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A Simplied PWM Technique for Isolated DC-DC Converter Fed Switched Capacitor Multi-Level Inverter for Distributed Generation

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ABSTRACT

This paper presents a simplied PWM technique to drive switched capacitor type multi-level inverter fed from isolated type DC-DC converter for distributed generation. Distributed generation (DG) is renowned power generation at point of utility with no environmental a ects and reduces transmission line losses. Photovoltaic system is considered as renewable energy source for DG and the low voltage from PV system is boosted to required voltage using an isolated type single-input multi-output (SIMO) DC-DC converter. DC output from isolated SIMO DC-DC converter is fed to switched capacitor type multi-level inverter (SC-MLI) to feed the AC load. Isolated SIMO DC-DC converter apart from boosting the DG output voltage, also eliminates the problem of voltage unbalancing in SC-MLI topology. Closed loop operation of SIMO DC-DC converter employs only single PI controller instead of three controllers was presented in this paper. Modes of operation of SCMLI and PWM switching pattern were explained. Simulation of proposed system was developed using MATLAB/SIMULINK software.

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1. INTRODUCTION

Distributed generation (DG) plays a vital role due to advancements in power system like smart grids and shifting electrical power generation from conventional energies to sustainable energies. The name distributed generation suggests that electrical power generation is distributed. DG can be de ned as small scale electrical power generation at load centers in conjunction with power grid [1]-[2]. When DG is feeding grid, the power generation from the conventional power source is reduced. The demand power is met from both main power source and DG. DG can be operated in two modes -standalone mode and grid connected mode of operation. In grid connected mode, the power from DG is fed to grid reducing the power drawn from conventional power source. In standalone mode of DG operation, power from DG is fed directly to loads. DG is a back-up type of power, it improve the reliability of the power system. DG reduces the investment for generate electrical power than compared to that of conventional power stations. Since DG can be installed at load points, transmission losses are gradually reduces and provisions for power transmission and distribution is eliminated [3]. DG operates with renewable sources of energy which are freely available and while generating electrical power, zero pollution is achieved which is lauded by global bodies. The major reason for penetration of distributed generation in power system is due to economic, environmental and technical reasons. Many researchers have worked towards DGs and the sizing of a particular DG is very important factor to be considered while installing in power system.

Photo-voltaic (PV) system is considered to be renewable energy source. Output voltage of PV system is low and needs to be boosted to required value based on system requirement. To boost the PV output voltage, DC-DC converter is employed. For operating the distributed energy source or distributed generation in standalone mode or in grid connected mode of operation, the output of DC-DC converter is fed sent inverter for converting into AC.

Inverter is a power electronic converter circuit which converts DC input to AC output. Conventional inverters generate output voltage with square wave shape. Square wave output consists of infinite harmonics and to smoothen the square wave filter circuit is used. Size of filter needed to smoothen the square wave to sinusoidal is of large in size and increases the cost of equipment. The voltage stress across switches during transition of output voltage of conventional inverter is very high and causes insulation breakdown. This phenomenon gave scope to develop multi level inverter concept. Multi level inverters [4]-[5] generates stepped output of different levels depending on the switching operation of the circuit. Output voltage of the multi level inverter consists of less Total Harmonic Distortion (THD) as compared to conventional inverter.

Less THD in the output voltage reduces the size of the output filter and eventually reducing the size of the equipment. Voltage stress across switches in multi level inverter during transition of output voltage is less and thus insulation level can be reduced.

This paper employs multi level inverter topology with minimum number of switches. In [6]-[7] simple topology of MLI is proposed. But these structure requires more number of sources. To boost the low voltage DC, DC-DC converters or Impedance source inverters [8]-[9] are used. Switched capacitor type multi level inverter with diode clamped structure is discussed in [10]. This structure requires comparatively more switching devices than the proposed. But the main disadvantage of switched capacitor type multi level inverter is the voltage unbalance across capacitors in SC circuit. This paper employs an isolated single-input multi-output (SIMO) DC-DC converter at the front end of SC-MLI. The isolated SIMO DC-DC converter serves for two purposes- one is to boost the low voltage DC to high voltage DC and the other as to balance the voltage across capacitors in SC-MLI topology. The complete schematic block diagram of proposed system is shown in Figure 1.

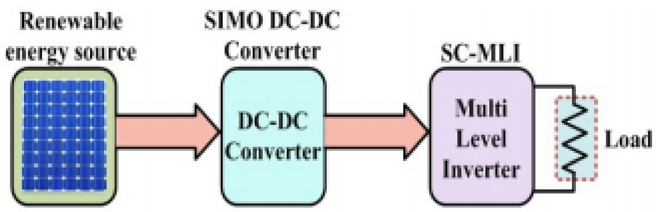


Figure 1. Schematic block diagram of proposed system

The paper presents a novel simplifed PWM technique to drive switched capacitor type multi-level inverter fed from isolated type DC-DC converter for distributed generation. Closed loop operation of SIMO DC-DC converter employs only single PI controller instead of three controllers was presented in this paper. Modes of operation of SC-MLI were explained. Simulation of proposed system was developed and results are obtained using MATLAB/SIMULINK software.

2. SINGLE-INPUT MULTI-OUTPUT (SIMO) ISOLATED DC-DC CONVERTER

In this section the operation of SIMO in open loop and closed loop operation is discussed. The comparison table is presented.

2.1. Single-Input Multi-Output Isolated DC-DC Converter

The circuit representation of single-input multi-output (SIMO) isolated DC-DC converter is shown in Figure 2. DC-DC converter consists of transformer for isolation of input side to the output. The transformer is of multi winding and gives three output ports. At the input, the transformer is supplied from a DC source.

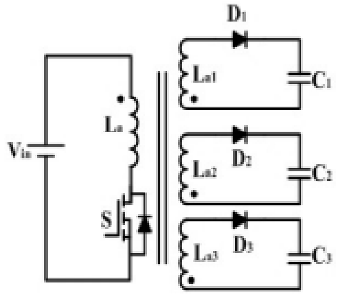


Figure 2. Isolated single-input multi-output DC-DC converter

The DG output is supplied as input to transformer primary. A MOSFET switch is connected to transformer primary and the switching operation of MOSFET switch decides the charging time of transformer primary coil. The primary has single input port, secondary of the transformer has three output ports and hence the circuit is termed as single-input multi-output isolated DC-DC converter. Each output port of the DC-DC converter has a diode connected along with the capacitor at the output terminal. Diode is placed to prevent reverse current flow from capacitor to secondary windings of a transformer.

2.2. Close-Loop Control of Single-Input Multi-Output (SIMO) Isolated DC-DC Converter

The closed-loop control of single-input multi-output isolated DC-DC converter is shown in Figure 3. The operation of MOSFET switch connected at primary side of transformer yields mutual flux that links with the three secondary windings of the isolated DC-DC converter. Mutual flux that links to the secondary windings induces self induced EMF in three secondary windings of SIMO isolated DC-DC converter. As the secondary terminals are closed, the self induced EMF forces current to pass through each of the three secondary windings. This phenomenon charges the capacitor connected at the output terminals of the multioutput isolated DC-DC converter. Conventional multi-output converters when operated in closed-loop, it requires multiple PI controllers to reduce the error. This paper presents the use of only single PI controller to reduce the error in all three output ports of DC-DC converter.

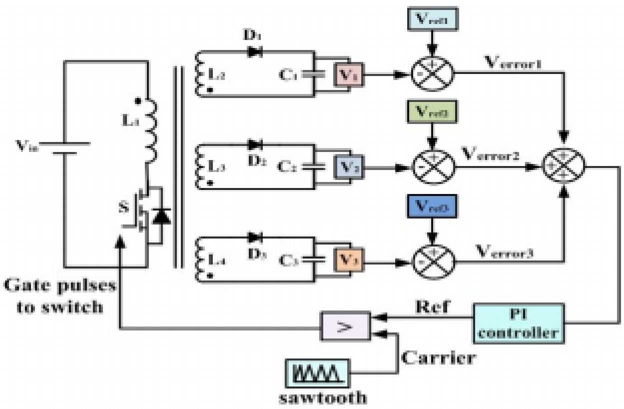


Figure 3. Closed-loop control of single-input multi-output isolated DC-DC converter

The voltage across each of the three output ports of single-input multi-output isolated DC-DC converter are measured across respective capacitors connected at the respective output port terminals of DC-DC converter. The actual output voltage across capacitor is measured and is compared with reference voltage, yielding the error in each of the individual secondary sides. The process error in all the three voltages across capacitors is added and sent to a PI controller block. PI controller reduces the error and yields the reference signal. This reference signal is compared logically with carrier (saw-tooth) signal (when reference greater than carrier signal) for generating switching pulses to MOSFET. ON/OFF times of MOSFET reflects the charging time of transformer primary and hence each of the output capacitors are charged to equal voltages. This phenomenon balances the voltage across capacitors of SC-MLI. Also, during the ON time of MOSFET, the primary coil of transformer is charged and boosts the input voltage and transfers the input voltage to the secondary side. This SIMO isolated DC-DC converter performs two major tasks – one is to boost the input DC voltage to higher value of voltage (DG output is the input to primary of SIMO DC-DC converter) as boost converter and the other is to balance the voltage across capacitors in SC-MLI topology. Table1 shows the comparison of SCMLI with conventional and recently proposed MLI. The number of switching devices, diodes, capacitors and sources required is very less.

Table 1. Comparison of SCMLI with conventional converters

	[DCMLI]	[CCMLI]	[CHMLI]	[10]	SC-MLI
Main switches	2(n-1)	2(n-1)	2(n-1)	2(n-1)-2	(n+1)
Main Diode	2(n-1)	2(n-1)	2(n-1)	2(n-1)-2	0
Clamping Diodes	(n-1) (n-2)	0	0	(n-3)(n-2)	0
Flying Capacitors	0	(n-1)(n-2)/2	0	(n+1)/2	0
DC Bus Capacitors	(n-1)	(n-1)	0	(n-1)/2	(n-3)/2
DC Sources	1	1	(n-1)/2	1	1
Voltage balancing	Poor	Moderate	NA	Perfect	Perfect

3. SWITCHED CAPACITOR MULTI LEVEL INVERTER

The basic circuit diagram of seven-level switched capacitor multi level inverter is shown in Figure 4. The seven-level switched capacitor multi level inverter structure consists of three capacitors, seven switches along with the load. The three capacitors C1, C2 and C3 deliver required voltage through switching operation of power switches S1 to S7. The switches S1 to S4 form a bridge to invert the DC link voltage and produces AC across the load. The switches S5, S6 and S7 are switched correspondingly to deliver voltage from capacitors to the load section.

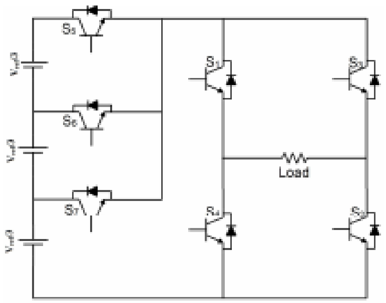


Figure 4. Seven Level Multi level inverter

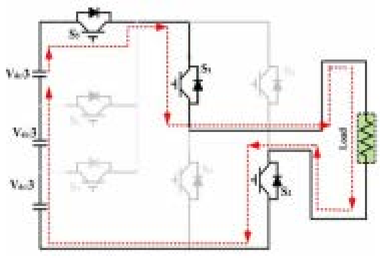
The voltage balance across each of the switched capacitors is an issue in this type of inverter topology and in this paper the voltage balancing is achieved by SIMO DC-DC converter placed at the front end of the switched capacitor type multi level inverter. The modes of operation of seven-level switched capacitor multi level inverter are shown in Figure 5.

3.1. Mode 1: SC-MLI Producing Output Level Vdc

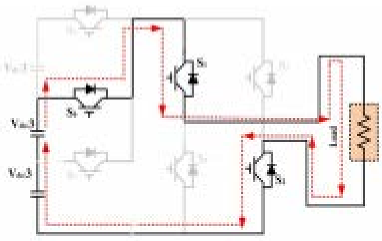
Mode 1 produce output level of Vdc from switched capacitor multi level inverter is shown in Figure 5(a). In this mode of operation, the switch S5, S1 and S2 are turned ON. The three capacitor voltages of each Vdc/3 are in series and get added to yield total voltage of Vdc. The voltage Vdc is impressed across load, current flows through S5, S1, S2 and load. The current path is shown in the circuit. The current enters load positive and hence voltage is positive.

3.2. Mode 2: SC-MLI Producing Output Level 2Vdc/3

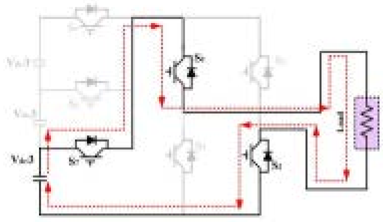
Mode 2 produce output level of 2Vdc/3 from switched capacitor multi level inverter is shown in Figure 5(b). In this mode of operation, the switch S6, S1 and S2 are turned ON. Only two capacitor voltages, each of Vdc/3 are in series and get added to yield total voltage of 2Vdc/3. The voltage 2Vdc/3 is impressed across load. The current flows through S6, S1, S2 and load. The current path is shown in the circuit. The current enters load positive and hence voltage is positive.



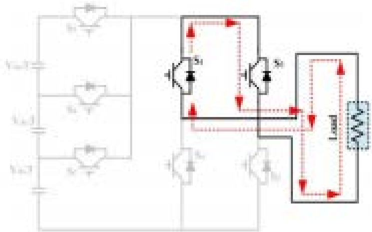
(a) Mode 1: Output voltage V_{dc}



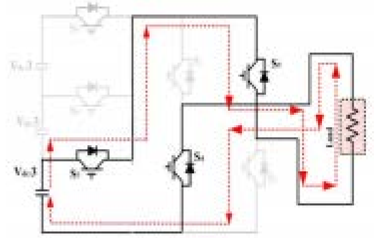
(b) Mode 2: Output voltage $2/3V_{dc}$



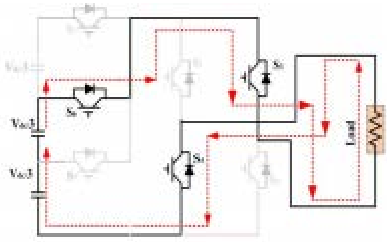
(c) Mode 3: Output voltage $1/3V_{dc}$



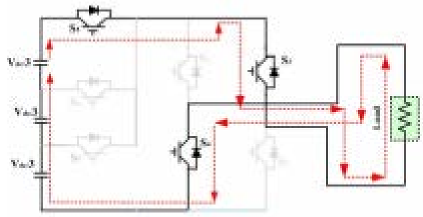
(d) Mode 4: Output voltage 0



(e) Mode 5: Output voltage $-1/3V_{dc}$



(f) Mode 6: Output voltage $-2/3V_{dc}$



(g) Mode 7: Output voltage $-V_{dc}$.

Figure 5. Modes of operation

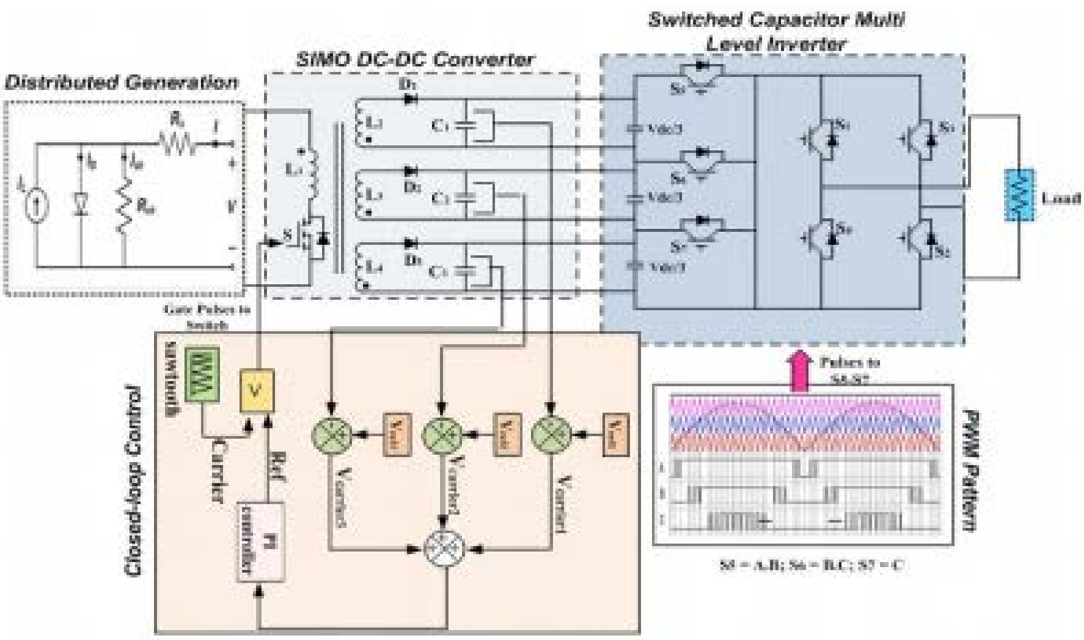


Figure 6. Schematic arrangement of DG fed isolated DC-DC converter for SC-MLI

Table 2. Switching pattern

Level of output	Switching Sequence S1	S2	S3	S4	S5	S6	S7
V_{DC}	ON	ON	OFF	OFF	ON	OFF	OFF
$2/3V_{DC}$	ON	ON	OFF	OFF	OFF	ON	OFF
$1/3V_{DC}$	ON	ON	OFF	OFF	OFF	OFF	ON
0	ON	OFF	ON	OFF	OFF	OFF	OFF
$-1/3V_{DC}$	OFF	OFF	ON	ON	OFF	OFF	ON
$-2/3V_{DC}$	OFF	OFF	ON	ON	OFF	ON	OFF
V_{DC}	OFF	OFF	ON	ON	ON	OFF	OFF

3.3. Mode 3: SC-MLI Producing Output Level Vdc/3

Mode 3 produce output level of Vdc/3 from switched capacitor multi level inverter is shown in Figure 5(c). In this mode of operation, the switch S7, S1 and S2 are turned ON. Only one capacitor voltage of Vdc/3 is in series and gets added to yield total voltage of Vdc/3. The voltage Vdc/3 is impressed across load. The current flows through S7, S1 and S2 and load. The current path is shown in the circuit. The current enters load positive and hence voltage is positive.

3.4. Mode 4: SC-MLI Producing Output Level 0

Mode 4 produce output level of 0 from switched capacitor multi level inverter is shown in Figure 5(d). In this mode of operation, the switch S1 and S3 are turned ON. No voltage is impressed across load and current flowing from S1, S3 and load. The current path is shown in the circuit. As no voltage is impressed, the SC-MLI produces zero output voltage level.

3.5. Mode 5: SC-MLI producing output level -Vdc/3

Mode 5 produce output level of -Vdc/3 from switched capacitor multi level inverter is shown in Figure 5(e). In this mode of operation, the switch S7, S3 and S4 are turned ON. Only one capacitor voltage of Vdc/3 is in series and gets added to yield total voltage of Vdc/3. The voltage -Vdc/3 is impressed across load. The current flows through S7, S3, S4 and load. The current path is shown in the circuit. The current enters load negative and hence voltage is negative.

3.6. Mode 6: SC-MLI Producing Output Level -2Vdc/3

Mode 6 produce output level of -2Vdc/3 from switched capacitor multi level inverter is shown in Figure 5(f). In this mode of operation, the switch S6, S3 and S4 are turned ON. Only two capacitor voltages of each Vdc/3 are in series and get added to yield total voltage of 2Vdc/3. The voltage -2Vdc/3 is impressed across load. The current flows through S6, S3, S4 and load. The current path is shown in the circuit. The current enters load negative and hence voltage is negative.

3.7. Mode 7: SC-MLI Producing Output Level -Vdc

Mode 7 produce output level of -Vdc from switched capacitor multi level inverter is shown in Figure 5(g). In this mode of operation, the switch S5, S3 and S4 are turned ON. The three capacitor voltages of each Vdc/3 are in series and get added to yield total voltage of Vdc. The voltage -Vdc is impressed across load. The current flows through S5, S3, S4 and load. The current path is shown in the circuit. The current enters load positive and hence voltage is positive.

Table 2 represents the switching pattern of power switches from S1 to S7 during different modes of operation of SC-MLI. The schematic circuit representation of the system with switched capacitor type multi-level inverter fed from isolated type DC-DC converter for distributed generation is shown in Figure 6.

4. NOVEL PWM TECHNIQUE

PWM pattern of switching power switches gives many advantages over conventional type of switching the power converters [11]-[12]. Particularly, PWM inverters produce fewer losses in switching devices and reduce the harmonics in output voltage. This phenomenon insists for less sized filters eventually reducing the cost of the system.

Pulse width modulated (PWM) inverters are among the most used power-electronic circuits in practical applications. These inverters are capable of producing ac voltages of variable magnitude as well as variable frequency. The quality of output voltage can also be greatly enhanced, when compared with those of square wave inverters. The PWM pattern is shown in Figure 7.

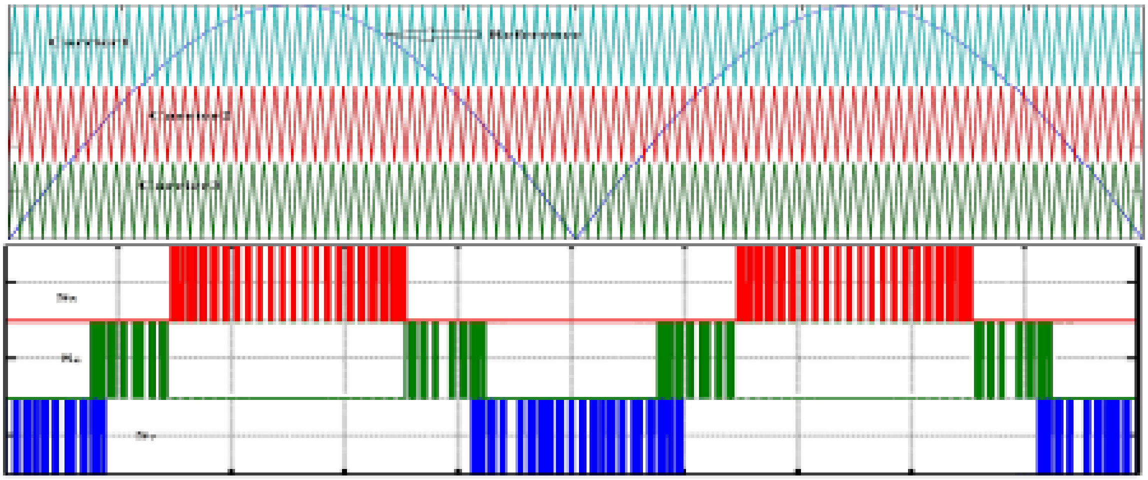


Figure 7. PWM Pattern

For generating seven level output, three phase-disposition carriers are used along with sine reference with 50 Hz frequency. All three carrier signals are in phase having same frequency and amplitude with level shift. When the magnitude of reference signal exceeds the carrier signal, pulses are obtained. A group of pulses are generated by comparing carrier with reference signal. The generated pulses are combined logically by using logical commands AND, NOT and OR before applying to respective switches. The pulse width modulation (PWM) pattern used for switching switched capacitor multi level inverter is shown in Figure 6.

5. RESULTS AND DISCUSSIONS

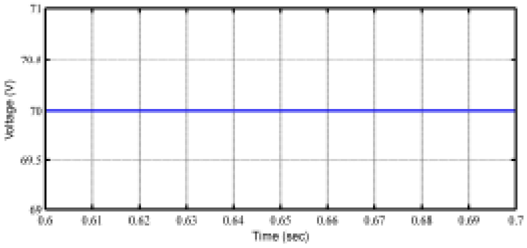
The simulation results are presented in this section. Simulation results are shown with R and RL laod. Where, Vref1 = Vref2 = Vref3 = Vref/3.

5.1. DG Fed SIMO Isolated DC-DC Converter for SC-MLI with R-Load

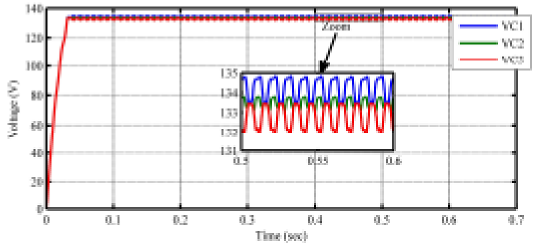
The performance of SC-MLI with R load is shown in Figure 8. Figure 8(a) shows the DC input voltage to the system. The DG voltage of 70V is fed to the SIMO isolated DC-DC converter for SC-MLI with R-Load. The input voltage of 70V from DG is boosted to 400V using SIMO DC-DC converter. The voltage across each capacitor is shown in Figure 8(b). Each capacitor is charged to 133.3V. The total input voltage to SC-MLI is 400V and is equally shared among three capacitors to produce 7-level output. The 7-level output voltage of the SC-MLI is shown in Figure 8(c). The 7-level output is a stepped waveform with equal steps and with a peak value of 400V. Output current passing through R-load of the SC-MLI is shown in Figure 8(d). Figure 8(e) shows the Total Harmonic Distortion (THD) analysis in output voltage of SC-MLI. Harmonic distortion of 18.17% is present in the output voltage of MLI.

5.2. DG Fed SIMO Isolated DC-DC Converter for SC-MLI with RL-Load

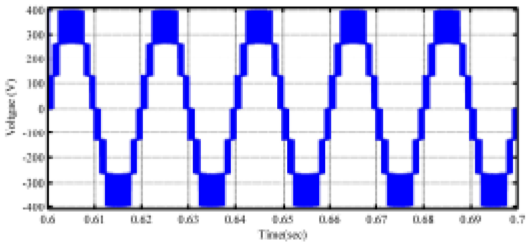
The performance of SC-MLI with RL load is shown in Figure 9. The output voltage across each capacitor is shown in Figure 9(a) for the system DG fed SIMO isolated DC-DC converter for SC-MLI with RL-Load. Each capacitor is charged to 133.3V. The total input voltage to SC-MLI is 400V and is equally shared among three capacitors to produce 7-level output. The 7-level output voltage of the SC-MLI is shown in Figure 9(b). The 7-level waveform is a stepped output with peak value of 400V. Output current passing through RL-load of the SC-MLI is shown in Figure 9(c). With RL-load, the output current smoothens to nearer sinusoidal shape when compared to R-load condition. Figure 9(d) shows the Total Harmonic Distortion (THD) analysis in output voltage of SC-MLI. Harmonic distortion of 18.69% is present in the output voltage of MLI.



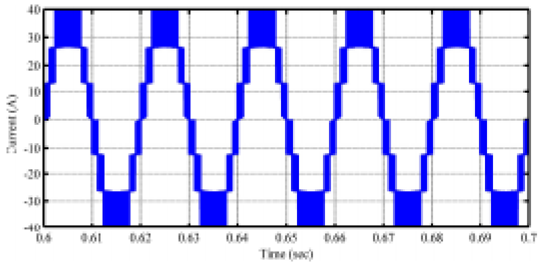
(a) DC Input voltage



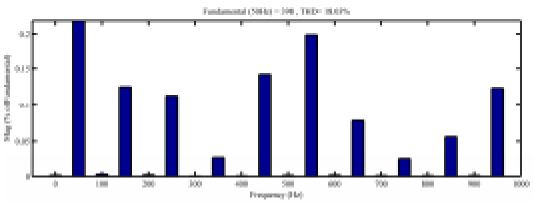
(b) Voltage across three capacitors



(c) Voltage across the load

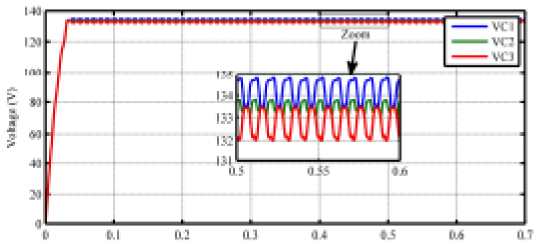


(d) Output current

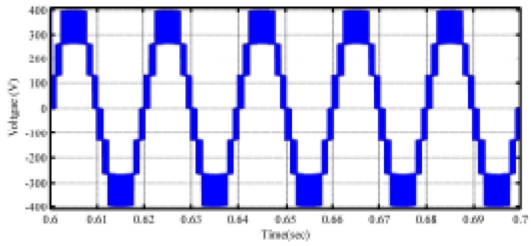


(e) Total Harmonic Distortion

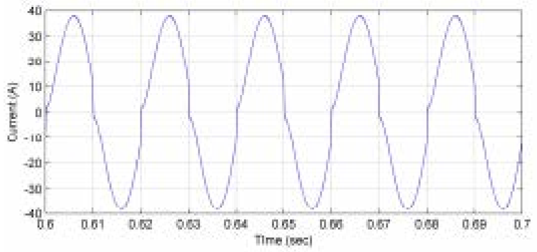
Figure 8. Inverter performance with R Load



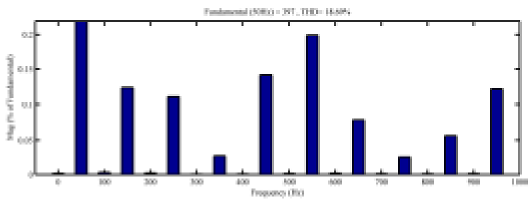
(a) Voltage across three capacitors



(b) Voltage across the load



(c) Output current



(d) Total Harmonic Distortion

Figure 9. Inverter performance with RL Load

6. CONCLUSION

This paper presents a novel simplified PWM technique to drive switched capacitor type multilevel inverter fed from isolated type DC-DC converter for distributed generation. The low voltage from PV system is boosted to required voltage level using isolated single-input multi-output (SIMO) DC-DC converter. Isolated SIMO DC-DC converter apart from boosting the DG output voltage also eliminates the problem of voltage unbalancing in SC-MLI topology. The set voltage is obtained across all Switched capacitors. Closed loop operation of SIMO DC-DC converter employs only single PI controller instead of three controllers. Number of switching devices, diodes, DC bus capacitor, flying capacitos and number of sources required is very less when compared to conventional inverters.

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