# "SEVEN LEVEL PACKED U CELL MULTILEVEL INVERTER FOR REAL TIME APPLICATIONS"

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***Abstract***—*In this thesis, simulation is shown to get seven level voltage at the output of the grid connected inverter model for real time applications using a Model Predictive Control on the Packed U-Cell inverter which has one isolated DC source and one capacitor as an auxiliary DC link. The MPC is used to regulate the capacitor voltage at the desired magnitude to have seven voltage levels at the output of the inverter. Since grid-connected application is targeted by this application the inverter should be capable of supplying requested amount of active and reactive power at the point of common coupling as well. Multilevel inverter has wide application in high power industries due to the high voltage and low harmonics. Since there are various types of multilevel inverters, due to reduction in number of switches and low switching losses compared to the others type of inverters here Packed U Cell type of multilevel inverter. This is called Packed U cell because of the arrangement of one source and two power switches. It provides energy conversion in high quality using a small number of power semiconductor devices and capacitors in which the production cost is reduced.*

## 1. INTRODUCTION

The global electrical energy consumption is estimated to rise on a positive slope for the coming years; therefore the installed production capacity of classical high power stations may not be able to meet the ever increasing demand. Moreover, tolerating the conventional energy sources such as fossil fuel, nuclear and perhaps gas is becoming a social issue limiting possible implementations of such technology due to pollution impact and for safety consideration as well. In order to answer the ever growing energy demand, call for clean and renewable type of energy sources, to fill up the gap left by holding classical plant development, is answered by the industry which nowadays is developing commercial Solar, Wind, Biomass, and Geothermal.

These sources have become an important asset of the world's energy resources because of their non-polluting nature, little maintenance, at acceptable price. The solar cell behaves as a controlled current source which converts the irradiance energy directly into DC current. To convert the DC current/voltage into AC current/voltage while targeting high efficient scheme, less polluted with low emission of harmonics, power electronic converters are necessary; moreover, multilevel family type of converters are the most appropriate topologies to be considered.

Conventional inverters have some drawbacks like non sinusoidal output voltage rich in harmonic distortion (THD), high switching losses and thermal stress at high switching frequency with high level of common mode noise. Multilevel inverters constitute a class of devices which present interesting features that are naturally adapted to solar energy conversion schemes and therefore constitute an interesting solution to the proliferation of solar energy technology. Multilevel inverters make use of switches and floating capacitors to produce various symmetrical voltage levels when controlled properly. The higher number of voltage levels produced, the lower is the harmonic content. Traditional multilevel inverters present many drawbacks though, they are costly and hard to implement when the number of voltage levels increases. In order to attenuate the impact of such problems, several studies have been conducted and new multilevel inverters topologies have been proposed. One promising topology is the Packed U-Cells (PUC) which combines advantages of flying capacitor (FC) and cascaded H-Bridges (CHB) and makes use of only one isolated DC source while the second DC bus should be regulated at a desired voltage level which influence the output voltage number of level.

Several control techniques have been studied concerning the PUC like hysteresis current control, and nonlinear controllers. All those controllers have been implemented on the stand-alone inverter or rectifier application of the PUC topology. Therefore, they were mainly dealing with unity power factor operation as well as supplying power to the stand-alone loads. Moreover, adjusting multiple gains and using modulators to send the required switching pulses to the power electronic devices are the main drawbacks of the reported works.

Nowadays, power inverters are asked to provide both active and reactive power for the utility in which the grid voltage and current phase-shift as well as the current amplitude should be monitored and regulated online. Though the idea of MPC was developed in 1960s, it remains simple and intuitive.

Comparing MPC to other classical controllers, a large number of calculations should be executed at each time step before sending the appropriate optimal signal to the devices. MPC consists of calculating the future behavior of the controlled variables, comparing them to their references, calculating a cost function that should be minimized in order to choose the optimal state. On the other hand, it features some interesting characteristics such as fast dynamic response, accurate tracking, and no gains to tune and no need to use an external type of modulators. Some other research work dealt with studying the delay effect on MPC compensation performance as well.

In this paper, MPC is developed for the PUC inverter for grid-connected application. The PUC inverter has been studied and investigated as a renewable energy conversion device to deliver green power to the grid while generating multilevel voltage waveform with low harmonic contents at the ac output. Consequently, the PUC inverter capacitor voltage and the grid current should be controlled to have desired predefined power quality regulated voltage of the second DC bus as well as the desired operating Power Factor by changing the grid voltage and current phase-shift accordingly. The paper is organized as follow: after an Introduction to multilevel converters and MPC, section II includes the PUC topology description and switching sequences. MPC technique applied on the PUC inverter has been investigated and designed accurately.

## 2. Packed U Cell Topology and Switching Sequences

PUC converter has been introduced by Al-Haddad in 2011 and developed by Vahedi in 2015. It can be used as single-phase converter as well as three-phase configuration. This topology is an intermediate hybridization of FC and CHB with reduced number of capacitors and semiconductors components. The general structure of the grid-connected PUC inverter is shown in Fig. 1. The inverter is connected to the grid through a line inductor (L) having a parasitic resistor (r). The line current is controlled to flow from the inverter to the grid with different phase angle proving therefore controlled active and reactive power at the Point of Common Coupling (PCC).

DC source and link amplitudes indicate the number of output voltage levels; using the 1/3 ratio leads to producing seven voltage level at the inverter output. Therefore, if V1 = 3V2 = 3E, then the output voltage waveform (Vinv) contains the voltage levels of 0, ±E, ±2E, ±3E.To reduce the number of isolated DC sources, an energy storage device (DC capacitor) is used at the second DC bus which needs voltage balancing methods like linear/nonlinear controllers or the advance predictive control to fix the DC voltage accordingly.

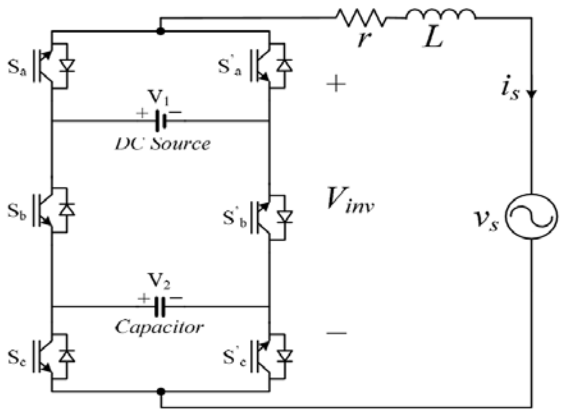


Fig. 1. 7-Level PUC Inverter in grid-connected application

TABLE I PUC SWITCHING STATES

| States | Sa | Sb | Sc | Vinv | Vinv Value |
|---|---|---|---|---|---|
| 1 | 1 | 0 | 0 | $V_1$ | +3E |
| 2 | 1 | 0 | 1 | $V_1 - V_2$ | +2E |
| 3 | 1 | 1 | 0 | V2 | +E |
| 4 | 1 | 1 | 1 | 0 | 0 |
| 5 | 0 | 0 | 0 | 0 | 0 |
| 6 | 0 | 0 | 1 | $-V_2$ | –E |
| 7 | 0 | 1 | 0 | $V_2 - V_1$ | –2E |
| 8 | 0 | 1 | 1 | $-V_1$ | –3E |

PUC inverter consists of six active switches. Each switch can have two states, where switches S’a, S’b and S’c are working in complimentary with the associated switches of Sa, Sb and Sc. all switching states and corresponding voltage levels have been listed in table I. The use of 6 switches allows reaching eight switching states including two redundant ones.

Comparing to the CHB or FC topologies generating 7-level voltage, the PUC converter has less number of isolated DC sources, DC capacitors and switching devices. However, the main problem with this topology is the different voltage rating of switches. Fortunately, the upper two switches working at the fundamental frequency should suffer the highest voltage while the four lower switches that have higher switching frequency see the lower voltage which is compatible with semiconductor devices performances.

## 3. Model Predictive Control

Different control methods for voltage balancing and current control exist such as linear/nonlinear controllers, predictive model, fuzzy, etc [33-37]. Model Predictive Control or MPC uses a model of the system to predict the future behavior of the variables [24, 27].One of the major advantages of the FCS-MPC compared to a traditional PI controller is the flexibility to control different variables, with constraints and additional system requirements. Besides, using MPC avoids the cascade structure which implies inner faster dynamic loop and outer slower dynamic loop to control system parameters; such a scheme is typically used in a linear control. The drawbacks of FCS-MPC is that such a controller can operate at variable switching frequency and also It requires a high number of calculations to generate its output, compared to a classical continuous control scheme.

Fig. 2 presents a general scheme for MPC to control the grid-connected inverter. In general, MPC consists of measuring the variable x(k) and use it in the predictive control in order to calculate the future value x(k+1) of the controlled variable for each one of the switching states. Then, a cost function is calculated in order to choose the minimum value corresponding to the optimal state and apply it on the PUC inverter through the switching pulses. Switching pulses are produced according to the appropriate switching state chosen by the MPC from the recalculated switching table.

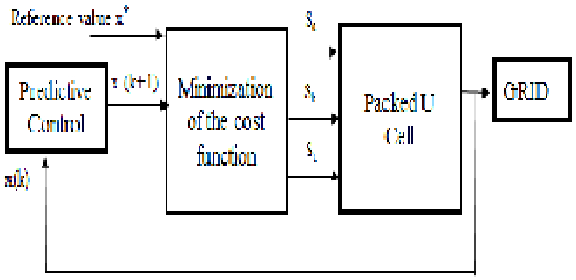


Fig. 2. General Scheme for MPC

## 4. Simulation Model, Coding and Results

### *4.1 Model Developed*

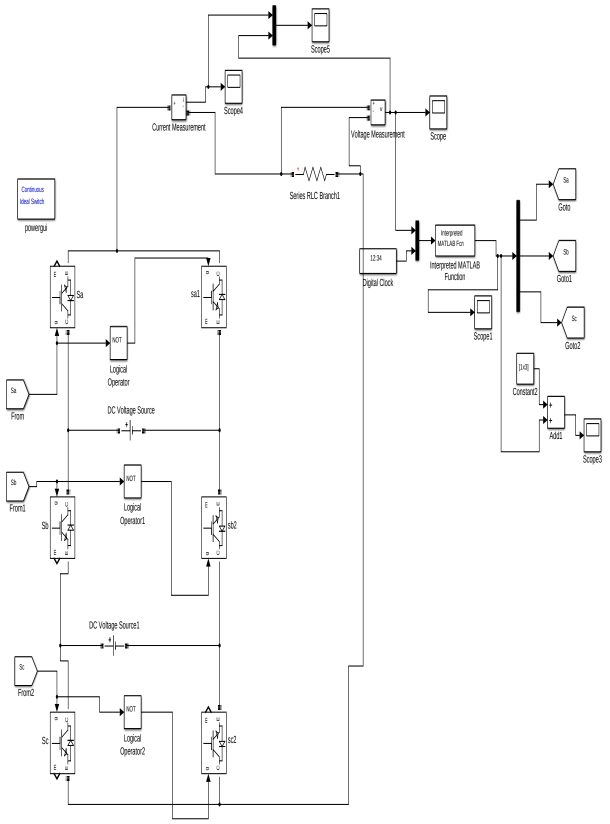

Fig. 3 Model Developed

### *4.2 Coding*

```
function y=mpc_control(u)
a=[1 0 0;1 0 1;1 1 0;1 1 1;0 0 0;0 0 1;0 1 0;0 1 1];
global x;
global prew;
cur=u(1);
if u(2)==0
prew=0;
if prew==0 & cur==0
x=a(3,:);
end
end
u
if prew==0 & cur==0
x=a(3,:);
end
if prew==0 & (cur>0 & cur<=50)
x=a(2,:);
end
if (prew>0 & prew<=50) & (cur>50 & cur<=100)
x=a(1,:);
end
if (prew>50 & prew<=100) & (cur>100 & cur<=150)
x=a(2,:);
end
if (prew>100 & prew<=150) & (cur>50 & cur<=100)
x=a(3,:);
end
if (prew>50 & prew<=100) & (cur>0 & cur<=50)
x=a(4,:);
end
if (prew>0 & prew<=50) & cur==0
x=a(6,:);
end
if prew==0 & (cur<0 & cur>=-50)
x=a(7,:);
end
if (prew<0 & prew>=-50) & (cur<-50 & cur>=-100)
x=a(8,:);
end
if (prew<-50 & prew>=-100) & (cur<-100 & cur>=-150)
x=a(7,:);
end
if (prew>=-150 & prew<-100) & (cur>=-100 & cur<-50)
x=a(6,:);
end
if (prew>=-100 & prew<-50) & (cur<0 & cur>=-50)
x=a(4,:);
end
if (prew<0 & prew<=-50) & cur==0
x=a(3,:);
end
prew=cur;
y=x;
end
```

### *4.3 Simulation Results*

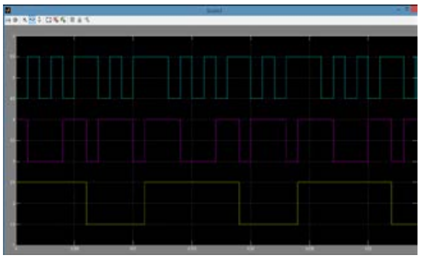

Fig 3.3.1: Switching pulses of Sa, Sb & Sc

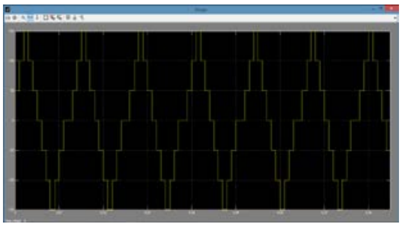

Fig 3.3.2: Output Voltage of 7 level u cell inverter

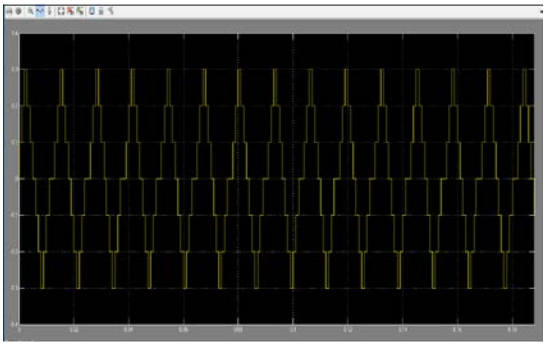

Fig 3.3.3: Output current of 7 level u cell inverter

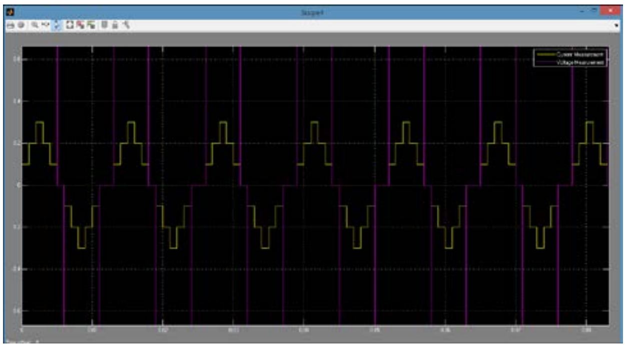

Fig 3.3.4: Output Voltage and current of 7 level u cell inverter shows PF is unity

## 5. CONCLUSION

In this simulation, a Model Predictive Control has been used for the seven level PUC inverter in grid-connected mode of operation, an excellent candidate for photovoltaic and utility interface application to deliver green power to the utility. MPC is a simple and intuitive method that does not have confusing gains to adjust. It has been demonstrated that the DC link capacitor voltage has been regulated at desired level and 7-levellvoltage waveform has been generated at the output of the inverter. The injected current to the grid was successfully controlled to have regulated amplitude and synchronized waveform with the grid voltage to deliver maximum power with unity power factor. Thus this 7-level PUC inverter gives the 7-level voltage waveforms at the inverter output with simple circuit which combines advantages of flying capacitor and cascaded H-Bridges and makes use of only one isolated DC source with Unity power factor and with the great efficiency than the conventional inverters.

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