Wind Energy Conversion System Using Finite Control Set Method: Predictive Control Model Connected to the Grid

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Abstract: The development of Wind Energy Conversion System (SKEA) technology is quite significant as seen from the advance-ment of power electronics technology in turbines and generators. Power electronics technology has been applied to save energy and obtain quality electricity. Quality electricity will affect the load used. To achieve quality electricity in the SKEA system, this study aims to apply the Finite Control Set - Model Predictive Control method in order to obtain quality electricity results or obtain voltage and frequency according to the needs in Indonesia. The results of the study have obtained wind speed data in 2020, namely min 5.34 m/s, average 7.4 m/s, and max 9.4 m/s. When the wind speed is 5.34 m/s the speed of the generator is 18 rad/s when the wind speed is 7.4 m/s the speed of the generator is 31 rad/s and when the wind speed is 9.4 m/s the speed of the generator is 50 rad /s. The electricity to be distributed is based on the DC voltage generated by the conversion of wind energy. This method is applied to produce a voltage of 600 Volts, a phase difference of 120°, and a frequency of 50 Hz which will enter the electricity grid in Indonesia.

1 INTRODUCTION

Energy POLICY (KEN) and the Paris Agreement are step transition Indonesia 's energy towards use energy new and updated. Policy National Energy (KEN) and the Paris Agreement are step transition Indonesian energy going to use energy new and updated. For prepare for the future 2025, the NRE mix must reached at 23 with adoption generator electricity power wind (PLTB) 1,807 MW. Energy wind is source energy supplied by the wind (Teknologi et al., n.d.). wind power is one _ type energy new for replace ingredient burn the fossil the more thinning. Use power wind as generator power electricity is very fast development for Fulfill needs power continuous electricity increase every year (Generation & Design, 2011). Potency wind determined by speed wind. Potency the wind in Indonesia has potency enough wind big in the coastal area Island Java part south and part of Indonesia east, with speed wind average above 5 m/s to 8 m/s. With potency enough wind big, Indonesia has also develop utilization power wind as generator power electricity (IRENA, 2020).

Development technology System Conversion Energy Wind (SKEA) is enough significant. Development this cover technology electronics power on turbines and generators (Mahela & Shaik, 2016). In development this, characteristic turbine wind and turbine wind is very complex in operation on micrograds. Speed the wind that doesn't determined will impact on current electricity and system network. Fluctuation power on grid could produce voltage and frequency that are not determined (Faisal et al., 2018). one solution application technology electronics power is with keep energy and is possible solution for increase quality, efficiency use electricity and reliability network (Faisal et al., 2018).

A number of studies discuss quality electricity generated During conversion power wind. In study (Al-falahi et al., 2017), evaluation technology system conversion energy wind and sun independent done. System conversion power wind could shared

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Becomes a number of next category shared Becomes a number of class depending on converter energy used and compared based on volume, weight, cost, efficiency, reliability, system and capacity. Change speed turbine wind with PMSG and converter scale big is the most popular and interesting technology. Research (Lamsal et al., 2019) has develop output power smoothing (OPS) method using capacitor. System conversion power wind this using PMSG and for achieve maximum output, speed PMSG rotation set use controller based on prediction speed wind and difference speed wind (turbine torque wind and generator torque). Prediction speed wind use method square smallest. Converter power adjust the generator torque to the reference torque through PWM settings. Moment speed wind increases, the torque difference between turbines and generators will more big from zero, so you need increase generator speed. Based on results simulation, the generator torque can be refined. Research (Atherton et al., 2017; Lamsal et al., 2019; Ren et al., 2017; Wang et al., 2020) Review and analysis of different energy leveling strategies for system conversion energy wind. Method purification electricity shared Becomes two type, that is method using _ device storage energy like supercapacitor, battery, flywheel, cell ingredient burn and methods that don't use device storage energy. Method smoothing power that is not stored including correct kinetic, correction angle, and setting voltage circuit medium. Methods involved in storage energy efficient, but increase cost installation and maintenance. On the other hand, the method non-energy storage could by significant reduce cost. A number of method has considered, but method using correct energy kinetic is method smoothing most power efficient.

In studies this our discuss converter power. Research (Meghni et al., 2017; Putri et al., 2018) analyze two structure control generator electricity power wind using PMSG: control speed and torque control. PMSG always connected with AC/DC converter because voltage and frequency output depends on speed wind. Based on results simulation, control speed is scheme control best for applied because use algorithm control traditional like PI controller for make system stable and easy operated. Controlling torque for create a stable system, on the other hand, is very difficult. Turbine wind little standing alone suitable for bring power wind to area secluded outside network. Control strategy required for could produce high efficiency because must notice a number of factor that is efficiency and cost economical. Also, trouble with output converter is that switching causes harmonics. On research this (Multazam et al., 2017), connection switching network overcome with use Suite control power direct frequency constant (DPC). Research (Zhang et al., 2017), constant switching frequency could overcome but use large calculations and complicated methods. Research (Tarisciotti et al., n.d.) made scheme *finite control set – predictive control model* (FCS-MPC) for scar direct conversion for get constant frequency.

For get good FCS-MPC calculation, this need time execution outside transition phase locked loop (PLL) and monitoring power maximum. For resolve limitations, there is a modulated MPC (M2MPC) with use constant switching frequency (Tarisciotti et al., n.d.; Y. Zhang et al., 2016). M2MPC designed for move rectifier active three phase use seven Step Step H-Bridge and converter matrix, so that burden computing use method this is huge.

In research (Yang et al., 2017) FCS-MPC uses switching so that the existing network could balanced. Performance in the form of reduction arc on the off grid inverter can be used for Settings speed on machine permanent synchronous motor (PMSM) based on Torque and flux control. In order this, the inverter switchboard order is not taken into account (Ali et al., 2021; Guo et al., 2017; Nadour et al., 2020).

Research combines method hysteresis and svpwm for rectify current and voltage(Purnata et al., 2017) . Enhancement current use method hysteresis band whereas SVPWM uses method strengthening voltage. From the above study, research this want to knowing energy wind in the district Cilacap especially on location Cilacap State Polytechnic and implement with FCS-MPC method as control conversion energy wind to energy electricity.

2 RESEARCH METHODS

For knowing conversion energy wind Becomes power electricity apply FCS MPC method on the connected converter with network. As for the block diagram system conversion energy wind shown in Figure 1.

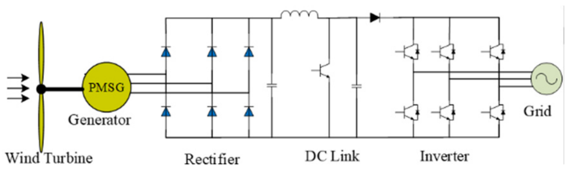

Figure 1: System Conversion Energy Wind.

Based on Figure 1 can is known that there is the four main steps of implementation system conversion energy wind. As for the explanation of each step development the in detail as following:

1) Determination Speed Wind

Determination speed wind on research this to do observation directly on the NASA database. Data obtained on satellite data nasa with position at Cilacap State Polytechnic latitude -7.7178 and longitude 109.0201 with speed wind range 50 meters.

2) Modeling Turbine Wind

Turbine wind is one component important in system conversion energy wind (SKEA). Technology turbine wind has developed and can categorized as based on orientation round axis turbine wind and speed rotation. Turbine model wind state connection Among input turbine wind in the form of speed wind and torque power generated by the turbine wind that. Energy wind generated by speed wind v (m/s) hitting area of A (m^2) can be expressed by the equation

$$P_w = \frac{1}{2}\rho A v_{wind}^3 \quad (1)$$

$$P_m = C_p(\lambda,\beta)\,\frac{\rho A}{2}\,v_{wind}^3 \quad (2)$$

Where $P_m$is the mechanical power of the turbine (W), cp coefficient of performance on the turbine, air density (kg/m^3), A turbine area (m^2), v_{wind} Wind speed (m/s), *Tip speed ratio* on blade to wind speed, *Blade pitch angle* (degrees).

3) PMSG Modell

convert power mechanic Becomes energy electricity. Permanent magnet synchronous generator (PMSG) is a generator that uses permanent magnets for system excitation (producing magnetic field). PMSG dynamic model can be declared with use Suite equivalent dq as shown in Figure 2. In the rotor circuit model, the current Medan in stated rotor winding as source current constant (If) in Suite axis d. Based on Suite the equality voltage for synchronous generator could declared with

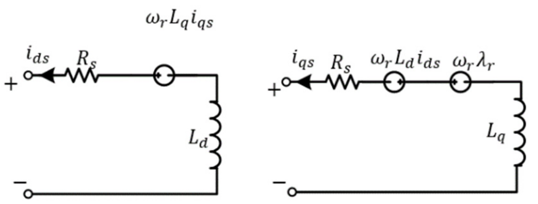

Figure 2: PMSG series.

$$v_{ds} = -i_{ds}.Rs + \omega_r.L_q.i_{qs} - p.L_d.i_{ds} \quad (3)$$

$$v_{qs} = -i_{qs}.Rs - \omega_r.L_d.i_{ds} + p.L_q.i_{qs} \quad (4)$$

Where id is d- axis stator current, iq is q - axis stator current, vd is the stator voltage on the d-axis, $v_q$is the stator voltage on the q-axis, Rs is the resistance of the windings (Ω), Ld is the inductance of the windings on the d-axis (H), Lq is the inductance of the windings on the q(H) axis, p is the number of poles and r is speed rotation PMSG electricity (rad/s). The electromagnetic torque generated by PMSG can be calculated with use equality like following:

$$T_e = \frac{3P}{2}\left(i_{qs}\lambda_{ds} - i_{ds}\lambda_{qs}\right) = \frac{3P}{2}\left(i_{qs}\lambda_r + i_{ds}i_{qs}\left(L_d + L_q\right)\right) \quad (5)$$

PMSG rotor speed can be determined with equation:

$$\omega_r = \frac{P}{JS}(T_e - T_m) \quad (6)$$

Power electricity (P) generated could declared with equality

$$P = 1{,}5\,(v_{sd}.i_{sd} + v_{sd}.i_{sd}) \quad (7)$$

1) FCS MPC Power Converter

Rectifier is converter that converts voltage and current alternating (AC) to voltage and current direct (DC). Converter power used in research _ this isa converter full scale power because simple, efficient and easy natural settings. Converter full scale power used consist from converter rotor and converter side grid side. Converter the side of the rotor consists of from rectifier 3 - phase diode and boost converter while converter the grid side is a voltage source inverter (VSI)

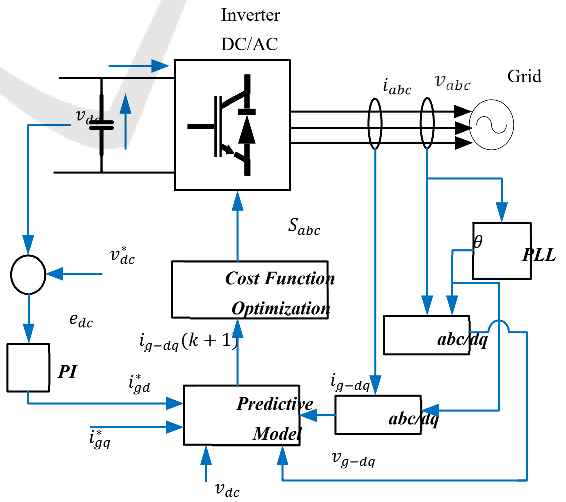

Figure 3: Converter FCS MPC.

Reference current moment time short $(K+1)$on the current prediction block according to the following equation:

$$i_d^*(k+1) = 3i_d^*(k) - 3i_d^*(k-1) - 3i_d^*(k-2) \quad (8)$$

$$i_q^*(k+1) = 3i_q^*(k) - 3i_q^*(k-1) - 3i_q^*(k-2) \quad (9)$$

Just like above, when prediction moment $(K+2)$

$$i_d^*(k+2) = 3i_d^*(k+1) - 3i_d^*(k) - 3i_d^*(k-1) \quad (10)$$

$$i_q^*(k+2) = 3i_q^*(k+1) - 3i_q^*(k) - 3i_q^*(k-1) \quad (11)$$

Current prediction moment $(k+1)$

$$i_d(k+1) = 3i_d(k) - 3i_d(k-1) - 3i_d(k-2) \quad (12)$$

$$i_q(k+1) = 3i_q(k) - 3i_q(k-1) - 3i_q(k-2) \quad (13)$$

Already know current from prediction, then there is repair which current is the real current compared with prediction current, for generated current _ follow the equation below this:

$$i_{dq}(t) = A \sin \omega T \quad (14)$$

In time discrete, then:

$$i_{dq}(k) = A\ \sin \omega T_s \quad (15)$$

$$i_{dq}(k-1) = A\ \sin \omega T_s\,(k-1)$$
$$i_{dq}(k-1) = A \sin \omega T_s k - \omega T_s = A \sin \omega T_s\, k \cos \omega T_s - A \sin \omega T_s \cos \omega T_s\, k \quad (16)$$

$$i_{dq}(k-2) = A\ \sin \omega T_s\,(k-2)$$
$$i_{dq}(k-2) = A \sin \omega T_s k - 2\omega T_s = A \sin \omega T_s\, k \cos 2\omega T_s - A \sin 2\omega T_s \cos \omega T_s\, k \quad (17)$$

From equation (16) we get

$$\cos \omega T_s\, k = \frac{1}{A \sin \omega T_s}(A \sin \omega T_s\, k \cos \omega T_s - y(k-1)) \quad (18)$$

Equality (17) eliminated _

$$y(k-2) = A \sin \omega T_s k - 2\omega T_s = i_{dq}(k) \cos 2\omega T_s - \frac{A \sin 2\omega T_s}{A \sin \omega T_s}(i_{dq}(k) \cos \omega T_s - i_{dq}(k-1)) = i_{dq}(k) \cos 2\omega T_s - \frac{\sin 2\omega T_s \cos \omega T_s}{\sin \omega T_s} i_{dq}(k) + \frac{\sin 2\omega T_s}{\sin \omega T_s} i_{dq}(k-1) \quad (19)$$

Equality (19) simplified with suppose

$$\cos 2\omega T_s = p$$
$$\frac{\sin 2\omega T_s \cos \omega T_s}{\sin \omega T_s} = q$$

And

$$\frac{\sin 2\omega T_s}{\sin \omega T_s} = r$$

So t $i_{dq}(k-2) = p\, i_{dq}(k) - q\, i_{dq}(k) - r\, i_{dq}(k-1)$ hat equation (19) could written repeat be:

$$i_{dq}(k-2) = (p-q) i_{dq}(k) - r\, i_{dq}(k-1)$$
$$(p-q) i_{dq} = -r\, i_{dq}(k-1) + i_{dq}(k-2)$$
$$i_{dq}(k) = -\frac{r}{p-q} i_{dq}(k-1) + \frac{1}{p-q} i_{dq}(k-2) \quad (20)$$

Equality (20) substituted will be:

$$i_{dq}(k) = -\frac{\frac{\sin 2\omega T_s}{\sin \omega T_s}}{\cos 2\omega T_s - \frac{\sin 2\omega T_s \cos \omega T_s}{\sin \omega T_s}} i_{dq}(k-1) + \frac{1}{\cos 2\omega T_s - \frac{\sin 2\omega T_s \cos \omega T_s}{\sin \omega T_s}} i_{dq}(k-2)$$

$$y(k) = -\frac{\sin 2\omega T_s}{\sin \omega T_s \cos 2\omega T_s - \sin 2\omega T_s \cos \omega T_s} y(k-1) + \frac{\sin \omega T_s}{\sin \omega T_s\ \cos 2\omega T_s - \sin 2\omega T_s \cos \omega T_s} y(k-2)$$

$$i_{dq}(k) = -\frac{\sin 2\omega T_s}{\sin(\omega T_s - 2\omega T_s)} i_{dq}(k-1) + \frac{\sin \omega T_s}{\sin(\omega T_s - 2\omega T_s)} y(k-2) \quad (21)$$

$$i_{dq}(k) = -\frac{\sin 2\omega T_s}{-\sin \omega T_s} i_{dq}(k-1) + \frac{\sin \omega T_s}{-\sin \omega T_s} i_{dq}(k-2)$$

$$i_{dq}(k) = \frac{\sin 2\omega T_s}{\sin \omega T_s}\left(i_{dq}(k-1) - i_{dq}(k-2)\right)$$

$$i_{dq}(k+1) = \frac{\sin 2\omega T_s}{\sin \omega T_s}\left(i_{dq}(k) - i_{dq}(k-1)\right) \quad (22)$$

Repair current compare Among current that has been predictable with generated current _ before enter to in cost functions. Repair current here too can in prediction moment $i_{dq}(k-2).i_{dq}(k-1)$ up to $i_{dq}(k+1)$. From equations (22) and (13) then obtained results prediction based on the forward euler approach.

$$\begin{bmatrix} u^*_d(k+1) \\ u^*_q(k+1) \end{bmatrix} = \begin{bmatrix} R_s - \frac{L_d}{T_s} & -\omega_e L_q \\ \omega_e L_q & R_s - \frac{L_d}{T_s} \end{bmatrix} \begin{bmatrix} i_d(k+1) \\ iq(k+1) \end{bmatrix} + \begin{bmatrix} \frac{L_d}{T_s} & 0 \\ 0 & \frac{L_q}{T_s} \end{bmatrix} \begin{bmatrix} i^*_d(k+2) \\ i^*_q(k+2) \end{bmatrix} + \begin{bmatrix} 0 \\ \omega_e \varphi_r \end{bmatrix} \quad (23)$$

after determine repair current and prediction current, output from prediction that is *cost function* in accordance with vector in the appropriate converter with equality following:

$$g = |u^*_d(k+1) - u_d(k+1)| + |u^*_q(k+1) - u_q(k+1)| \quad (24)$$

Matlab /Simulink programming is used for demonstrate on the app use FCS MPC method. The simulation results obtained with parameters like table following this, Table 1 is the system parameters for implementation of FCS MPC. Implementation system could seen in Figure 4 , which is a flow chart implementation . The stages in the flow chart first from calculation current until with get cost function value.

Table 1: System Parameter.

Parameter	Unit	Value
DC Voltage	v_{dc}	900 V
Grid-voltage amplitude	v_g	$230\sqrt{2}$
Converter Side Inductor	L_1	20 mH
Grid Side Inductor	L_2	1.6 mH
Filter Capacitor	C	$65.25\ \mu F$
Capacitor Resistance	R_c	5 Ω

3 RESULTS AND DISCUSSION

On research this conducted measurement speed wind with use satellite nasa on the web https://power.larc.nasa.gov/data-access-viewer/ on site Cilacap State Polytechnic. Measurement Results speed wind for 1 year in 2020 is shown in Figure 4 which is average profile in per month.

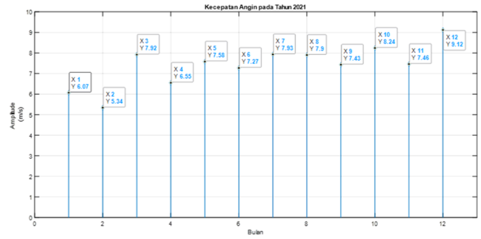

Figure 4: Average speed results wind in the district Cilacap.

Based on speed the wind in figure 4, the average month speed at Cilacap State Polytechnic which is the highest in the month December of 9.12 m/s and the lowest speed in the month February of 5.34. The average speed in 2020 is of 7.40 m/s and with a median of 7.52. This data then processed for determine the Weibull distribution at speed wind. With speed maximum in month December of 9.12 m/s for determination of nominal mechanical power on turbine speed wind like shown in figure 5.

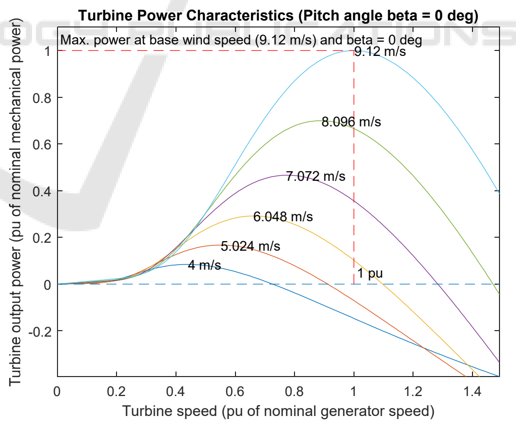

Figure 5: Connection Among power mechanic turbine wind and speed turbine wind.

Figure 6. Show Weibull distribution for take into account condition wind external. The resulting power output is results from the average value obtained by the turbine wind. Election Weibull distribution can model variance wind with utilise function from density probability.

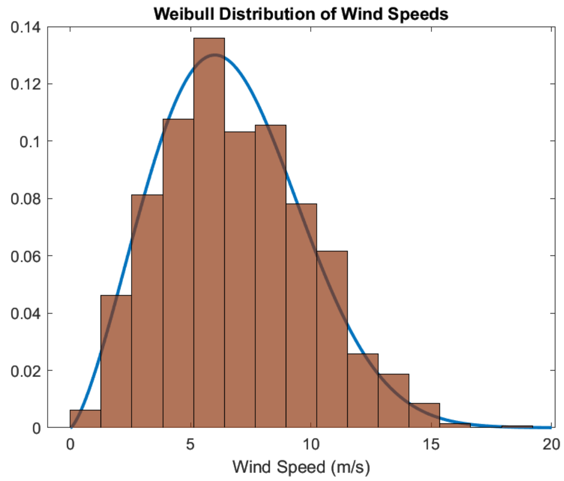

Figure 6: Weibull Distribution of Wind Speed.

After knowing profile energy the wind at the Cilacap State Polytechnic, stages next enter into the PMSG modelling for knowing comparison Among speed wind and generator speed generated. The speed of the generator depends on the wind speed obtained by the wind turbine. As shown in Figure 7, the higher the wind speed, the greater the power generated.

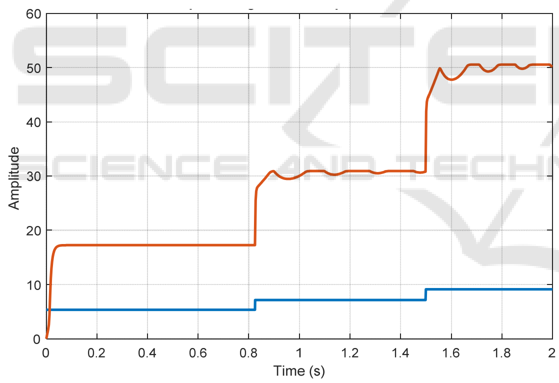

Figure 7: Comparison Wind speed and Generator Speed.

Figure 7 is comparison speed wind with generator speed, speed wind taken in 2020, which is 5.34 m/s min, 7.4 m/s average and 9.4 m/s max. Moment speed wind at 5.34 m/s generator speed is 18 rad/s, when speed wind 7.4 m/s generator speed of 31 rad/s and moment speed wind 9.4 m/s generator speed of 50 rad/s. This result It is known in Figure 10 that the more big wind so the more the speed of the rotor on the generated generator is also large. Stages next that is enter *converter control*. Key main for get results voltage output from the converter that is from voltage output rectifier shown in Figure 8.

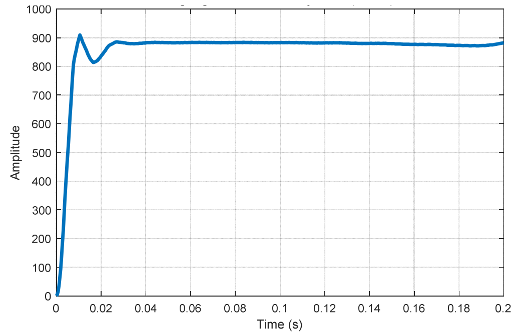

Figure 8: Voltage Output Rectifier.

Figure 8 is voltage rectifier that will processed for determine results from inverter output. Speed given wind so that like picture 8 that is of 7.4 m/s according to with monthly average in 2020. Voltage in the direction shown in Figure 8, namely of 890 Volts with the desired from voltage unidirectional as big as 900 volts or have *steady state error* of 1%.

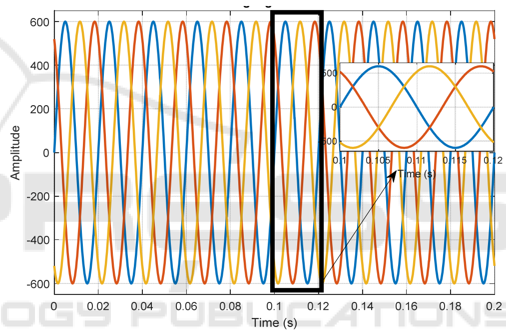

Figure 9: Output Voltage Source Inverter.

For get voltage the output of the inverter depends on $v_{dc}$the DC link. How big is the DC input voltage it will be the equivalent AC voltage. The inverter output is not a pure sine wave but a sine signal of the form box generated by switching power electronics components, namely IGBT. Figure 9 shows output of the inverter with apply FCS MPC method with without a filter with an amplitude of 600 volts, different fasa 120 °and a frequency of 50 Hz. Figure 10 shows voltage and current output of the phase inverter. sine wave va that is as big as 600 volts and he of 1200 Ampere.

4 CONCLUSION

By results research that has been conducted for convert energy wind to energy electricity and apply FCS-MPC method, first get speed data wind in 2020, the minimum is 5.34 m/s, the average is 7.4 m/s and the max is 9.4 m/s. Moment speed wind at 5.34 m/s generator speed is 18 rad/s, when speed wind 7.4 m/s generator speed of 31 rad/s and moment speed wind 9.4 m/s generator speed of 50 rad/s. For get voltage the output of the inverter depends on $v_{dc}$the DC link. How big voltage DC input then will Becomes equivalent AC voltage. Result of application FCS MPC method with without filter get 600 Volt amplitude, different fasa 120 °and a frequency of 50 Hz.

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