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A New Delta Inverter System with Multi Tapped Forward Converter

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ABSTRACT: The installation of photovoltaic power stations has been increasing tremendously both on residential scale and at the commercial or utility scale. Solar PV at the time of publication still has a long way to go in terms of financially competing successfully with conventional electricity. It has been established that reducing the inverter equipment and maintenance cost is essential to make solar energy more cost competitive .To achieve this goal, new methods to efficiently convert DC power to AC with low cost and high reliability are required. A new grid connected DIS for large scale solar photovoltaic power systems are introduced. The delta inverter achieves DC to three phase AC conversion by using only three power semiconductor devices instead of six devices as in a conventional full bridge three phase inverter. A large scale PV field grouped into three DC voltage blocks, each block connected to a front end MPPT forward converter which is connected to a three switch DIS interfaced to the utility grid. Advanced pulse width modulation (PWM) techniques are investigated for DIS for operation under unbalanced condition.

KEYWORDS: Delta inverter system, Utility grid, Photovoltaic power plants, Sine pulse width modulation

I. INTRODUCTION

A new grid- connected delta inverter system (DIS) is used for large scale photovoltaic (PV) power systems. The delta inverter achieves DC to three phase AC inversion by using only three power semiconductor devices as in a conventional full bridge three phase inverter. This reduction in the number of switching devices contributes to higher power density for PV energy conversion systems and potentially, an increase in reliability and lifetime. Advanced pulse width modulation (PWM) techniques are investigated for DIS for operation under unbalanced condition.

Less than 1% of the global electrical energy consumption comes from photon-to- electron conversion. But the installation of photovoltaic (PV) power stations has been increasing tremendously both on residential scale and at the commercial or utility scale. Oil and electricity prices have been soaring as the supply of global energy increasingly become deficient. The limited availability of energy source has become an inevitable global problem. Therefore, energy conservation and carbon emission reduction are important issues in modern- day society. Past technological developments were intended to improve human life and have been oriented toward eliminating inconveniences. Currently, environmental protection is a primary concern, in which available energy from natural resources is developed for ease of use. Such developments are also designed to generate inexpensive and effective energy sources while highlighting the importance of minimizing environmental destruction and pollution. Solar energy is one of the most extensively exploited sources of effective natural energy. An increasing number of countries and research institutions infuse substantial manpower and monetary investments in solar energy- based projects. Solar PV, at the time of publication, still has a long way to go in terms og financially competing successfully with conventional electricity. It has been established that reducing the inverter equipment and maintenances costs is essential to make solar energy more cost competitive. To achieve this goal, new methods to efficiently convert DC to AC with low cost and high reliability are required.

Reduced semiconductor devices and components count reduce failure rates and maintenance costs over the life time of a PV inverter. The architecture proposed of a delta inverter based system which utilizes the three DC voltage sources and three semiconductor devices to produce a three phase output. The delta inverter was first introduced primarily for adjustable speed drives. Pulse width modulation (PWM) techniques are used for control of the delta inverter. The delta

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inverter did not find acceptance in practice primarily due to the limitation of requiring three separate DC sources. But the need for more efficient PV topologies opens new possibilities for the delta inverter. The delta inverter system (DIS) architectures used for PV applications have the following advantages:

1. DIS employs three switching devices which results in fewer components in the overall system (gate drive circuitry, heat sinks, bus bars, fuses, etc.). This leads to higher reliability due to reduced number of power switching semiconductor devices which in turn results in higher lifetime of inverter and lower maintenance costs.
2. Advanced PWM techniques will enable operation of DIS even while the insolation levels are unbalanced for the three PV sources.

However, the DIS suffers from some disadvantages such as the requirement for higher switch voltage ratings up to 3Vdc; and the requirement for three isolated DC voltage sources. The two DIS architectures are within the context of PV applications, since isolated PV arrays could produce isolated DC voltage sources, overcoming the latter of the above two disadvantages.

II. DELTA INVERTER

The delta inverter is a novel circuit which uses only three power transistors to produce a three phase supply. Requiring approximately half the components of a conventional bridge inverter it therefore has potential cost and reliability advantages. The basic operating principles of the delta inverter are explained, using passive resistive and inductive loads. The delta inverter as shown in Fig:1, consists of three branches (a, b and c) connected in delta fashion and each branch consists of an isolated DC voltage source and a forward blocking semiconductor switch. The line-to-line output voltages are directly modulated by switches S_{ab}, S_{bc} and S_{ca}.

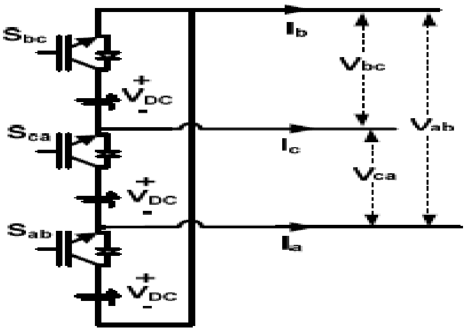

Fig.1: Three Phase Delta Inverter

The main attraction of the delta inverter is the reduced number of components that it requires. Offsetting this advantage is the need for three isolated DC supplies. However, these may be derived from a battery source, if the stack is split into three sections. The potential area of application for the delta inverter is therefore thought to be in the field of battery-fed variable speed drive systems. These are used in industrial handling systems, such as fork-lift trucks and in battery vehicles. The delta inverter was therefore devised in an attempt to reduce the complexity of a three phase inverter. It conceivably contains the minimum number of devices possible for a three-phase inverter system.

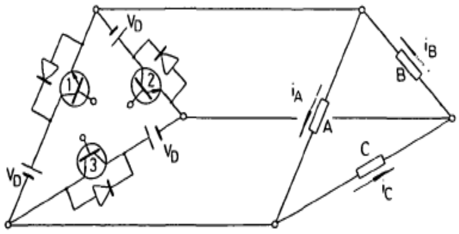

Fig.2: Delta Inverter and Load

The modes of operation of the delta inverter are relatively complex and it has therefore been investigated experimentally and theoretically with two types of passive loads. First, it was used to drive a purely resistive load. This

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was constructed so that it had negligible inductance. Secondly, iron-cored chokes were used to provide a purely inductive load. One advantage of these two leads is that they can be handled graphically and analytically in a relatively convenient manner. They also allow the essential characteristics of the delta inverter to be studied and set the limits within which an RL load with an intermediate time constant would operate. The description of the behaviour of the inverter assumes that the transistors and diodes behave as ideal devices. Primarily results have also shown that the delta inverter will operate in both the motoring and regenerating modes with an induction machine. The prototype delta inverter was constructed using power transistors as the power switching elements. All tests were carried out under balanced three phase conditions. For convenience, a microprocessor was used in an open loop mode to generate the transistor switching signals. Peak device current of around 20A were used in the tests. In order for the DIS to operate properly, two and only two switches must be closed at any time. In the case that only one switch is ON imbalances in the line currents occur and all three switches being ON results in a catastrophic short circuit through the DC voltage sources. If only two switches are closed at all times, there are 3 possible states, which are shown in fig.3. At any time, two switches of the inverter are ON. It is ensured that the sum of the three switching functions Sab+Sbc+Sca = 2 at all times.

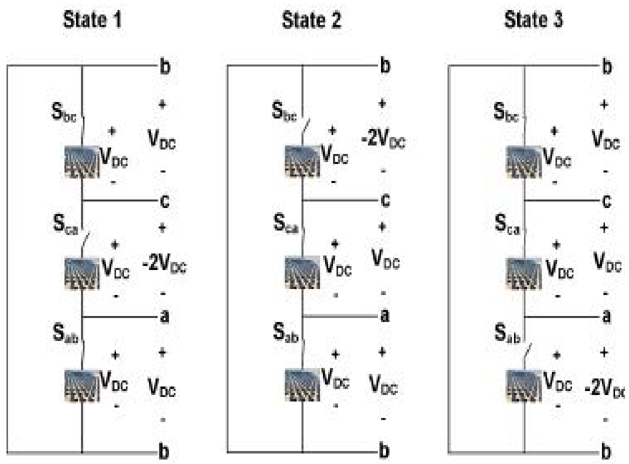

Fig.3: Three Possible States of Switch Combinations in Delta Inverter for PV Application

The PWM line-to-line output voltages that are produced in each of the different states are given in table 1. It can be seen that in any given state, the sum of the three line-to-line voltages is zero, in other words, the out voltage is balanced. Because the negative voltages twice the magnitude of the positive voltages, as seen from the table, in order to obtain a zero average value for one period, the modulation mark-to-space ratio must be set to 2:1.

Table1: PWM Line to Line Output Voltages for Three Switching States in DIS

State	V_{ab}	V_{bc}	V_{ca}
1	V_{DC}	V_{DC}	$-2V_{DC}$
2	V_{DC}	$-2V_{DC}$	V_{DC}
3	$-2V_{DC}$	V_{DC}	V_{DC}

III. PWM TECHNIQUE

PWM is the pulse width modulation technique. The PWM switching strategy chosen was a single-edge modulation scheme. A positive slope sawtooth carrier and a negative slope sawtooth carrier are used to modulate three phase sinusoidal reference signals displaced by 120°. When the modulating signal has a positive slope, the negative-slope carrier is used and when it has a negative slope, the positive-slope carrier is used.

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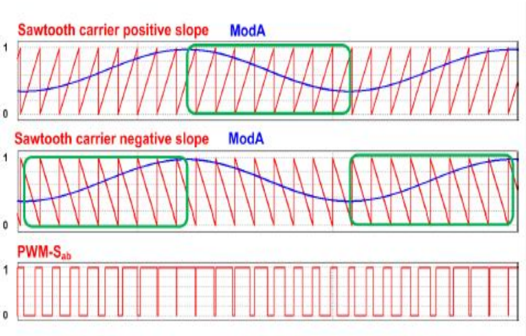

Fig.4: Positive Slope Sawtooth Carrier is Chosen During Negative Slope of Modulating Function and Vice-Versa

PWM-Sab is the sum of ModA produced PWM and the NAND logic of PWMs produced by ModB and ModC. This is done to ensure that only two switches are ON at any time. . The generated PWM signal is applied to the gate drive circuitry only for the most-positive 240° of the modulating signal. For the remaining 120°, the switch is simply turned ON to satisfy Sab+Sbc+Sca = 2, taking to a freewheeling function. Fig.4 shows the carrier control scheme for Sab. With this control scheme the line-to-line output voltages from a three phase balanced set.The fundamental component of V_{ab} has a zero average as expected. Fig.5 shows the instantaneous line-to-line voltage V_{ab} produced by a delta inverter and its fundamental component.

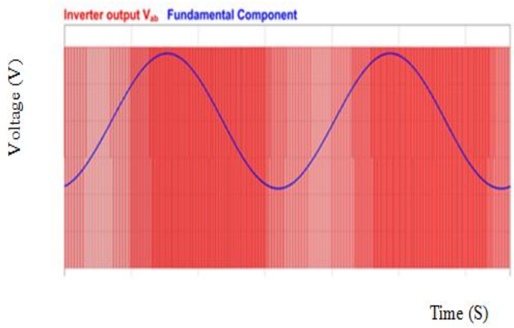

Fig.5: PWM Line-to-Line Output Voltage V_{ab} of Delta Inverter

IV. ADVANCED PWM TECHNIQUE UNDER UNBALANCED OPERATION

When the insolation levels of the three PV arrays connected to a delta inverter change and become asymmetric, the controller uses advanced PWM techniques to produce balanced three phase output voltages from three unequal DC voltage sources during the transition period. The line-to-line instantaneous PWM output voltages of the DIS under unbalanced operations are given by:

$$-\left|V_{DC,bc}\right| - \left|V_{DC,ca}\right| \le V_{ab} \le V_{DC,ab} \quad (1)$$

$$-\left|V_{DC,ab}\right| - \left|V_{DC,ca}\right| \le V_{bc} \le V_{DC,bc} \quad (2)$$

$$-\left|V_{DC,ab}\right| - \left|V_{DC,bc}\right| \le V_{ca} \le V_{DC,ca} \quad (3)$$

The positive peak value of any line-to-line output voltage is that of the associated DC voltage source and the negative peak value is the sum of the remaining two DC voltage sources. This results in the following average value expressions for the line-to-line output voltage.

$$-\frac{1}{2}\left|V_{DC,bc}\right| - \frac{1}{2}\left|V_{DC,ca}\right| \le \langle V_{ab} \rangle \le V_{DC,ab} \quad (4)$$

$$-\frac{1}{2}\left|V_{DC,ab}\right| - \frac{1}{2}\left|V_{DC,ca}\right| \le \langle V_{bc} \rangle \le V_{DC,bc} \quad (5)$$

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$$-\frac{1}{2}\left|V_{DC,ab}\right| - \frac{1}{2}\left|V_{DC,bc} \leq \langle V_{ca} \rangle \leq V_{DC,ca}\right| \quad (6)$$

The modulation index associated with the lowest DC voltage source must first b calculated s that the DC offset is eliminated. This is done by decreasing the negative peak value by adjusting the modulation depth and position of the sinusoidal reference signal. Accordingly, the modulating signals of the other two DC sources must also be adjusted, since three phase balanced output voltages need to be produced. Hence the peak line-to-line output is limited by the lowest DC voltage source.

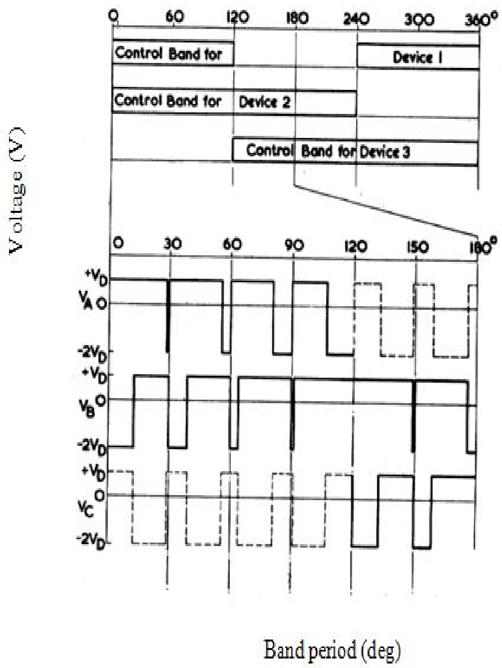

Fig.6: Sinusoidal Pulse Width Modulation Strategy

Development of a sinusoidal pulse width modulation strategy for the delta inverter starts from the observation that if at any instant in time 1 two devices are ON, the three output voltages of the inverter are completely defined, and the sum of these voltages is zero. Under these conditions a line voltage is always +VD when its corresponding device is ON and always -2VD, when it is OFF. VA is +VD when TI is ON and -2 VD when T2 and T3 are ON. A further consideration is that if for a portion of the cycle two particular devices are modulated in such a way as to make the fundamental components of two corresponding output voltages two of a three-phase sinusoidal set, then the resulting third voltage must necessarily be the third member of that set.

The Fig.6 illustrates how these principles are applied to produce sinusoidal pulse width modulation for the delta inverter. This figure is for 12 modulating pulses per cycle (carrier frequency to modulating frequency ratio of 12). This small number has been chosen only for illustrative purposes in order that the drawing, which is approximately to scale, can show individual pulses in detail. it is not suggested that 12 pulses per cycle is an optimum number. A "control band" extending over two thirds of a cycle is defined for each device, and two control bands exist at all times throughout the cycle. During its control band a device is switched to produce a sinusoidally modulated waveform for its corresponding output. It can be seen that, as defined in Fig.6, T1 is switched during the first and last portions of the cycle, to produce a cosinusoidal fundamental waveform for V_A with its positive maximum at the zero reference of the figure. In view of the available voltages states, i.e., +VD and -2VD, the modulation must be adjusted accordingly. For example, to produce zero average voltage during a modulating pulse a mark to space ratio 2:1 is required. The corresponding waveforms for V_B and V_C during the control bands of their devices T2 and T3, respectively, are also shown as full line portions of the waveforms in Fig.6. Outside its control band a band a device I only switched ON if this is required to fulfill the condition that two devices are always ON. For example, during the first one-third of the cycle shown T3 is only ON when either T1 or T2 is OFF. The resulting waveform for Vc during this portion is shown

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as a dotted line. The equivalent waveform for V_A is also shown dotted. Sinusoidal pulse width modulation is a well-known wave shaping method for power inverters. In a conventional three phase bridge inverter, each "leg" voltage can be controlled independently, and the problem of implementing sinusoidal pulse width modulation reduces in principle to one of generating and applying the required control signals.

V. DIS WITH FORWARD CONVERTER

Forward converter is a popular switched mode power supply (SMPS) circuit that is used for producing isolated and controlled dc voltage from the unregulated dc input supply. As in the case of fly-back converter the input dc supply is often derived after rectifying (and little filtering) of the utility ac voltage. The forward converter, when compared with the fly-back circuit, is generally more energy efficient and is used for applications requiring little higher power output. The DIS with multi tapped forward converter is shown in Fig.7. A multi kW PV array is interfaced via a multi tapped forward converter, the outputs of which form the DC voltage sources in a DIS.

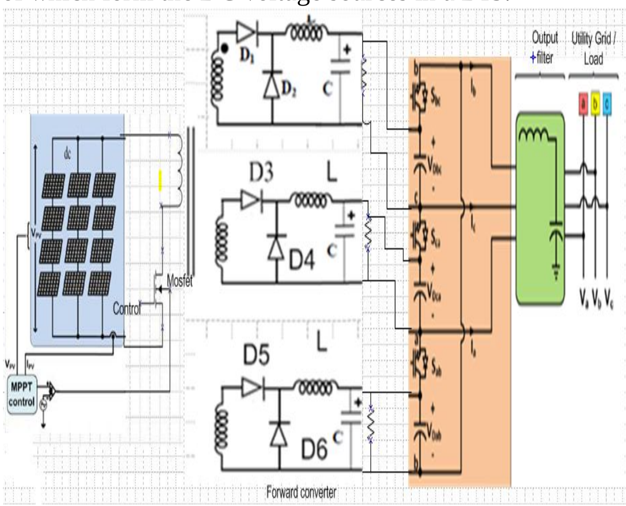

Fig.7: DIS With Multi Tapped Forward Converter

Forward DC-DC conversion stage provides MPPT control and better balancing of DC voltages at the delta inverter stage. The forward converter serves as the MPPT stage, the transformer turns ratio also contributing to the voltage gain of the converter. The inverter switches are controlled using the same SPWM technique. The inverter output is also connected to an LC filter tuned at half the switching frequency. The filtered output of the delta inverter is then interfaced to a load.

VI. SIMULATION RESULTS

Simulation of proposed delta inverter is performed using MATLAB. The output waveforms of proposed delta inverter are given. All input DC sources are equal. MATLAB 7.10.0(R2010a) is used for simulation part of the project. Simulation of the proposed topology of delta inverter is performed using MATLAB. Simulation results for the proposed system are given below. Modulation techniques are used in delta inverter to synthesis a controlled output voltage. There are various modulation techniques. Sinusoidal pulse width modulation technique is used here.

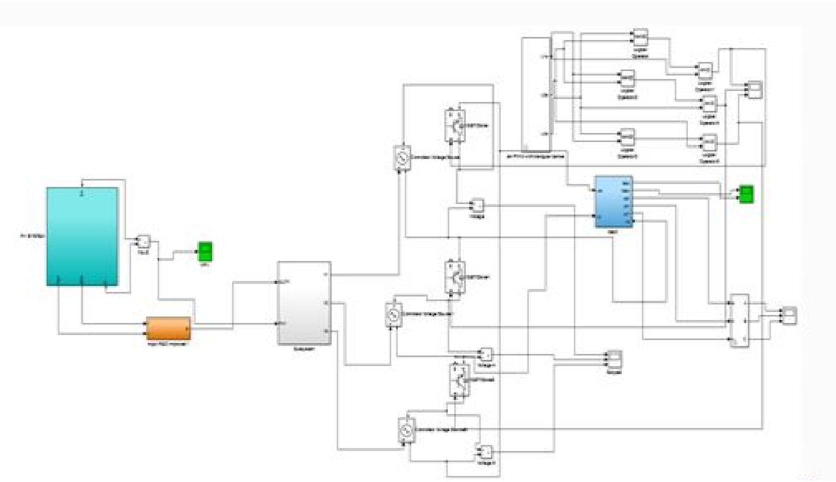

Fig.8: Matlab Model of Proposed DIS With Forward Converter

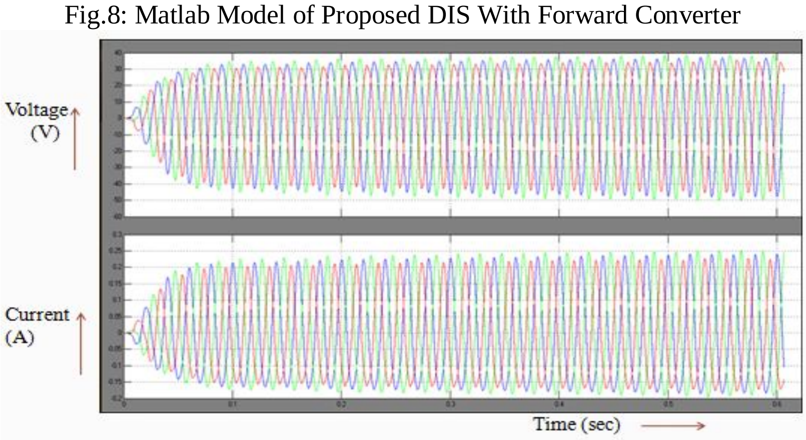

Fig.9. Output Waveform of DIS with Forward Converter

V.CONCLUSION

The delta inverter appears to be a novel circuit and has features which make it an attractive proposition for some applications. In particular, its reduced component count give lower manufacturing costs and improved reliability. The basic operation of the delta inverter was described and an advanced PWM control scheme was used for operation with unbalanced DC voltage sources. The delta inverter system with forward converter is used for utility interface. This DIS topology has advantages over centralized full bridge PV inverters, such as reduced component count and higher energy yield.

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