Modified Modulated Predictive Control for a 3-Phase 2 Level PWM Rectifier

Objective: In order to improve the steady-state performance of the finite control set model predictive control (FCS-MPC), this paper proposes a simplified modulated predictive current control scheme for a three-phase two-level PWM rectifier. In the proposed scheme, the optimal vector is evaluated initially in a similar way like the conventional finite control set model predictive control (FCS-MPC). Later, an additional stage is included to compute the duty cycle of the optimal voltage vector obtained from the stage-1 by using the simplified relationship between the cost-function values and the duty cycle. Compared to the prior art the proposed method can effectively improve the THD of the input current with less complexity. The proposed method retains the fast dynamic response of the FCS-MPC with an improved steady-state performance. In addition, the fixed switching frequency operation is also obtained.

Proposed Methodology:

The voltage vectors for the converter under study are shown in Fig. 2 along with the six sectors. The conventional FCS-MPC computes the following cost function for all the converter voltage vectors for the power converter and selects the optimal switching state based on the cost-function minimization. The cost-function is defined as:

$$g = (i_\alpha^*[k+2] - i_\alpha[k+2])^2 + (i_\beta^*[k+2] - i_\beta[k+2])^2$$

The converter switching state which gives the minimal value of the cost-function is selected as the optimal switching state and applied as actuations. However, the FCS-MPC does not provide a constant switching frequency operation and also the performance of the FCS-MPC is not comparable with other linear controllers such as DPC-SVM. Thus, it is desirable to develop a control technique which can retain some key advantages of the FCS-MPC and also provides improved steady-state performance with constant switching frequency. Thus, in this paper a modified MPC technique is proposed which can improve the performance of the FCS-MPC and operate at a fixed-switching frequency. With the proposed method one active vector and one zero vector will be applied instead of single vector application. The aim is to obtain a fixed-switching frequency operation with improved performance.

The duty cycle for active vector to be applied is d_{opt} and the duty cycle for the zero-vector is d_0. T_s is the total sampling time. Thus, the following expressions holds true.

$$d_{opt} + d_0 = T_s$$

If the error associated with each voltage vector related to the cost-function is denoted as ε then for the application of a duty cycle dopt the weighted average error can be written as $d_{opt}\varepsilon$. The relationship between the cost-function values with the duty cycle is obtained using the minimization of this error as reported in [13]. Considering the Karush–Kuhn–Tucker condition and the Lagrange mulplier method for the optimization problem an approximate relation between the duty cycle and cost-function can be obtained. The duty cycle is found to maintain a reciprocal relationship with the cost function value. Thus,

$$d_0 \propto \frac{1}{g_0}$$

$$d_{opt} \propto \frac{1}{g_{opt}}$$

This can be written as,

$$d_0 = \frac{k}{g_0}$$

$$d_{opt} = \frac{k}{g_{opt}}$$

Now,

$$\frac{k}{g_0} + \frac{k}{g_{opt}} = T_s$$

$$\Rightarrow k \,.\, \frac{g_{opt} + g_0}{g_{opt} . g_0} = T_s$$

$$\Rightarrow k = \frac{T_s \,.\, g_{opt} . g_0}{g_{opt} + g_0}$$

Thus,

$$d_{opt} = \frac{T_s \,.\, g_{opt} . g_0}{(g_{opt} + g_0) . g_{opt}}$$

$$= \frac{T_s . g_0}{(g_{opt} + g_0)}$$

This allows computing the optimal duty cycle for the optimal active voltage vector. d_0 can be computed as:

$$d_0 = T_s - d_{opt}$$

The overall process is depicted with a flow-diagram shown in Fig. 3

I. Simulation Results

In order to provide support to the theoretical approach simulation study is performed in Matlab-simulink environment. The parameters used in the simulation are listed in Table-I.

Table-I: Parameters for the simulation.

Parameters	Value
Grid Voltage (rms)	415-V
Filter Inductance	8-mH
Filter parasic resistance	0.1Ω
Nominal load resistance	50-Ω
Sampling frequency	40-µs
DC-Bus voltage	600-V
Fundamental frequency	50-Hz

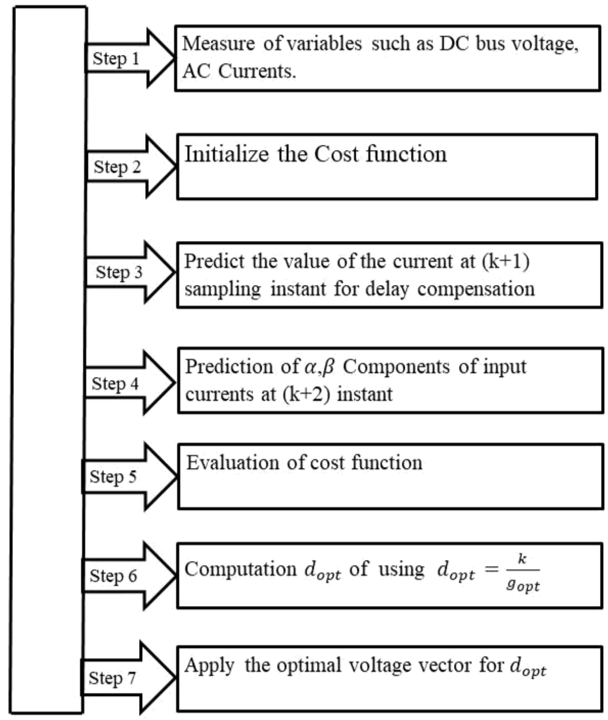

Fig. 3: Flow diagram showing the implementation process of the proposed method.

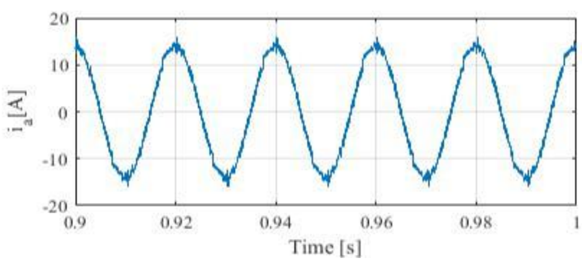

Fig.4: Input current of FCS-MPC with 50 Ω load.

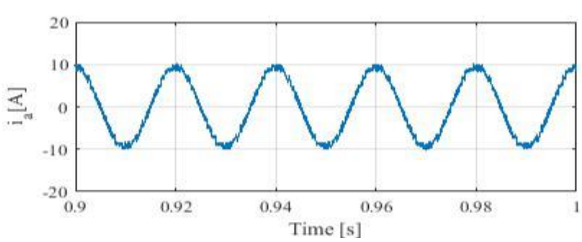

Fig.5: Input current of FCS-MPC with 75 Ω load.

The proposed method can significantly improve the THD of the input current. At the rated load the THD decreased from 5.88% to 3.81%. At light load the THD decreased from 9.19% to 7.61%. The FFT spectrum of the FCS-MPC for different loading conditions is shown in Figs. 8-11 while the FFT spectrums with the proposed method are shown in Figs. 13-15. .

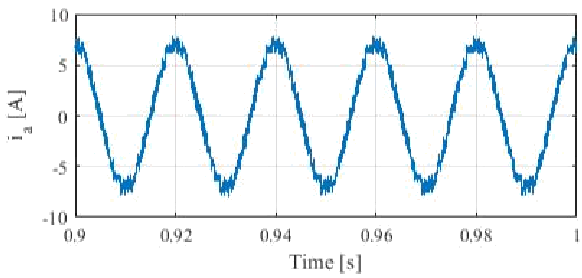

Fig.6: Input current of FCS-MPC with 100 Ω load.

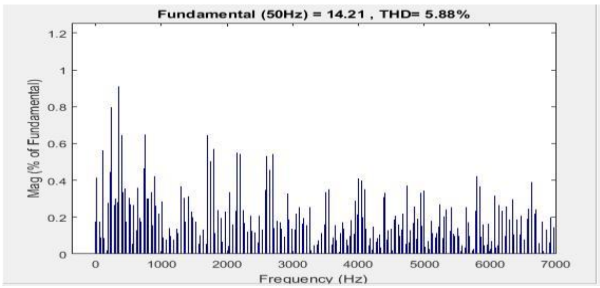

Fig.7: FFT spectrum of FCS-MPC with 50 Ω load.

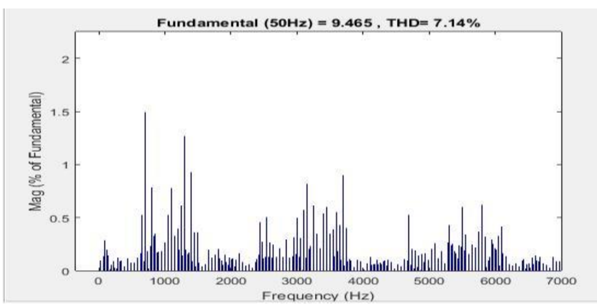

Fig.8: FFT spectrum of FCS-MPC with 75 Ω load.

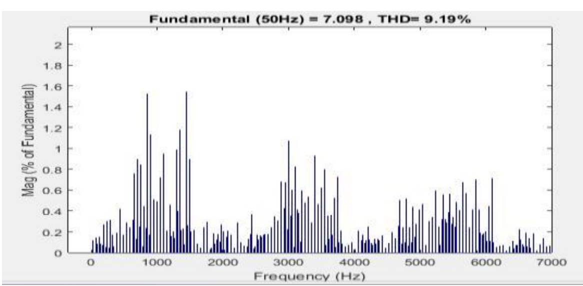

Fig.9: FFT spectrum of FCS-MPC with 100 Ω load.

It can be seen that the steady-state performance of converter is improved with the proposed method compared to the FCS-MPC. Moreover, the application of duty cycle implies to the fixed-switching frequency operation and solves one of the major problems of the FCS-MPC.

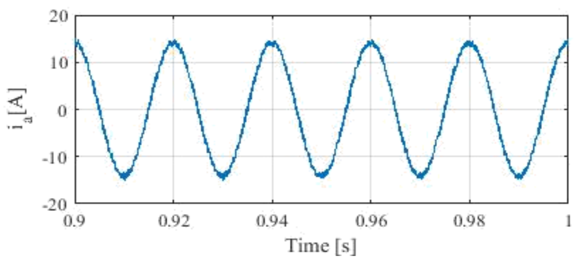

Fig.10: Input current of the proposed method with 50 Ω load.

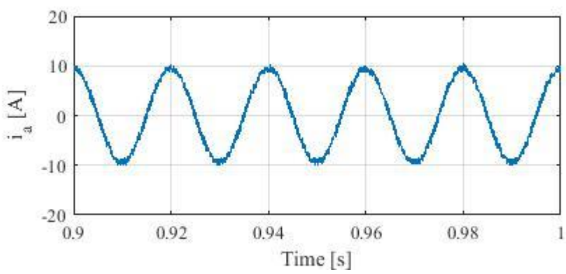

Fig.11: Input current of the proposed method with 75 Ω load.

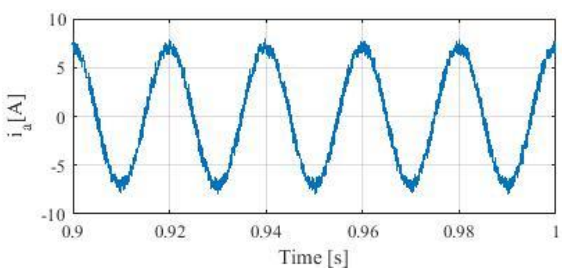

Fig.12: Input current of the proposed method with 100 Ω load.

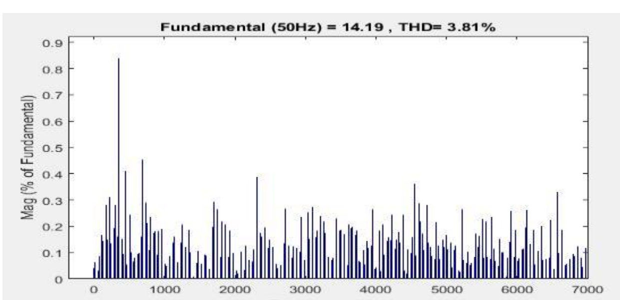

Fig.13: FFT spectrum of the proposed method with 50 Ω load.

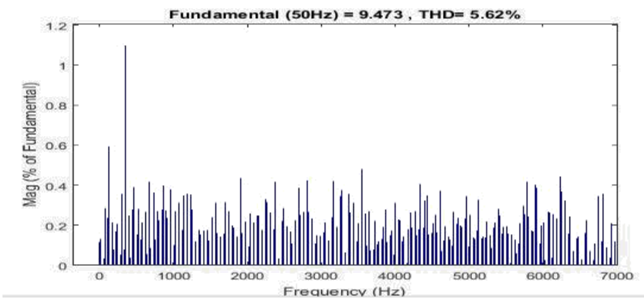

Fig.14: FFT spectrum of the proposed method with 75 Ω load.

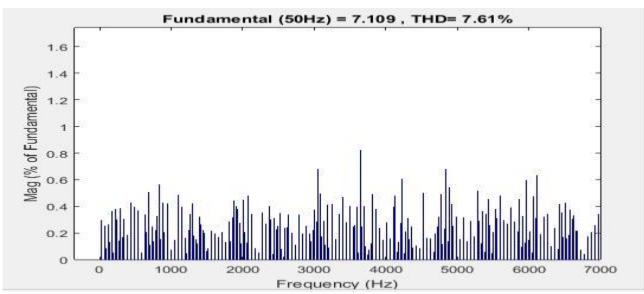

Fig.15: FFT spectrum of the proposed method with 100 Ω load.

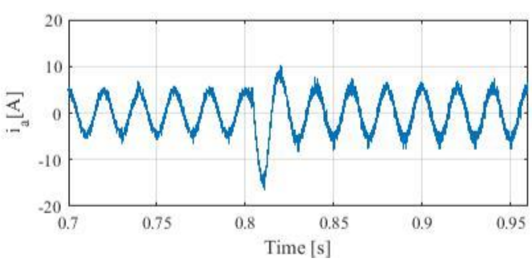

Fig. 16: Transient response with the FCS-MPC.

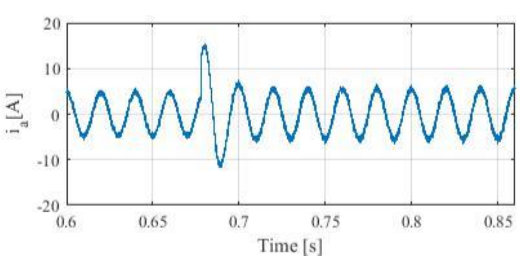

Fig. 17: Transient response with the proposed method.

Conclusion: The transient performance with the FCS-MPC and the proposed method is shown in Fig. 16 and Fig. 17 respectively. It can be seen that both methods perform in similarly and it can be concludes that the proposed method retains the high dynamic performance criterion of the FCS-MPC with an improved steady-state performance.

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