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FINITE CONTROL SET MODEL PREDICTIVE CONTROL BASED 7-LEVEL TRIPLE BOOST INVERTER FOR 1-Φ GRID CONNECTED APPLICATIONS

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***Abstract* – Due to its reliability and great power handling capacity, multi-level inverters (MLIs) have been the preferred option for the majority of industrial applications. This multilevel inverter suggests an innovative 7-level triple boost inverter that can be controlled by the Model Predictive Control (MPC). This design decreases components just by using eight switches, one diode, and two capacitors for 7-level inverter. Two of the eight switches are also used in the path for charging the capacitors. This approach can overcome the limitations of traditional control methods used with MLIs because it is simple to implement. A greater variety of voltages can be obtained by the conventional system. The proposed 7-level MLI is controlled using a Finite Control Model Predictive Control (FCS-MPC). MATLAB/Simulink can be used to model this 7-level structure. The results show that the Control scheme can effectively track the load current as well as the system functions properly.**

Keywords— Switched capacitors, triple boost multi -level inverter, tracking performance, FCS-MPC, THD.

I. INTRODUCTION

Due to several properties including less Total Harmonic Distortion (THD), less stress on the switches, and others, Multi-Level Inverters (MLIs) are currently receiving attention as a solution for moderate voltage high power applications [1]. In the writings [1], Traditional multilevel inverters can be broadly categorized into three groups: Flying Capacitor (FC) MLIs, Cascaded H-Bridge (CHB) MLIs, and Neutral Point Clamped (NPC) MLIs [2]. A numerous components used and the complexity of controlling capacitor voltages are the main drawbacks of these topologies. Numerous MLI topologies have been presented in the literature as solutions to these issues.

For the conventional and reduced device count MLI, voltage amplification is not achievable. This level boost will be essential in system that convert renewable power since the low voltage generated by fuel cells and PV panels makes them unsuitable. The researchers developed the switching capacitor technology to produce a wider range of power values and greater gain from a single dc power supply. To significantly improve voltage levels, this method includes connecting the parallel capacitors with the DC supply and also discharge them to a load in series with DC source [3], [4]. In [5], authors proposed a single dc power supply, 7-level triple boost configuration. The architecture is capable of generating negative voltage levels without employing an cascade bridge, and switches can block up to 2Vdc. Two capacitors connect the non-isolated interleaved power converter and an inverter in [6] to boost voltage. In [7], a novel topology involving fewer components and less power stress upon these switches was introduced to obtain a voltage of 3.

In [8], authors developed a structure with a triple gain. In [9], a generalized 5-level inverter is constructed from an unique 5 inverters with a gain of two. The capacitors may self-discharge to the source if they are overcharged, according to the inventors, who claim that their architecture may regenerate power. A full bridge inverters and 2, 3-level T-type structures were used in the architecture developed in [10] to obtain 7-level voltage, However, the number of switches is relatively more. All of the articles mentioned above can produce an output voltage with 7-levels and a gain of 3.

There are numerous architectures described in the literature with 7- level output voltage, but they only have such a 1:1.5 boost ratio. [11] presents a new 8 switch boosting ANPC for a 7-level inverter. A half bridge and switched capacitor circuit are due to several properties including less Total Harmonic Distortion (THD), less stress on the switches, and others, Multi-Level Inverters (MLIs) are currently receiving attention as a solution for moderate voltage high power applications [1]. In the writings [1], Traditional multilevel inverters can be broadly categorized into three groups: Flying Capacitor (FC)multi-level inverters, Cascaded H-Bridge (CHB) multi-level inverters, and Neutral Point Clamped (NPC) multi-level inverters [2]. A numerous components used and the complexity of controlling capacitor voltages are the main drawbacks of these topologies.

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II. PREDICTIVE CURRENT CONTROL SCHEME

The suggested predictive control method is based on the assumptions that a fixed converter can only generate a finite number of operating modes and it's possible to forecast how the variables will operate in every switching state using models of the system. For the discrete time modeling of the current to fully forecast the load current, the voltage vector of each switch condition on the inverter output end is fed into the model. Following that, the potential vector with the smallest difference is chosen by comparing all the predicted values of the current with reference value. The single-phase inverter's following output is then regulated based on the switch condition determined by select voltage vector.

The steps involved in this control method are as follows:

1. Create a model of the inverter output side voltage vector.
2. Create a load current model.
3. Specify the quality function. G.

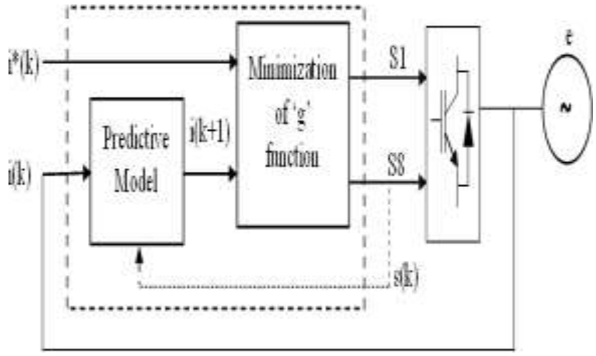

Fig.1 Predictive Control Block Diagram

Fig.1 depicts the model predictive control framework. The steps involved in the predictive current control is as follows:

1. The measured load current value is i(k), and the reference load current value is i*(k).
2. A load current forecasting model is used to calculate every potential load current value in the future.
3. Compare results to determine the switch state with the lowest G value.
4. Discrete-time and mathematical models of the load current

III. PREDICTIVE CURRENT CONTROL FLOW CHART

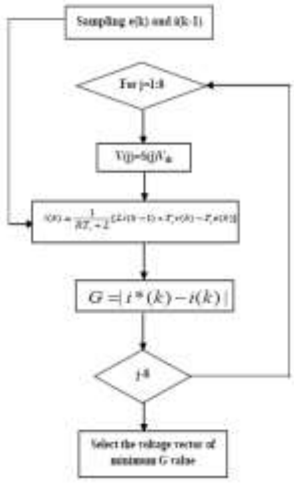

Fig.2 Predictive Current Control Flow Chart

The predictive control's algorithm and pertinent principles are depicted in the flow diagram seen in Fig.2. The quality function can be minimized using the cycle represented in the diagram, which forecasts every output voltage, assess the quality function and saves the minimal value and the coefficient of determination of a corresponding switching state.

IV. TRIPLE BOOST MLI TOPOLOGY

This topology is from [18]. Due to the low voltage produced by sources of sustainable energy, an high gain inverter must be employed in applications that integrated renewable energy to match the grid voltage. Therefore, by additionally connecting the three elements (2 switches and 1 capacitor), as shown in fig. 3, The conventional 7-level configuration described above may be expanded to any number of levels.

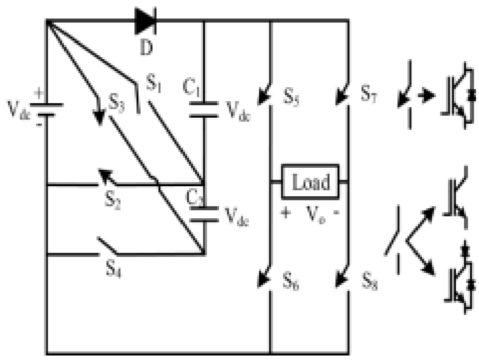

Fig.3 Triple Boost Inverter Toplogy

No. of Levels in output voltage = N (1)

No. of switches = 2N+2 (2)

No. of capacitors = N-1 (3)

The highest load stress on the H-bridge = NV_{dc} (4)

The highest load stress on the diode= (N-1) V_{dc} (5)

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TABLE I SWITCHING FORMATIONS AND THEIR IMPACT ON CIRCUIT SWITCHING CAPACITORS FOR 7-LEVEL TOPOLOGY

S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8	C_1	C_2	V_0
0	0	1	0	1	0	0	1	↓	↓	$+3V_{dc}$
1	0	0	1	1	0	0	1	↓	↓	$+2V_{dc}$
0	1	0	0	1	0	0	1	↓	-	$+V_{dc}$
0	1	0	0	1	0	1	0	↓	-	0
0	1	0	0	0	1	0	1	↓	-	0
0	1	0	0	0	1	1	0	↓	-	$-V_{dc}$
1	0	0	1	0	1	1	0	↓	↓	$-2V_{dc}$
0	0	1	0	0	1	1	0	↓	↓	$-3V_{dc}$

One distinct diode & two series diodes were needed for such structure for any number of levels. There are two switches with Maximum Bridge Voltage (MBV) of Vdc, 2 switches with the MBV of 2Vdc, 2 switches with the MBV of 3Vdc, etc., among switches from S1 to S2N- 2. During each output cycle, by carefully selecting the charging and discharge pathways, all capacitors may be evenly balanced at Vdc.

V. CONTROL OF THE TRIPLE BOOST MLI

Considering an inductive load, the continuous-time model of the proposed 7L-MLI can be written as follows

$$v_{inv}(t) = Ri_o(t) + L\frac{d}{dt}i_o(t) \qquad (6)$$

where the resistance is R, the inductance is L, and the output current is io. Typically, the discrete-time domain is used to construct the FCS-PC. The derivatives of a load current in the discrete-time domain can also be roughly represented as using the Euler forward approximation.

$$\frac{d}{dt}i_o(t) = \frac{i_o[k+1] - i_o[k]}{T_s} \qquad (7)$$

Ts is the sampling time, k is the current sample, and k + 1 is the next sampling time. Accordingly eq (1) can be written in the discrete-time form as

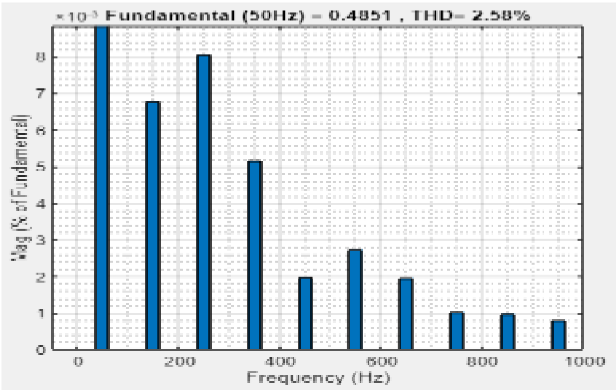
$$v_{inv}[k] = Ri_o[k] + L\frac{i_o[k+1] - i_o[k]}{T_s} \quad (8)$$

To design the proposed FCS-PC, the current prediction in the next sample can be realized by

$$i_o[k+1] = \left(1 - \frac{RT_s}{L}\right)i_o[k] + \frac{T_s}{L}v_{inv}[k] \quad (9)$$

Based on Table 1, the proposed MLI has 8 switching states producing 17 Voltage Vectors (VVs). Those 17 VVs are used in Equation (4) to predict 17 values of output current. Then, cost function is represented in eq (10) is used to choose the voltage vector with the lowest error.

$$g[k+1] = \left|i_{o,ref} - i_o[k+1]\right| \qquad (10)$$



VI. RESULTS AND DISCUSSION

Model predictive control strategies have been simulated using MATLAB/Simulink for a 1-Φ grid-connected triple boost inverter, as shown in fig.4. Parameters of the simulated system: V=100v, R=50, L=150mH, e=20v, TS=50μs.

Fig.5 represents the conventional simulation model of the 7-level triple boost inverter. In Fig.5, a load current as well as its reference value were displayed. A load voltage waveform clearly resembles the one of the reference in many ways. According to this result, the current tracking result is perfect. The results show that predictive model control has potent anti-interference features, excellent dynamic performance, and behavior that is like sine wave. The load current's tracking error is also found to be quite low.

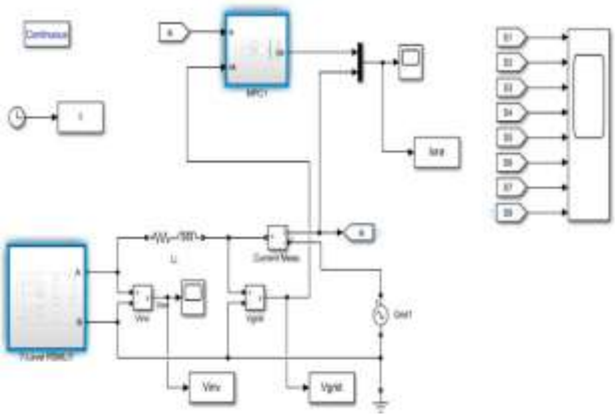


Fig. 4 Simulink model for 1-Φ grid connected triple boost inverter

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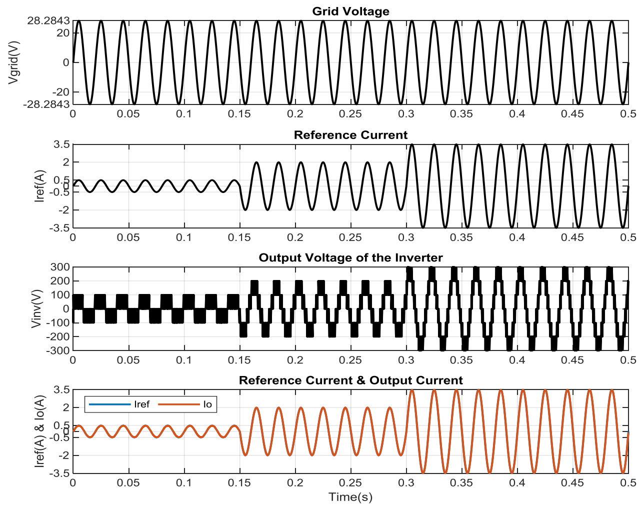

Fig.5 Output waveforms of Voltage and Current of an inverter by using MPC.

The reference current is 0.5A from 0 to 0.15 seconds, and the inverter acts as a 3-level inverter. The reference current is 2A during this time, and the inverter acts as a 5-level inverter. The reference current is 3.5A during this time, and the inverter acts as a 7-level inverter.

The Total Harmonic Distortion for the fundamental current shown in Fig.6 is incredibly low, as well as the THD with different reference current values as shown in the figures below.

Fig.6(a) Harmonic spectrum of the reference current and the fundamental current, I_L =0.5A

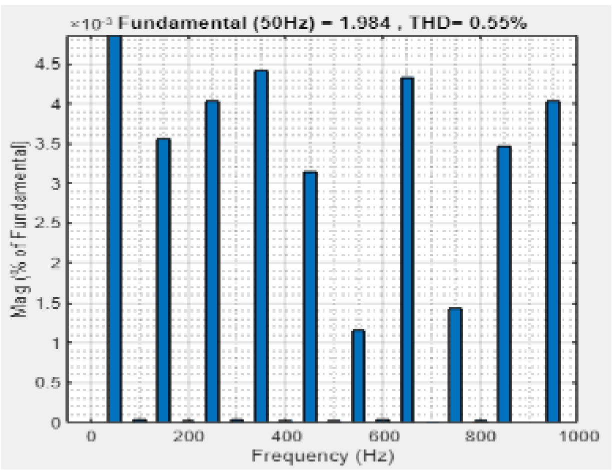

Fig.6(b) Harmonic spectrum of the reference current and the fundamental current, I_L =2A

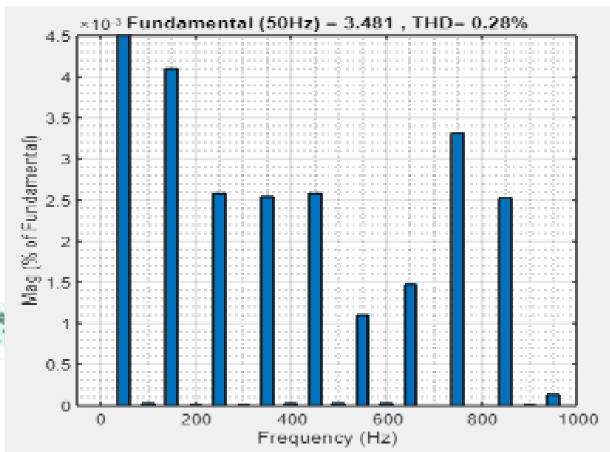

Fig.6(b) Harmonic spectrum of the reference current and the fundamental current, I_L =3.5A

In fig.6 (a),6(b),6(c) shows that the fundamental current is perfectly tracking the reference current and the total harmonic distortion is decreasing.

TABLE II. HARMONIC SPECTRUM ANALYSIS WITH CHANGE IN LOAD CURRENT

Reference Current	**Fundamental Current (I_L)**	**THD (%)**
0.5	0.481	2.58
2	1.984	0.55
3.5	3.481	0.28

Table 2 shows that, as reference current increases, fundamental current rises as well, whereas Total Harmonic Distortion decreases.

VII. CONCLUSION

A single-phase grid connected reduced switch, triple boost inverter with seven levels is presented in this study. The output current of the 7-level-MIL is controlled using the Finite-Control-Set Model Predictive Control (FCS-MPC). The approach is simple to digitized and has a unique physical model. In contrast to the conventional single phase triple inverter control approach, it does not alter the PI settings and may achieve universal utilization. According to the simulation findings, the model predictive control load current has a low harmonic content, a quick dynamic response, and high tracking performance. It has a highly promising future for development and can also successfully adhere to the guiding principles of grid-connected inverter control approach.

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