 1 have been studied at varying load conditions as shown in the Figure 2(a) and 2(b). The nature of IT1 to IT8 clearly resembles that the values at rated load i.e. 100% has been observed as minimum.



(a)



(b)

Figure 2: Magnitude of DC component vs. different load conditions under various inverter configurations, (a) for IT1 to IT6 and (b) for IT7 and IT8.

In inverters (IT1 to IT6) the magnitudes of DC component under overload conditions i.e. 125%, 150%, 175% and 200% loading have been observed of same magnitudes.
During under load and no load conditions the magnitudes are slightly decreasing as the load decreases.

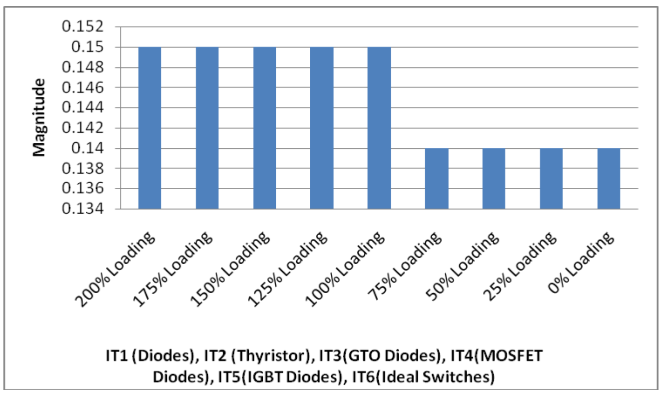
Considering inverters IT1 and IT6, during over load condition, the magnitudes of DC components are decreasing in nature as the load increases. On the other hand, the magnitude under no load as well as under load i.e. 75%, 50%, and 25% loading the magnitude continuously increases in a uniform order as the load decreases.

VI. ASSESSMENT OF TOTAL HARMONICS DISTORTION (THD)

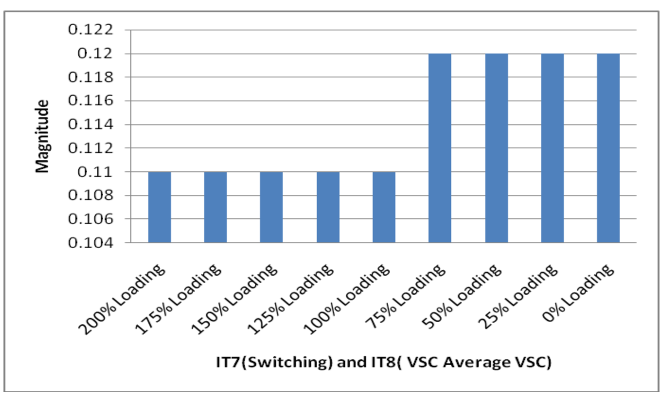
The total harmonic distortion is a measurement of the harmonics distortion present in a signal and can be defined as the degree to which a waveform deviates from its pure sinusoidal values. THD of two different groups of inverter has been noticed, THD values for different inverter configuration under varying load conditions have been presented in Table 2.

Table: 2 THD values for different inverter configuration under varying load.

Inverter Type (IT)	THD									Remarks
	Over load				Rated load	Under load				
	0% Loading	25% Loading	50% Loading	75% Loading	100% Loading	125% Loading	150% Loading	175% Loading	200% Loading	
IT1	**0.12**	**0.12**	**0.12**	**0.12**	**0.11**	**0.11**	**0.11**	**0.11**	**0.11**	**IT1 to IT6 shows same nature**
IT2	**0.12**	**0.12**	**0.12**	**0.12**	**0.11**	**0.11**	**0.11**	**0.11**	**0.11**	
IT3	**0.12**	**0.12**	**0.12**	**0.12**	**0.11**	**0.11**	**0.11**	**0.11**	**0.11**	
IT4	**0.12**	**0.12**	**0.12**	**0.12**	**0.11**	**0.11**	**0.11**	**0.11**	**0.11**	
IT5	**0.12**	**0.12**	**0.12**	**0.12**	**0.11**	**0.11**	**0.11**	**0.11**	**0.11**	
IT6	**0.12**	**0.12**	**0.12**	**0.12**	**0.11**	**0.11**	**0.11**	**0.11**	**0.11**	
IT7	**0.14**	**0.14**	**0.14**	**0.14**	**0.15**	**0.15**	**0.15**	**0.15**	**0.15**	**IT7 to IT8 shows same nature**
IT8	**0.14**	**0.14**	**0.14**	**0.14**	**0.15**	**0.15**	**0.15**	**0.15**	**0.15**	



(a)



(b)

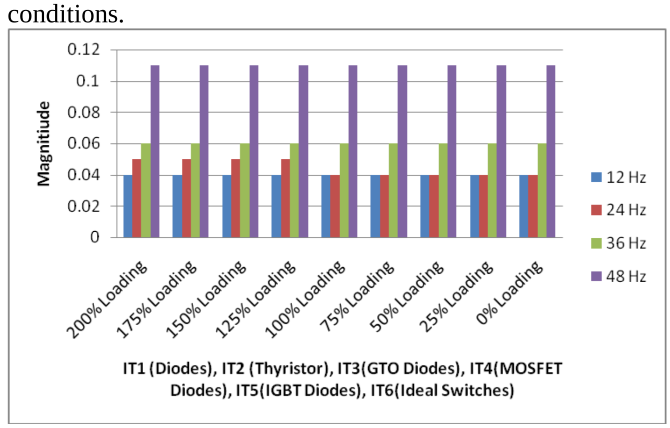
Figure 3: Magnitude of THD vs. varying load conditions for different inverter configurations, (a) for IT1 to IT6 and (b) for IT7 and IT8.

Magnitude of THD vs. different load conditions for varying inverter configurations has been shown in Figure 3(a) and 3(b). THD values under over-load and rated load conditions i.e. 200%- 100% are of same magnitude for IT1 to IT6. On the other hand, in case of no load or under load condition the value are constant but slightly less than over load/ rated load. For IT7 and IT8, the reverse nature can be notice where in under and no-load condition it shows maximum value of 0.12 and slightly decreases in full-load as well as over-load conditions.

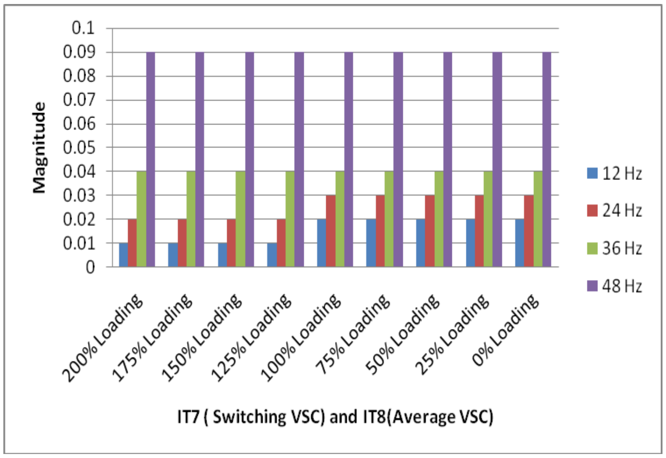
VII. SUB HARMONICS COMPONENTS

A special subset of inter harmonics which have frequency values less than that of fundamental frequency are known as sub-harmonics frequency. The magnitude of sub harmonics frequencies for different inverter configuration during over-load, rated-load and under-load conditions have been shown in figure 4.

From the obtained result the nature of IT1 to IT6 shows exact identical, whereas, IT7 and IT8 shows a different nature.
In the same way, two separate figures, i.e. 4(a) and 4(b) have been shown representing magnitudes of sub harmonics frequencies vs. different load conditions. Four sub harmonic frequencies have been considered i.e. 12, 24, 36, 48 Hz for both the case. In IT1 to IT6, at 12, 36 and 48 Hz the magnitude is constant for different load but at 48 Hz the magnitude is high for overload conditions than rated to no load conditions. Similarly in IT7 and IT8, the values are same for 12 and 36 Hz. On the other hand at 12 and 24 Hz sub harmonic frequencies the magnitude are less in over-load conditions but increases slightly from rated load to no load conditions.



(a)



(b)

Figure 4: Magnitude of Sub harmonics frequencies vs. different inverter type under varying load conditions, (a) for IT1 to IT6 and (b) for IT7 and IT8.

VIII. CONCLUSSION

Comparative study chart has been prepared using captured values of inverter secondary currents to establish the specific relations with respect to DC Components, THD and Sub-harmonics and presented in Table 3.

Table: 3 Nature of THD and DC components and Sub-harmonics under different inverter configuration and varying load conditions

Inverter Group	Load conditions	Parameters	Remarks
Group-A IT1 to IT6	Over Load (200%, 175%, 150%, 125%)	THD	THD values Maximum at Over load and Rated load whereas Minimum at Under load and no load
	Rated Load (100%)	DC components	Magnitude of DC components increases with increase in Rated load to Over load, on the other hand from Under load to no load value decreases
	Under Load (0%, 25%, 50%, 75%)	Sub-harmonics	Sub harmonics value of currents for both group- A and group-B categorise of inverter at 12 Hz, 24 Hz, 36 Hz and 48 Hz have been observed almost same.
Group-B IT7 to IT8	Over Load (200%, 175%, 150%, 125%)	THD	THD values Minimum at Over load and Rated load whereas Maximum at Under load and no load.
	Rated Load (100%)	DC components	Magnitude of DC components increases with increase in Rated load to Over load, on the other hand from Under load to no load value increases
	Under Load (0%, 25%, 50%, 75%)	Sub-harmonics	Sub harmonics value of currents for both group- A and group-B categorise of inverter at 12 Hz, 24 Hz, 36 Hz and 48 Hz have been observed almost same.

The natures of inverter secondary currents for different configurations have been compared under varying load conditions.

In case of group- A type inverter, THD values have been observed maximum at over load and rated load conditions and minimum during under load and no load. Magnitude of DC components increases from rated load to over load. On the other hand, DC component values decreases from under load to no load.

In case of group- B type inverter, magnitudes of THDs have been noticed as minimum at over load and rated load conditions but, slightly greater for under load conditions.
DC component values have been noticed as maximum during under load and minimum at over load conditions.
Sub harmonics value of currents for both group- A and group-B categorise of inverter at 12 Hz, 24 Hz, 36 Hz and 48 Hz have been observed almost same.
This may also be helpful in load monitoring i.e. over load, rated load and under load on micro grid.

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Authors Profile

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Surajit Chattopadhyay was born in Hooghly, West Bengal, India on February 9, 1978. He has obtained B. Sc. Degree in Physics Honours from Ramakrishna Mission Vidyamandir (CU), in 1998, and then B. Tech., M. Tech., in Electrical Engineering and Ph. D (Technology) degrees from the Department of Applied Physics of University of Calcutta in 2001, 2003 and

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