An Improved Hysteresis Band based FCS MPC for Grid-connected Three Phase Inverter

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Abstract: The Indonesian government has begun to promote the use of non-oil and gas alternative energy. Optimizing renewable energy technology is a priority for system implementation. One method to overcome modulation in one computational stage is by using a Finite control set – predictive control model (FCS MPC) compared to traditional controllers such as PID, SPWM. This method is very challenging to find the optimal, especially in the field of prediction that considers far into the future. FCS MPC in this method provides the latest discovery by adding a hysteresis band to produce a better current. The results of research on optimization of renewable energy technology apply with direct current response system of 882.7 Volts with a steady-state error of 2 %. The optimal current has been obtained from the hysteresis band of 0.2 bands. On switching on the inverter, the second vector voltage or g2 is 0.47or this vector value is used for switching on the inverter. FCS MPC has been implemented to a two-level converter system, then the need for a filter circuit to produce a sine wave like a pure sine wave generated by a generator.

1 INTRODUCTION

Indonesia has large renewable energy capabilities such as hydropower, geothermal, wind, solar, oceanic, or biomass. Sources of power generation such as nuclear and fossil fuels depend on the depletion of natural resources and the process of generating electricity can damage the environment. The right choice to be sustainable is to use renewable energy because it has decent economic potential and is environmentally friendly (Secretariat General Of The National Energy Board Koutl Oo, n.d.).

The Indonesian government is starting to flock to apply non-fossil renewable energy. The solution is expected to be able to maintain the stock of energy resources in Indonesia. Based on the National Energy Policy (KEN), in 2025 Indonesia can use energy sources with a composition of 77% fossil and the remaining 23% from new and renewable energy. The government reaffirmed in Law No. 25 of 2000 on PROPERNAS (National Development Program) that this policy is the main program to increase the use of renewable energy. To achieve the National Development Planning, the experts must be from within the country, so that human resources can know and implement the National Development Plan (iesr, 2019). Converter technology on renewable energy is a special topic in this research, which focuses on the energy results obtained from power electronics devices, namely converters. Some of the problems raised following previous studies look at the problems, methods to the results obtained in previous studies. The study (Lyu, Ma, Yan, 2020) explained that MPC was introduced as a controller that can look ahead or predict and take advantage of low frequencies in switching and can manipulate system stability. MPC can also overcome flux and torque ripples. FCS-MPC is used to control power electronic devices. The basic concept of this method is to predict the system when switching then evaluate the cost function which will be the optimal value and applied to the next control. In the study (Vazquez et al, 2014) applying FCS-MPC which is easier than conventional controllers because this system is online to determine the optimization value. Some of the advantages of control in this study are the response generated is

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dynamic, does not have a modular, fast response and can overcome non-linear systems.

In addition, the problem in the output converter is in the switching which results in harmonics. In this study (Gendrin, Gauthier, Lin-Sh, 2016, p-5487), overcoming network-connected switching using a direct power control (DPC) sequence with a constant frequency. Research (Zhang et al, 2017), the constant switching frequency can be overcome but by using large calculations and complex methods. Research (Tarisciotti et al, 2014) made an FCS-MPC scheme to overcome switching to get a constant frequency.

To get a good FCS-MPC computation, the computation requires implementation time beyond the switching of the phase-locked loop (PLL) and maximum power tracking. To overcome this limitation there is a modulated MPC (M2MPC) by utilizing a constant switching frequency (Tarisciotti et al, 2014) (Zhang et al, 2016) (Yang et al, 2017). M2MPC is designed to control three-phase active rectifiers by using seven levels of H-Bridge cascade and using a matrix converter, therefore the computational burden of using this method is very large.

In the study (Guo et al, 2017) FCS-MPC using commutation so that the current network can be balanced. Efficiency in the form of a reduction in the form of sectors on the inverter, other than in the network can be used for speed control on a permanent motor synchronous machine (PMSM) based on torque and flux control. In this control, the order in the inverter switching table is not considered (Nadour et al. 2020).

Research by (Ali, 2021) (Purnata, 2017) combines the hysteresis band and svpwm methods for current and voltage improvement. Current improvement utilizes the hysteresis band method while SVPWM uses the voltage improvement method.

From some of the studies above, researchers have an idea to apply FCS MPC to a converter connected to the grid. This system is added a hysteresis band to produce a current limit that is more optimal than the ratio of the current value of idq.

2 MODELLING OF THE FCS MPC WITH GRID

2.1 FCS MPC

Model Predictive Control (MPC) or predictive control system is included in the design concept of process model-based controllers, where the process model is used explicitly to design controllers by minimizing a criterion function. The underlying idea for each type of MPC is (Wang et al, 2012). The FCS MPC block diagram can be seen in Figure 1:

Figure 1: above is a setting using FCS MPC by utilizing the optimization of the cost function from the calculation between the reference and the current prediction. The cost function equation can be shown in the equation below:

$$g = \left| i_d^*(k+1) - i_d^p(k+1) \right| + \left| i_q^*(k+1) - i_q^p(k+1) \right| \quad (1)$$

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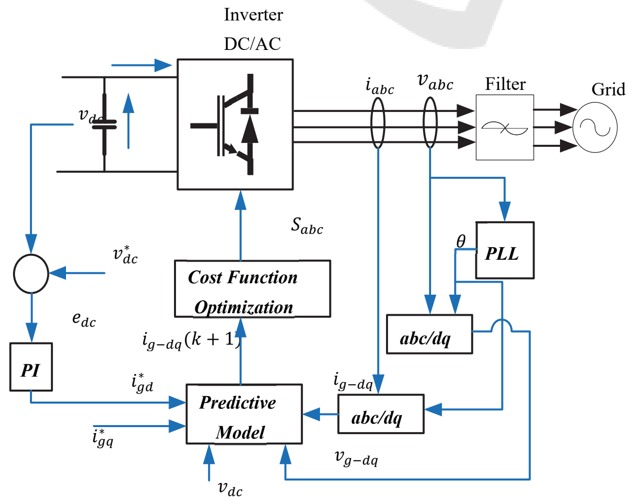

Figure 1: Block Diagram System FCS MPC.

Where $i_d^p(k+1)$ and $i_q^p(k+1)$ is part of the real and imaginary in the prediction model. $i_d^*(k+1)$ and $i_q^*(k+1)$ is the current reference. The output signal from the inverter corresponds to the generated DC voltage and the state of the switching signal S_a, S_b and S_c. The converter uses a two-level converter in which there are 6 sectors and 8 vectors following the equation below:

$$S_i = \begin{cases} 1\ jika\ top\ switch\ meninggalkan - th\ is\ ON \\ 0\ jika\ bottom\ switch\ meninggalkan - th\ is\ OFF \end{cases}$$

The value at the output voltage is defined as

$$\begin{aligned} v_{aN} &= S_a v_{dc} \\ v_{bN} &= S_b v_{dc} \\ v_{bN} &= S_b v_{dc} \end{aligned} \quad (2)$$

Where v_{dc} is a DC voltage source. Taking into account the unitary vector $a = e^{j2\pi/3} = -\frac{1}{2} + j\sqrt{3/2}$ which represents a phase shift of 120°, The output voltage on the grid can be defined as

$$v = \frac{2}{3}(v_{aN} + \boldsymbol{a}v_{bN} + \boldsymbol{a}^2 v_{cN}) \quad (3)$$

Where v_{aN}, v_{bN} and v_{cN} are the phase-to-neutral (N) voltages in the inverter. The possible combinations of the gate signal in the inverter, namely S_a, S_b and S_c, there are eight possible according to the table below

Table 1: Switching States Voltage Vector.

S_a	S_b	S_c	Voltage Vector v
0	0	0	$v_0 = 0$
1	0	0	$v_1 = \frac{2}{3}v_{dc}$
1	1	0	$v_2 = \frac{1}{3}v_{dc} + j\frac{\sqrt{3}}{3}v_{dc}$
0	1	0	$v_3 = -\frac{1}{3}v_{dc} + j\frac{\sqrt{3}}{3}v_{dc}$
0	1	1	$v_4 = -\frac{2}{3}v_{dc}$
0	0	1	$v_5 = -\frac{1}{3}v_{dc} - j\frac{\sqrt{3}}{3}v_{dc}$
1	0	1	$v_6 = \frac{1}{3}v_{dc} - j\frac{\sqrt{3}}{3}v_{dc}$
1	1	1	$v_7 = 0$

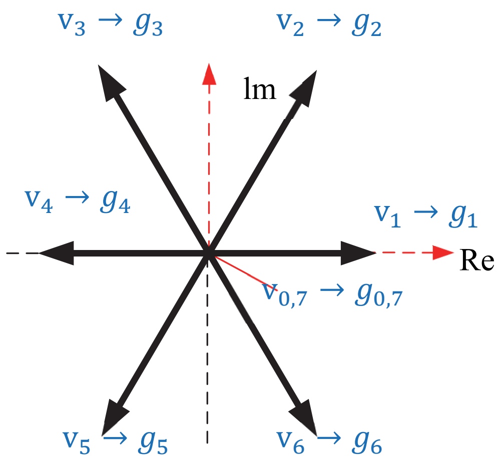

Figure 2: voltage with real and imaginary axes.

2.2 Grid Model

The three-phase axis with the X and Y coordinate systems showing the fixed axis and the rotating axis. The mathematical model on the grid will be shown in the image and equation below.

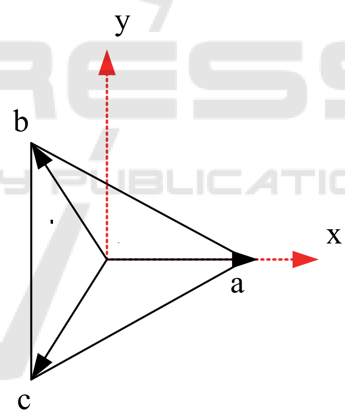

Figure 3: Grid Model.

$$v_a = v_m \cos(\omega.t) \quad (4)$$

$$v_b = v_m \cos\left(\omega.t - \frac{2\pi}{3}\right) \quad (5)$$

$$v_c = v_m \cos\left(\omega.t - \frac{4\pi}{3}\right) \quad (6)$$

Where v_m is the amplitude at the phase voltage and is the angular frequency. The three-phase currents in this system are shown in the following equation:

$$i_a = i_m \cos(\omega.t + \varphi) \quad (7)$$

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$$i_b = i_m \cos\left(\omega.t - \frac{2\pi}{3} + \varphi\right) \quad (8)$$

$$i_c = i_m \cos\left(\omega.t - \frac{4\pi}{3} + \varphi\right) \quad (9)$$

Where i_m is the amplitude of the phase current and is the phase voltage and current. From the symmetrical form, the line-to-line voltage can be defined as
This section must be in one column.

$$v_{ab} = v_a - v_b \quad (10)$$

$$v_{bc} = v_b - v_c \quad (11)$$
$$v_{ca} = v_c - v_a \quad (12)$$

The number of neutrals at current i_N is

$$i_N = i_a + i_b + i_c \quad (13)$$

In the case of the neutral current balance is zero $(i_N = 0)$ then the above equation can be simplified to:

$$i_a + i_b + i_c = 0 \quad (14)$$
$$v_a + v_b + v_c = 0 \quad (15)$$

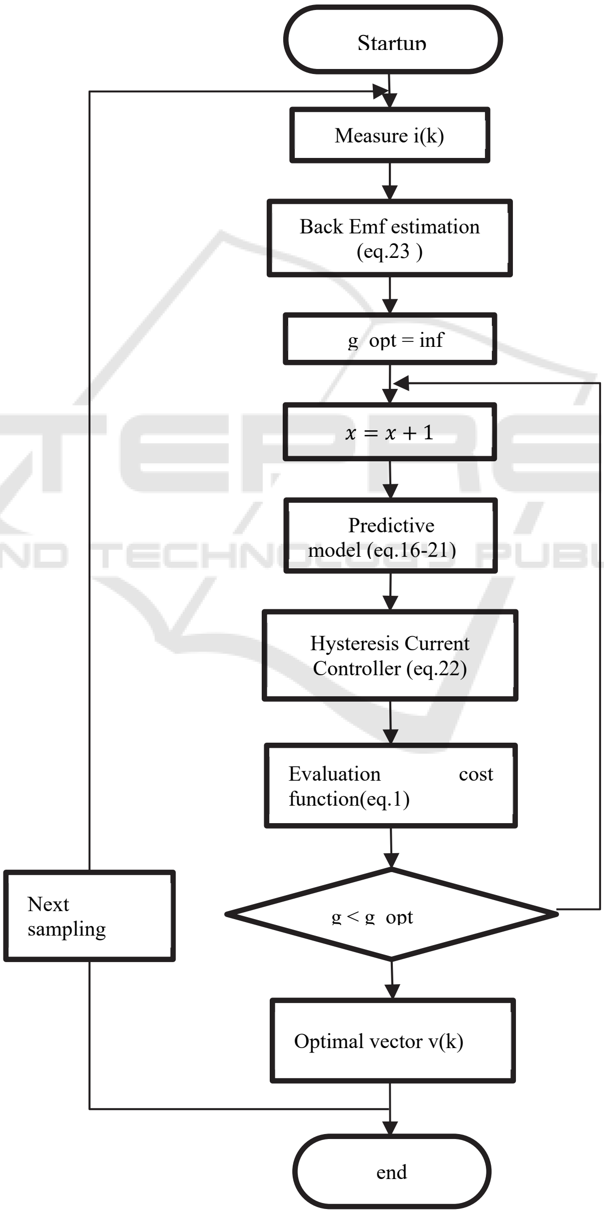

Figure 4: Flow Diagram Implementation FCS MPC.

The power flow in the grid converter can be controlled by improving the DC-link voltage with a constant limit.

3 PROPOSED SYSTEM

The model that will be implemented in this study is as shown in the image below, for determining the cost function, following equation (1). The following is an explanation for predicting the incoming current and providing a hysteresis band before entering the cost function

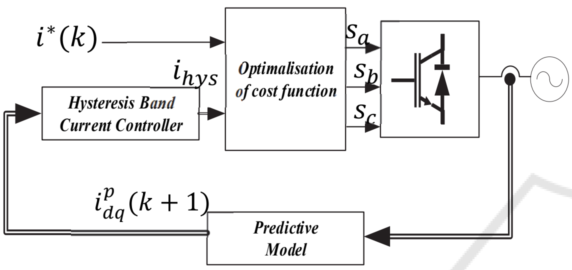

Figure 5: Block Diagram Proposed System.

The reference current for short time (K+1) in the current prediction block is following the equation below in equations (16) and (17) while the current (k+2) in equations (18) and (19). In addition to the current reference, the current prediction current (k+1) is shown in equations (20) and (21)

$$i_d^*(k+1) = 3i_d^*(k) - 3i_d^*(k-1) - 3i_d^*(k-2) \quad (16)$$

$$i_q^*(k+1) = 3i_q^*(k) - 3i_q^*(k-1) - 3i_q^*(k-2) \quad (17)$$

$$i_d^*(k+2) = 3i_d^*(k+1) - 3i_d^*(k) - 3i_d^*(k-1) \quad (18)$$

$$i_q^*(k+2) = 3i_q^*(k+1) - 3i_q^*(k) - 3i_q^*(k-1) \quad (19)$$

$$i_d^p(k+1) = 3i_d(k) - 3i_d(k-1) - 3i_d(k-2) \quad (20)$$

$$i_q^p(k+1) = 3i_q(k) - 3i_q(k-1) - 3i_q(k-2) \quad (21)$$

After knowing the current prediction, the use of Hysteresis Current Controller is a comparison between the current prediction and the previous current and by giving a band of 0.2 bands. The equation for determining the band before entering into optimization is

$$i_{hys} = i_{dq} - i_{dq}^p \quad (22)$$

The optimization used is to determine a vector that is truly optimal. To obtain the optimal vector, it is assumed that the input to the grid is a sinusoidal wave with a fixed amplitude and a fixed frequency. Vector can be seen from the equation below:

$$\mathrm{v} = Ri + L\frac{di}{dt} + \mathrm{e} \quad (23)$$

where v is the vector voltage generated from the inverter, i is the current flowing to the grid and e is the vector for the back emf. All switching states at $v(k)$ with current current $i(k)$ are compared with subsequent current $i(k+1)$ with estimates at $i^p\ (k+1)$.

4 SIMULATION RESULT

Matlab/Simulink programming is used to demonstrate the application using the FCS MPC method. The simulation results obtained with parameters such as the following table:

Table 2: System Parameter.

Parameter	Unit	Value
DC Voltage	v_{dc}	900 V
Converter Side Inductor	L_1	20 mH
Grid Side Inductor	L_2	1.6 mH
Filter Capacitor	C	65.25 μF
Capacitor Resistance	R_c	5 Ω

The first simulation result is to know the v_{dc} on the converter system. v_{dc} affects the result of the generated system.

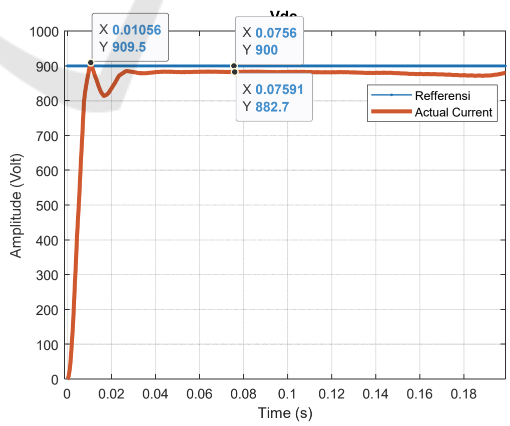

Figure 6: V_{dc}.

Figure 6: above is a v_{dc} response with a generated or reference voltage of 900 $Volts$, the voltage read is 882.7 $Volts$. In the picture there is a steady state error of 18 $Volts$ or 2%. The power demand from the DC

Link input is very influential for the process in the converter system.

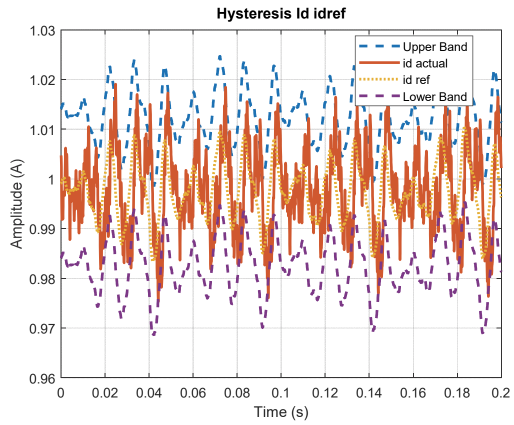

Figure 7: Response i_d actual and $i_d reff$.

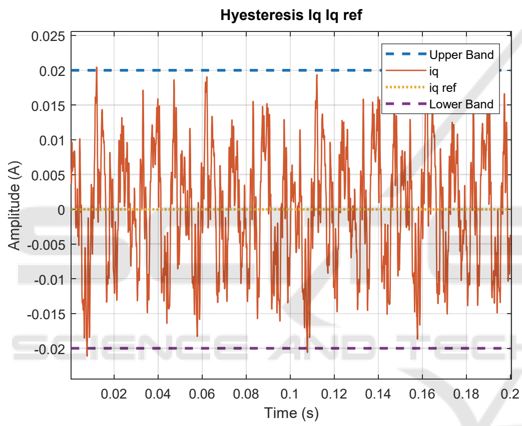

Figure 8: Response i_q actual and $i_q reff$.

Figure: 7 and 8 above are currents from i_{dq} then enter the range of the upper and lower bands on the hysteresis band. The use of the hysteresis band on i_{dq} here is to get the optimal value before entering the switching system and getting the cost function value.

Table 3: Cost Function.

Voltage vector	Cost function
v_0, v_7	$g_{0,7} = 0{,}55$
v_1	$g_1 = 0{,}76$
v_2	$g_2 = 0{,}47$
v_3	$g_3 = 0{,}65$
v_4	$g_4 = 1{,}27$
v_5	$g_5 = 1{,}45$
v_6	$g_6 = 0{,}37$

In the table above, the vector $g_2 = 0.47$ is said to be the lowest value or optimal value for the cost function. There are 8 voltage vectors that produce current to get the cost function value. The lowest value $g_2 = 0.47$ above is the value that will be used in the inverter.

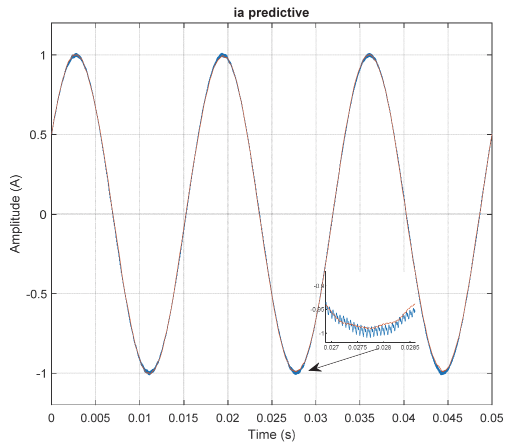

Figure 9: i_a Predictive.

In Figure 9 above, there are still ripples generated from back emf or caused by dynamic loads. The result of the flow above is an evaluation of the value of the cost function. The value of the cost function will be processed on switching on the inverter.

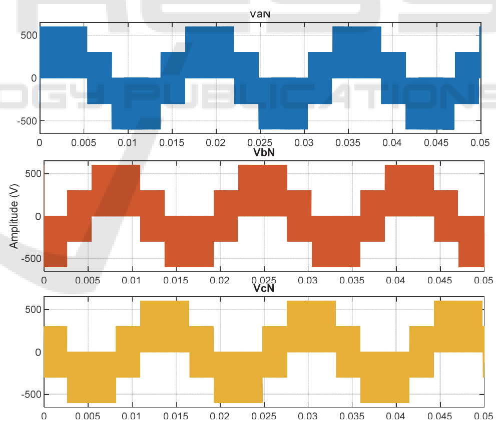

Figure 10: v_{aN}, v_{bN} and v_{cN} output inverter.

Specialization for implementation on FCS MPC using Two levels. Figure 10 above is the result of switching generated by the converter obtained from the cost function. The generated voltage is 600 Volts. The above wave is not pure sine but the result of some switching obtained. After getting the sine signal, the LC filter is given to make it a pure sine signal.

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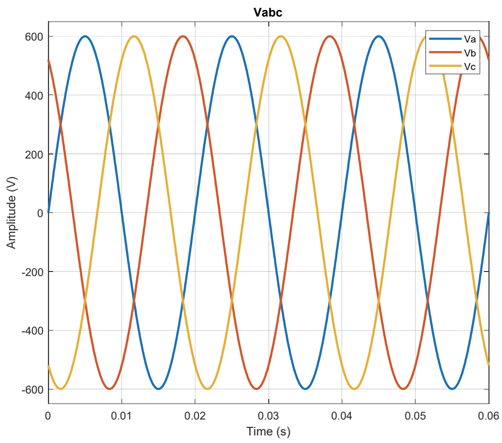

Figure 11: v_{abc} Output Grid.

The picture above is the final result of this research which is obtained from the filter and will be inserted into the transformer to be processed into the grid system or for use. The generated voltage amplitude is 600 Volts.

5 CONCLUSIONS

The FCS MPC which is implemented in the inverter is successfully used by obtaining the cost function. This system can be implemented on a renewable energy system in the form of wind, sunlight from a DC source or an AC source. This optimization renewable energy technology can be applied. The power demand from the DC Link input is very influential for the process in the converter system, the system can run well starting from the input dc voltage of 882.7 volts with a steady state error of 2%. The i_{dq} current is processed to produce an optimal current by utilizing the hysteresis band of 0.2 band. On switching on the inverter, the second vector voltage or g_2 is 0.47 vector value which is used for switching on the inverter. FCS MPC can be applied to a two level converter system, the results obtained are a voltage of 600 volts. The need for a filter circuit to produce a sine wave like a pure sine wave generated by a generator.

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