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Analysis of Output DC Current Injection in Grid Connected Inverters

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ABSTRACT: Solar energy technologies have gained much importance in the recent scenario due to their ability to produce clean, reliable, useful power. Grid connected Photovoltaic system requires conversion from DC to AC to harness the useful energy produced. A Photovoltaic inverter directly connected to the grid can cause, besides the generation of several current harmonics, a DC current component injection. Excessive DC current injection into the AC network can result in problems such as increased corrosion in underground equipment and transformer saturation. The paper aims at evaluating the output DC-current injection in grid connected inverter used for a 100kW solar power plant installed at Amal Jyothi College of Engineering, Koovapally, through experimental analysis. A simulation based study on output DC current injections in inverters with two different multilevel topologies is also conducted.

KEYWORDS: Grid connected inverter, DC offset current

I. INTRODUCTION

With the increase in energy crisis concerns growing during day by day, much recognition is being gained in the potential of solar energy as a sustainable energy source . Solar energy adds flexibility to the energy resource mix by decreasing the dependence on fossil fuels, but the greatest barrier to the technological expansion in this field is the costs of devices used for converting sun`s energy in the form of radiation into useful electrical energy, limited space and energy. Even though there has been a massive downward tendency in the price of PV modules, the price of grid connected inverters still remains high thereby increasing the overall cost. The efficiency of the plant plays a crucial role in the profit obtained from sustainable energy resources being harnessed. The major benefit of designing a reliable, stable, efficient and lower cost photovoltaic power electronics system is the availability of reliable and quality power without relying on the utility grid. It also avoids the major investment in transmission and distribution. To the nation, the major benefit lies in the fact that it reduces greenhouse gas emissions, responding to the increasing energy demands by establishing a new, high-profiled industry.Therefore, it is required to minimize the losses and improve the efficiency of power electronic devices used. Use of multilevel inverters has increased the quality of waveforms and thereby increasing efficiency of the system. H-bridge multilevel inverters are more suitable for renewable energy harvesting due to the presence of separate DC sources.

II. GRID CONNECTED INVERTER AND DC INJECTIONS

Grid connected inverters are used to convert the DC power thus obtained into AC power for further utilization. They are directly fed solar electricity to the grid. As it does not have the battery component, the cost of the system is low. The main quality requirements / factors affecting these power converters are total harmonic distortion (THD) level, DC current injection and power factor, the Impulse Withstanding ratio (or BIL), High Frequency Noise / Electromagnetic compatibility (EMC), Voltage Fluctuations and Flicker of Inverter System. Therefore, inverters connecting a PV system and the public grid are purposefully designed, allowing energy transfers to and from the public grid. [1-3]

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Due to approximate short circuit characteristics of AC network, a little DC voltage component can accidently be produced by grid connected inverters which can create large DC current injections. If output transformers are not used, these inverters must prevent excessive DC current injection, which may cause detrimental effects on the network components, in particular the network transformers which can saturate, resulting in irritant tripping. This may also increase the losses and reduce the lifetime of the transformers, if not tripped. Moreover, the existence of the DC current component can induce metering errors and malfunction of protection relays and can create an adverse effect on the overall functioning of the solar power plant.

Therefore, there are stringent regulations in many countries to prevent the network from the large DC current injection. Since most Indian standards published by BIS are aligned to IEC standards, DC injections up to ±1% is being proposed by the BIS in the Indian standard keeping with IEC 61727. The H-bridge or Multi Level inverter eliminates the DC component of the current by adding switches on the DC side to clamp the voltage during the zero voltage periods. This method could be also applied by clamping in the AC side. Both methods could not guarantee elimination of DC component as the unbalance due to forward power electronic switch voltages and PWM control can not be removed. [4-6]

There are many types of multilevel inverter topologies in its history.The diode-clamped utilizes a bank of capacitors to split the DC bus voltage and then the switched flying capacitor (or capacitor clamped) topology. For a DC bus voltage Vdc, the voltage across each capacitor is Vdc/4 and voltage stress on each device is limited to Vdc/4 through the clamping diode. The principle of diode clamping to DC link voltages can be extended to any number of voltage levels. Since the voltages across the semiconductor switches are limited by conduction of the diodes connected to the various DC levels, the inverter is called DCMLI. The H-Bridge inverter consists of two series connected H-bridge cells, which are fed by independent voltage sources. The outputs of the H-bridge cells are connected in series such that the synthesized voltage waveform is the sum of all of the individual cell outputs.[7-11]

III. EXPERIMENTAL RESULT

The main objective of the work is to conduct an analysis study of output DC injection in grid connected inverter installed at the 100kW solar plant in Amal Jyothi College of Engineering, Kanjirappally, India. Technical analysis of the plant is done to evaluate the effect of environmental and climatic conditions on the performance of the system. The analysis also evaluates the effects DC offset to variations in its operating conditions. The International Energy Agency (IEA) Photovoltaic Power Systems Program describes, in its IEC Standard 61724, the parameters used to assess the performance of solar PV systems.

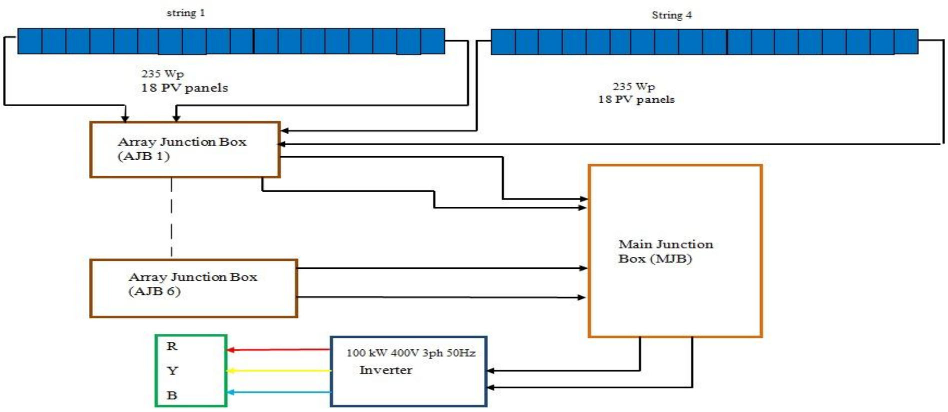

Fig 1: Block diagram of 100kW solar plant

The block diagram shown above represents the entire grid connected solar power plant installed at Amal Jyothi College of Engineering. 100kW solar panels are used to trap solar radiations. The energy obtained is converted to useful AC

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supply using a VACON built inverter.The energy harnessed from the sun is used to meet the requirements of an entire 7-storey building block. When the energy harnessed is not sufficient the required amount is taken from the KSEB grid.

Since Kerala is placed in the equatorial region, it has high solar insolation and temperature. The normal ambient temperature varies from 23-33degC. The variation in solar insolation and temperature affects the panel PV panel performance. Rise in temperature results in degradation of efficiency and power output of the solar panel. The solar insolation falling in the earth`s atmosphere has direct or beam radiation,diffused radiation and albedo or reflected radiation. In bright sunshine days, the beam and albedo radiations are greater . But that during cloudier days the diffused components are more. The data collection was made for sunny and rainymonths ie in the months of February, march, April and May. From, the analysis of the available data, it is found that the panel has different behavior for varying insolation,temperature etc. From the experimental Datas collected, the efficiency of the inverter has reached up to 87% during high radiation time i.e.the inverter is never operating near at its full capacity and the average DC to AC conversion is below 90%.The inverter efficiency very slowly declines after peak value is reached.PV system at its best is operating in the 20 to 40% range of rated output and hence is operating in the 87 to 91% efficiency range during the sunniest periods. Since the inverter is kept in a mechanical room under the roof and the temperature differences was not as drastic as they would be for inverters located outside.

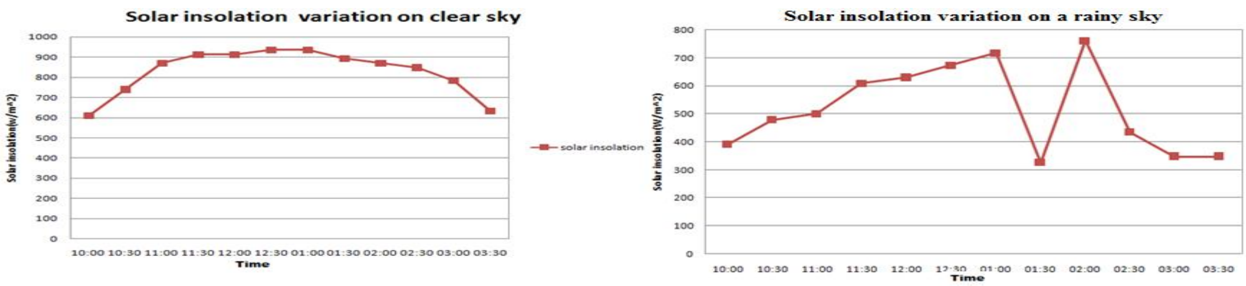

Fig 2. Solar insolation vs Time on a rainy day (a) and clear day (b)

From the analysis done, on a clear day with bright sunshine the panel receives daily average solar radiation of about 4.56kW/m2 to 5.24kW/m2. During the rainy days the solar radiation is about 3.13kW/m2 to 4.3kW/m2. Thus from the data collection it can be classified into two groups. First, high solar radiation groups that is available from January to mid April. The average solar insolation available over the region from the online satellite data the solar radiation available is in the range of 5 to 6kW/m^2 for sunny hours and is around 4kW/m2 for rainy hours. The plot describes the solar radiation for sunny and rainy days.

The main sources of DC injections are power supply, computer, network faults, geomagnetic phenomenon, cycloconverters, lighting circuits/ dimmers, embedded generators, AC and DC drives and photovoltaic grid inverters. Due to approximately short circuit characteristics of an AC network under a DC voltage excitation, a little DC voltage component that can be accidentally produced by the inverter will produce large DC current injection. This causes detrimental effects on the network components, in particular the network transformers which can saturate, resulting in irritant tripping. This may also increase the losses in and reduce the lifetime of the transformers, if not tripped. Moreover, the existence of the DC current component can induce metering errors and malfunction of protection relays. The effect of DC currents on the accuracy of Domestic Electricity watthour meters is both an issue in relation to the type of meter used and its method of connection to the supply network. As a consequence, it is believed that the effect of DC components acting upon watt hour meters merits further investigation, (best undertaken by direct testing due to the reluctance of manufacturers to discuss operation).There are thus stringent regulations in many countries to prevent the network from the large DC current injection.The solar insolation Vs output DC injection graph for a period of 3months is shown in the following graph.

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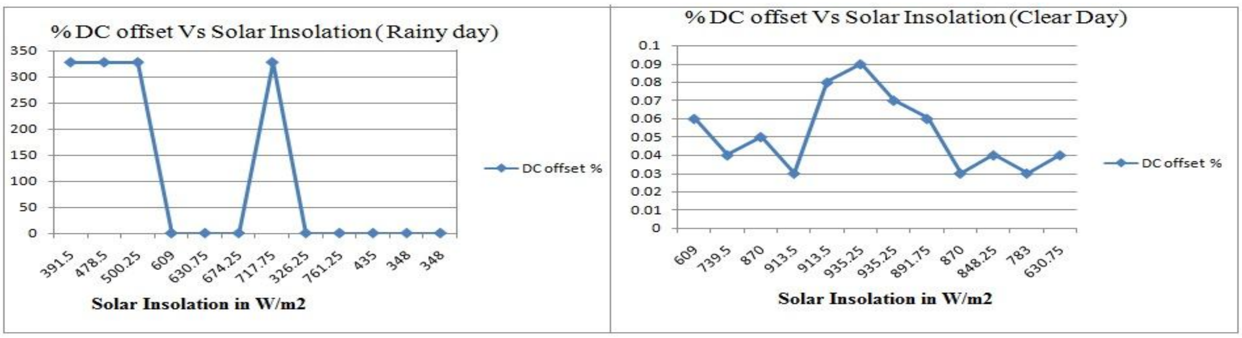

Fig 4. solar insolation vs DC offset on a rainy day & clear day

The VACON 8000 SOLAR inverters use special digital control techniques to limit the DC offset in the output obtained from the inverter. When solar insolation is below the required value (i.e.DC output voltage of solar panels is less than 340V) or when a fault occurs the inverter shutdowns and starts only 5mins after the fault condition is restored. This results in an error the value (357.67 %)of DC offset measured using FLUKE power analyzing meter. During March - mid April 2014 time period, the DC o_set varies between 0.04 (during high solar insolation) -0.19(During low solar-insolation) percent and during mid April- May 2014 time period,the DC offset varies between 0.03 during high solar insolation to 0.15 during low solar radiation time period. The maximum allowed DC offset in India is 1 % of the output obtained.

On analytic calculation of the PV inverter efficiency, it was found that between during the course of the experiment conducted between March to May on a sunny / clear day the efficiency of the 100 kW inverter was found to be 82.6%. Similarly for a rainy day the average efficiency of the inverter is calculated to be 80.23%. This can even drop if the solar insolation considerably drops. The daily average PV inverter output generation and efficiency can be noted to be 360kWh/day at 82.26% efficiency for a clear sky and about 200kWh/day at 80.23% efficiency for a rainy day.

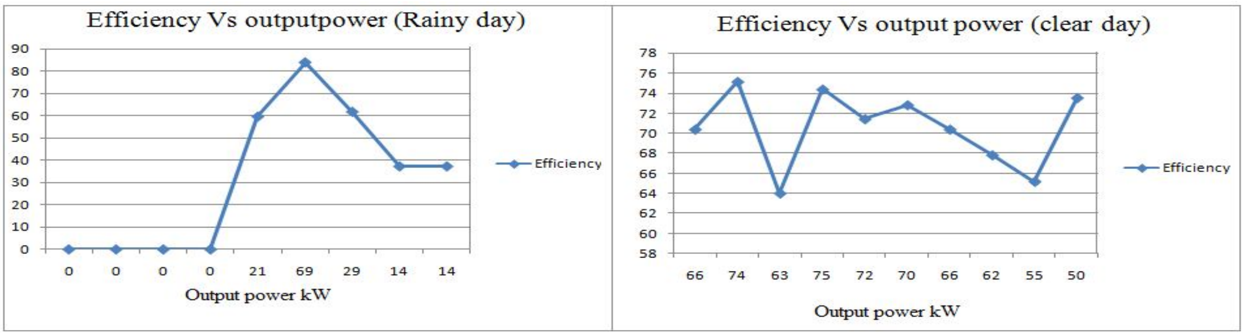

Fig 3. Efficiency Vs output power on a rainy day & clear day

The plots show the relation of DC inverter input power and inverter efficiency for clear and rainy day. The inverter is found to have a serious defect of frequent shutdown if the voltage drops to a low value that lasts only for a few seconds. The estimated fault is due to an error in one of the parameters coded in the software installed in the inverter. This defect is to be corrected and rectified otherwise it will result it complete failure of the system.Solar insolation or irradiance was measured using the pyranometer at an interval of 30 minutes along with other details collected. The total energy harnessed by the installed inverter upto 16th may 2014 is 123992kwh.

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IV. SIMULATION AND RESULT

Both Diode Clamped and H-bridge multilevel inverter circuit were simulated with PWM control technique. Figure1 shows the simulation of Diode clamped Multi level inverter. Each PV source used consists of a 36W PV panel, a boost converter for DC-DC converter and a filter to reduce the effect of noise in the output. Fig 5 shows the output waveform of five level Diode Clamped Multi Level Inverter. Figure 2 shows the result of FFT analysis conducted. The FFT analysis is done to evaluate the amount of DC component in the fundamental wave form.

Fig.5 : Output waveform of DC MLI

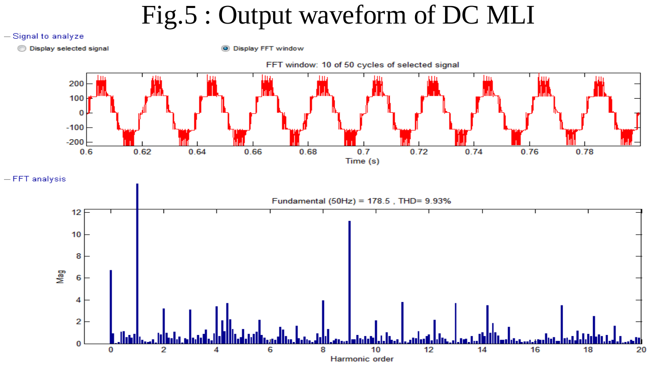

Fig.6 FFT Analysis on DC MLI

From the FFT analysis conducted on the system, it was found that for a fundamental value of 178.5 peak126.2 rms) at 50Hz, the amount of DC component present is 6.713. i.e. about 3.76% of the fundamental. According to BIS the total allowable DC component is ±1% of the fundamental. Therefore the standard limits are crossed in this case at a carrier frequency of 2500 Hz for PWM control. Figure 4 shows the Simulation of H- Bridge MLI.

Figure 7 and 8 shows the output waveform and the FFT analysis conducted on H- Bridge Multilevel inverter for the comparative study between the two multilevel topologies.

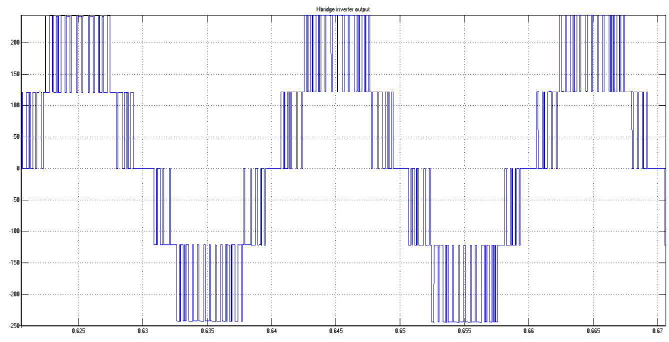

Fig.7 Outputwaveform of H-Bridge MLI

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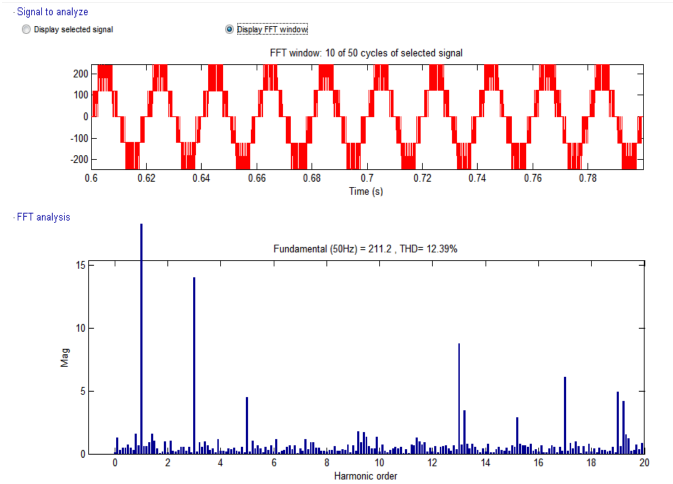

Fig.8 FFT analysis conducted on H-Bridge MLI

From the FFT analysis conducted it was found that for a fundamental frequency of 50Hz with a carrier frequency of 2500Hz used for PWM signal generation, the Total Harmonic Distortion is 12.39% and the DC component is 0.08086 for a fundamental of 211.2 peak(149.4 RMS).i.e. about 0.03% of the fundamental. This value is below the standard limits.

TABLE I. FFT ANALYSIS OF 5LEVEL MLI TOPOLOGIES

Sl.No	FFT ANALYSIS RESULT			
	MLI Topology	***Carrier Frequency (Fc)Hz***	***DC component***	***% of fundamental***
1	DCMLI	2500	6.713	3.76
2	H-Bridge MLI	2500	0.0806	0.03

The table given above shows the comparative study of the two multilevel inverter topologies under study with respect to the DC component present in each system.

V. CONCLUSION

The overall system efficiency can get effected if DC current injections are not limited to, the standards specified by Indian standards and IEEE standards. The installed control technique in the 100kW inverter limits the DC injection to standard values unless tripped. Performance evaluation conducted shows relation of solar insolation on DC offset and output power on the efficiency of the system. A comparison between Diode clamped Multi level inverter and H-Bridge inverter with pulse width modulation based on the amount of DC components in the output was studied. Large DC injections in the output cause corrosion in the underground cables, transformer losses, protective device malfunctioning and error in metering devices. Therefore it is essential to conduct studies on DC components in the inverter output and find solutions to limit them within the standard values. The percentage of DC component in DCMLI is 3.76% and H-Bridge is 0.03%, therefore implementation of H-bridge in grid connected photovoltaic system can limit the DC components below standard limits.

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