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Net metering based bi-directional power flow system and power quality improvement using multilevel inverter

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ABSTRACT

Recent advancements in Power Electronics converters has led to the development of Multilevel Inverters that has proved to be one of the most promising solutions for the medium voltage, high power applications. Multilevel Inverters are considered to be the best available choice for the Grid-connected Photovoltaic Modules (PV) as they (PV Modules) comprise of several sources on the DC side. By the use of MLI, output with high quality and with less harmonic distortions can be obtained which can further be improved by increasing the level of the Multilevel Inverter. This paper presents a model of a 15-level Cascaded H-Bridge MLI interfaced suitably with a Boost Converter and PV arrays. The proposed 15-level inverter is modelled and simulated in MATLAB 2018a using Simulink and Sim Power System toolboxes. Passive filters for power quality improvement is also used at the output stage of Multilevel Inverter

Keywords*— MLI, H-bridge, SM, SG, AMR, Net meter*

1. INTRODUCTION

Increase in human population has led to the increased demand for energy in India. The electricity sector in India is the second highest greenhouse gas producer after the transportation sector. The increase in energy consumption has left rural households with unreliable power supply and with poor power quality. Thus to fulfil this continuous increasing power demand, India has to search for a clean, economical and sustainable source of power generation.

With the rapid decrease in the cost of a photovoltaic cell as a result of advancements in technology, solar power has proved to be the most promising solution to this increased power demand in India. The recent increase in popularity of Solar photovoltaic has resulted in an increase in Global Cumulative Capacity from 1.5GW in the year 2000 to 65000GW in the year 2011[1]. For the areas out of reach of power supply [3], solar power is the best possible alternative. Shifting of power sources towards the renewable sources of energy like the sun can reduce the burden imposed on the non-renewable sources of energy currently in use. Clean power needs to be generated even in cities to reduce the dependency on fossil-based power sources. A country like India with around 300 sunny days in a year receives enough solar radiation for generating more than 500,000Terawatt hour per year [2]. India is still far behind the total PV installed capacity of the major solar markets like China, Germany, UK and Italy.

Though the Government has announced several new schemes like the Jawaharlal Nehru National Solar Mission (JNNSM) for the installation of cumulative capacity of 100 GW by the year 2022, there has been very slow growth in solar rooftop sector in India. Countries like Germany, Japan and the USA are leading the world in terms of solar rooftop installation. So in order to cope with the problem of energy deficiency, India has to develop its off-grid decentralized solar installations for commercial and residential purposes so as to provide clean and sustainable energy and ensure energy security to every citizen of the country. This is only possible through an efficient and robust Government Policies and corresponding support systems. This article describes how Power Electronics interfaces are used for integration of standalone PV system and supply Grid. DC-DC Boost converters have been used for raising the voltage level to meet the requirements of the load.

Inverters that gives AC output plays a vital role in a PV system. PWM inverters are generally used in a standalone PV system, but due to the increased harmonic distortion and similar such drawbacks in their output, they are not that efficient. Cascaded H-Bridge Multilevel Inverters with the advent of less distortion in the output are used to overcome these problems eliminating the use of a separate transformer for increasing the voltage level to the desired value.

2. NET METERING

One way communication was one of the major drawback faced by the old metering system along with other problems like faulty bill estimation and numerous such serious issues. This led to the evolution of Automated Meter Reading (AMR) that replaced old EM meters with the hybrid meters that were capable of providing Billing along with customer's information. The basis of data recording was the total consumption over a certain period of time instead of time-based consumption. The feasible solution to all these problems which took into consideration customer's participation was the SG. SM, a subsection of AMI provided various facilities like Time based pricing, remote control of smart appliances, Power Quality monitoring, prepaid energy usage, Net Metering (NM), etc.

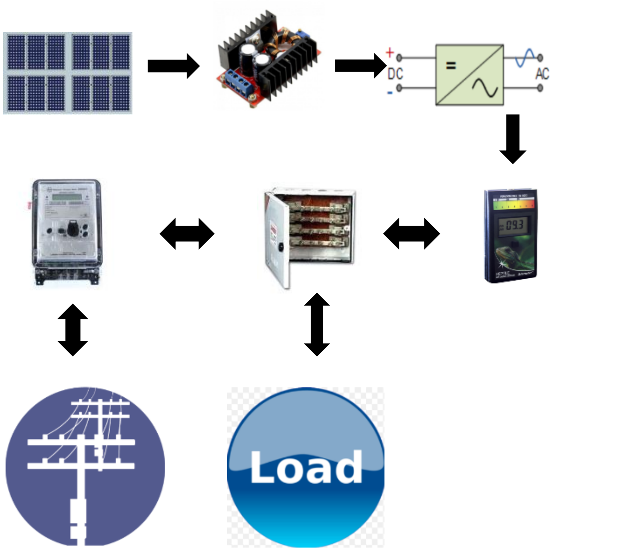

Fig. 1: Systematic diagram of net metering system

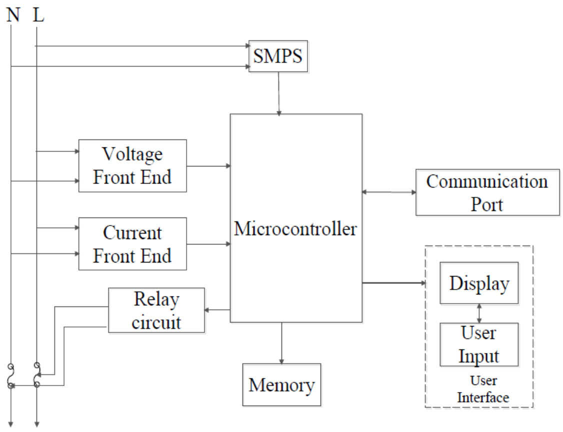

Fig. 2: Block diagram of net meter [9]

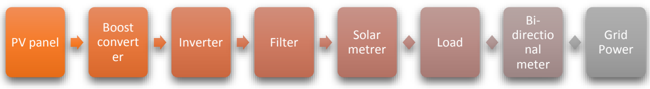

Fig. 3: Block diagram of the net metering system

The major focus of this paper is the use of NM in the integration of renewable sources of energy either with the SG or with the existing grid. Consumers are encouraged to get some benefits with some credits on their bill if they offset a portion of or the whole back to the grid to which it is connected. Net Metering is based on the concept of utilizing bi-directional energy meters which are capable of measuring supply from both the directions (utility to consumers and consumers to utility). This technique enables the utility to manage the loads during peak hours as well as helps the consumers towards their contribution to the power system in an indirect manner [4]. The NM techniques basically involve the installation of Solar PV panels on the rooftop of the building of the consumers. The output of the PV array which is the DC energy is converted to the AC supply using an inverter. The excess energy after feeding the consumer's load during the daytime is supplied to the grid. The Net meter which is actually a bidirectional meter is used to keep the records of energy transferred and the net unit consumption by the consumer from the utility.

In another scenario when the NM is not used, we require a second meter which needs to be installed at the consumer end to measure the amount of energy fed back to the grid. Thus, there is a need for a second energy meter for the measurement of power in both directions. However, this problem can be overcome by the use of a Net Meter that can keep a trace of both import and export of energy [5] discusses the NM scenario in India. A Net Meter can be simply understood as a meter capable of spinning in the forward direction while fetching energy from the utility and in reverse direction while supplying energy back to the utility. Thus, the total units consumed can be calculated in this way. The NM provides the consumers with a method of storing energy into a grid instead of storing energy in large batteries. This overall reduce the cost of energy storage. Hence the consumer is benefitted as the utility buys the energy at a good price in case of the peak demand enabling technical as well as economic growth of both the utility as well as the consumer. Power Quality, which is one of the frequent demand by the consumer is also improved by the use of Net Meter along with the SG. The various Net Metering models available from a market point of view is discussed in [6].

3. H-BRIDGE MULTILEVEL INVERTER

The back to back arrangement of several numbers of single-phase full bridge inverters is termed as H- Bridge multilevel inverter [7]. Every single unit of H Bridge consists of several switches (S1, S2, S3, and S4) and is capable of generating three output voltage levels **+V_{dc}** and **-V_{dc}** by the suitable connection of DC input from the PV panel to the corresponding ac output.

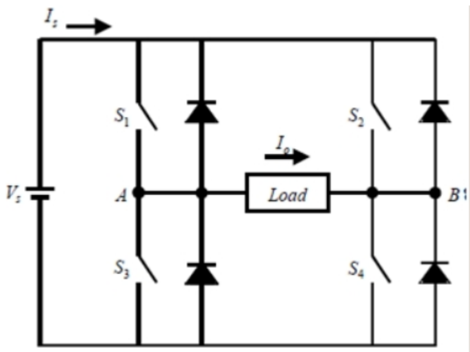

Fig. 4: Block diagram of H-Bridge Inverter

This is achieved through different switching (the four switches) combinations [8]. Different classification of H-bridge multilevel inverters includes symmetrical and asymmetrical configurations. φThe input magnitude of a symmetrical H-bridge multilevel inverter is same for each of the H-bridge but in case of the unsymmetrical configuration [7], the magnitude of the input is different for each of the H-bridge units.

The equation defining the number of output voltage level being' in a cascaded multilevel inverter is denoted by m = 2k + 1 where 'k' is the number of dc sources.

In a seven-level cascaded multilevel inverter, it is possible to obtain different voltage ranging from +3V_{dc}, +2V_{dc}, +V_{dc}, 0, -V_{dc}, -2V_{dc} and -3V_{dc} by the suitable firing of switch combinations of the three H-bridge units. The Multicarrier pulse width modulation technique in which a standard sinusoidal wave is compared with six levels of the triangular wave for the firing pulse generation is used for the generation of firing pulses for the switches of the multilevel inverter. The output of the multilevel inverter, which is generally a stepped waveform with distortions reduces the power quality of the overall system.

The simplest and cheapest of mitigating the distortions in the output of the multilevel inverter is the use of passive LC filters.

4. PV MODELLING

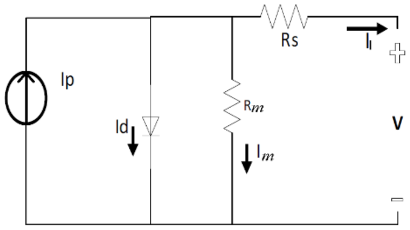

Fig. 5: PV cell equivalent circuit

According to figure 5 shown above, the output current is given as:

$$I_l = I_p - I_d - I'_m$$

Where I_p is the module photocurrent

$$I_p = [I_s + M (T - T_0)] G$$

Where,
I_s: Short circuit current in amperes
M: Short circuit current at a temperature of 25° C and 1000W/m^2
T: Operating temperature in degrees
T_0: Reference temperature (25° C)
G: Solar irradiance received per 1000W/m^2

The current through the diode (I_d) is given by:

$$I_d = T_0[\exp\left(\frac{V_d}{nV_t}\right) - 1]$$

Where
I_0 : Reverse saturation current of the diode
V_d: Voltage applied across the diode
n: Ideality factor of the diode
V_t: Thermal voltage of the diode (26mV)

5. BOOST CONVERTER

The output voltage of the PV cell is not sufficient to meet the demand of the load. Hence a Boost Converter is played an important role in boosting the voltage level at the output end. The figure shows the schematic diagram of the Boost converter. It consists of a diode, an inductor, Switch (MOSFET or IGBT) and a capacitor. The two modes of operation of Boost converter are Continuous and Discontinuous mode of operation.

The current through the inductor remains continuous and it never falls to zero. The associated parameters of a Boost Converter are calculated as:

Duty Cycle (**α**)

$$(\alpha) = \frac{Vop - Vin}{Vop}$$

Ripple Current (**ΔI**$_l$)

$$(\Delta I_1) = \frac{Vop \times D \times (1 - D)}{L\,fs}$$

Where,
V_{op}: Output Voltage of the Boost Converter
V_{in}: Input voltage of the Boost Converter
L: Value of Inductance.
C1: Value of capacitance
f_s: switching frequency

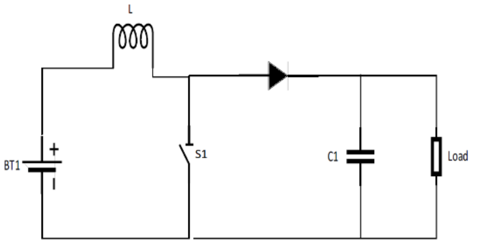

Fig. 6: Schematic diagram of a boost converter

6. SIMULATION RESULTS

The simulation analysis of fifteen levels CHB-MLI with a PV system is performed using MATLAB / Simulink.

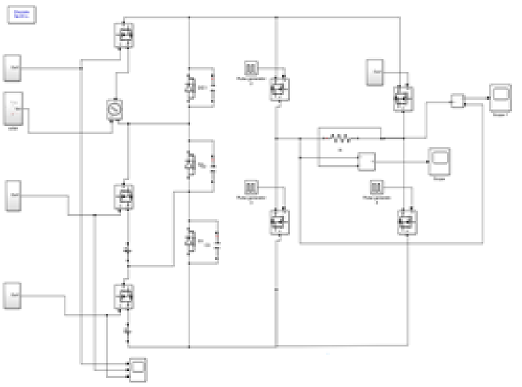

Fig. 7: MATLAB simulation of H-bridge inverter

The figure above shows the MATLAB Simulink model of the 15-level Cascaded H-Bridge Inverter

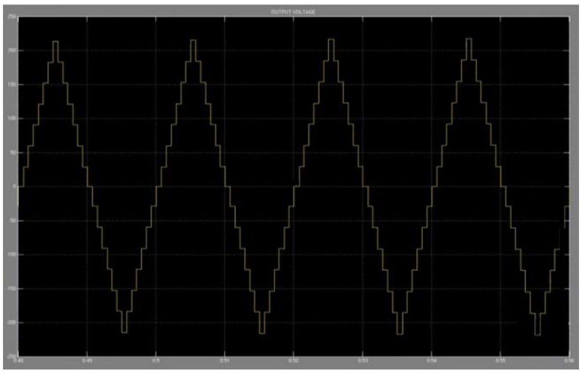

Fig. 8: Fifteen level cascaded H-bridge multi-level inverter output voltage

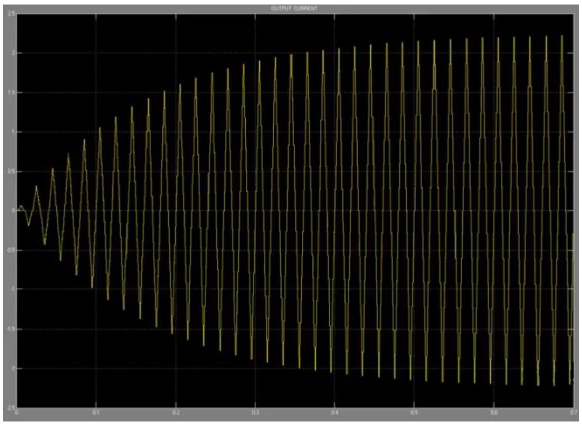

Fig. 9: Fifteen level cascaded H-bridge multi-level inverter output current

The waveforms corresponding to the MATLAB simulation of the Cascaded H-Bridge is shown in figure8 and 9.Figure 8 shows the output voltage and figure 9 shows the output current.

The level of the Inverter is raised to 15 so that the output has low harmonic distortion.

7. CONCLUSION

This paper emphasizes the use of renewable sources of clean energy like sun to decrease the burden imposed on the non-renewable sources of energy. The paper also presents a proposed model for integration of the PV arrays to the supply grid with the help of a Net Meter. The PV arrays installed on the rooftops of the consumer buildings supplies the excess energy produced by the PV modules to the supply grid after household consumption. Thus the net energy consumption from the supply grid is reduced considerably. A Boost converter is used after the PV module to step up the voltage level to the desired value followed by a Cascaded H-Bridge Inverter that reduces the amount of Harmonic Distortion in the AC output of the Inverter. Thus the power quality is also increased which is a major demand of the consumer. The power quality can further be improved by increasing the level of MLI.

8. REFERENCES

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