

## STATIC FREQUENCY CONVERTER ON GAS POWER PLANT

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### Abstract

*This Paper describes the characterizations of SFC-Using for discussion forum in the 3<sup>rd</sup> International Conference on Innovation Research on Science, Technology and Culture (IRSTC-ISTN) Banda Aceh, 2015. Indonesia has varied differential power plant to produce power energy for Enhancing National Competitiveness in Energy sector. One of main the power plants is gas power plant (PLTG). But operation of the gas power plant requires a combustion process. So, the gas power plant needs auxiliary starting device as prime mover to rotate gas turbine before combustion. The starting device of gas power plant at MuaraKarangis used a static frequency converter (SFC). The function of static frequency converter is to convert generator become motor when starting. The component of SFC consists of a transformator, converter, DC reactor and inverter. SFC 3.7 kV input voltage is converted into a voltage that can be varied to be supplied to the generator when the starting process. At MuaraKarang gas power plant, SFC output voltage of 3300 volts is required. To produce the required output voltage SFC as auxiliary prime mover amounting to 3300 volts, then can be settled the trigger of angle  $\alpha$  to the converter at  $36.05^\circ$ .*

**Key words** : Energy, Static Frequency, Trigger angle, gas power plant , converter.

### I. INTRODUCTION

Energy demand in the world continues to increase as increasing in development and population growth. Gas, Hydrocarbon fuels, magnetic materials and Renewable Energy provide the primary source of energy used in the world. Electricity demand in Indonesia is growing too this is because more consumers and population, growing residential and industrial sectors also continued to increase. So it needs power plant is too increase. This power house in this country also should be reliable in supplying power to the consumer. The reliability of generating units is supported by the auxiliary equipment in power plants. So, the performance of the electric generator is very dependent on the properties of the prime mover as auxiliary equipment is used. So, the applications of power electronic and electric drives in power system are growing rapidly. For examples of auxiliary equipment is in between the cooling system, lubrication system, oil seal system, start-up device. Readiness power plant is an important factor in the power system. For example the readiness is starting power plant. When stop condition and then no order from PLN so the power plant should immediately start up and get online to network interconnection. The gas power plant needs starting device for start up process . The starting device at Muara Karang gas power plant is

Static frequency Converter (SFC). Function of SFC is to change the generator into the motor at start up process. This will rotate gas turbine for combustion. After combustion, gas turbine can turn generator then it SFC auto stop at 2000 rpm.

Then gas turbine turn a generator up to rated speed at 3000 rpm. SFC is the latest technological starting device for gas power plant, more reliable in operation and more complete protection system. In the Muara Karang power plant there are two gas power plants and two SFCs, they are: SFC A and B. So, it can be chosen SFC A or SFC B for starting gas power plant. If SFC A fault so can be changed over to SFC B or otherwise and The system can be more protected.

## 2.1. SYNCRHONOUS GENERATOR AND INDUCTION VOLTAGE

Synchronous generator is a electrical machine that convert mecahanical power to electrical power with syncron rotation. If a coil is rotated at a constant speed in a homogeneous magnetic field, it will be a sinusoidal voltage induced in the coil. The magnetic field can be generated by the DC current or permanent magnets. To produce a magnetic field in the rotor coil excitation system it is necessary to supply DC current to the rotor. The following figure shows a synchronous generator excitation system.

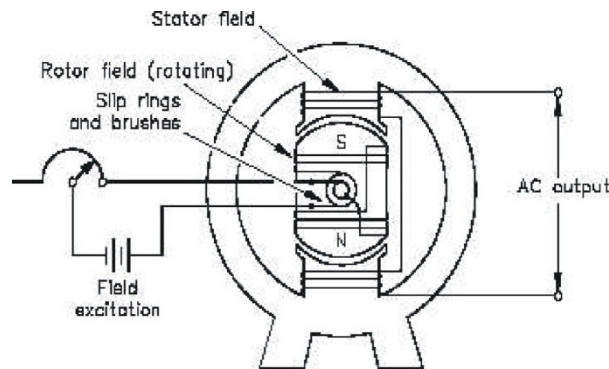


Figure 1 Synchronus generator excitation system

In the above figure 1 , DC current is passed the slip ring and carbon brush to the rotor windings to generate a magnetic field. The relationship between speed rotating magnetic field with a frequency generator on the engine is [1]:

$$f_e = \frac{n_r \cdot p}{120} \quad (1)$$

$f_e$  = frekuensi of generator system (Hz),  $n_r$  = rotor rotation speed , field magnet speed (rpm) and  $p$  = pole. To determine the induced voltage are generated in the stator [1]:

$$E = \sqrt{2} \pi \cdot N \cdot K_p \cdot K_d \cdot \phi \cdot f \quad (2)$$

$E$  = induction voltage at stator,  $N$  = Total coil winding,  $K_p$ =Pitch factor,  $K_d$  = Distribution factor,  $F$ = Frequency (Hz),  $\Phi$ = Fluks (weber)

## 2.2 SYNCRHONOUS MOTOR

Synchronous motors are synchronous machines that are used to convert electrical energy into mechanical energy. If the stator winding is connected to the three-phase voltage source then the three-phase current will through in the stator winding. Three-phase currents in the coil anchor produces a homogeneous rotating field (BS). Unlike the induction motor, synchronous motor excitation received from an external DC source is connected to the rotor circuit via the slip rings and brushes. DC current in the rotor produces a magnetic field of the rotor (BR) are fixed.

Rotor field poles got the pull of rotating stator field poles to also rotate at the same speed (synchronous). The resulting torque synchronous motor is a function of torsion angle ( $\delta$ ). The greater the angle between the magnetic field, the torque produced will be greater as the following equation [1].

$$T = k . B_R . B_{net} \sin \delta \quad (3)$$

The equivalent circuit of synchronous motor shown in the below figure 2 :

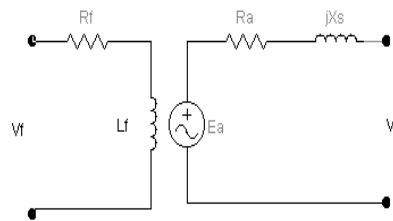


Figure 2 Equivalent circuit of synchronous motor

$R_f$ = Field resistance,  $V_f$ = Field Voltage,  $R_a$ = Stator resistance,  $jX_s$ = Stator Reactance,  $E_a$ = Induction voltage.

From Figure 2 can determine the formula for stator voltage :

$$V = E_a + I_a . R_a + j I_a . X_s \quad (4)$$

## 2.3 Phase Controlled Rectifier

Three phase controlled rectifier bridge system is a 3-phase full-wave rectifier that converts 3-phase AC wave into a wave of DC (direct current). The Controlled 3-phase converter circuit is shown in Figure 3 below. This converter is a 3-phase converters with two quadrant operation, wherein the thyristor is turned on at intervals  $\pi / 3$ . Therefore thyristor switched on every interval of  $60^\circ$ , then the frequency of the output ripple voltage is 6 times the frequency of the voltage source. The order of conduction of the thyristor into 6 pieces will follow the pattern of T1T2, T2T3, T3T4, T4T5, T5T6, and T6T1.

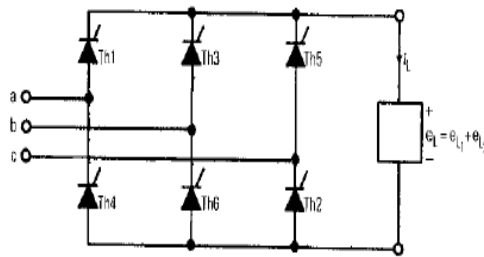


Figure 3 phase controlled rectifier

To determine  $V_{dc}$  output converter using the following formula:

$$V_{dc} = \frac{3\sqrt{3} V_m}{\pi} \cos \alpha \quad (5)$$

Where:  $V_{dc}$  =DC output voltage,  $V_m$  = Peak voltage =  $\sqrt{2}V_s$ ,  $V_s = \frac{V_{rms}}{\sqrt{3}}$  and SFC Input voltage  $V_{in} = 3700V$ , So, that

$$V_s = \frac{3700}{\sqrt{3}} = 2136,2 V \quad \text{and} \quad V_m = \sqrt{2} \cdot 2136,2 = 3021 V$$

And the effective voltage ( $V_{rms}$ ) can be determined :  $I_{rms} = \frac{V_{rms}}{R}$

$$V_{rms} = \sqrt{3}V_m \sqrt{\left(\frac{1}{2} + \frac{3\sqrt{3}}{4\pi} \cos 2\alpha\right)} \quad (6)$$

## 2.4 Inverter

The Inverter is one of power electronics components. The power electronic system is generally getting their power from the utility source. It is an enabling technology, providing the needed interface between the electrical source and the electrical load. Adjustable speed electric driver represent an important application of power electronic. The controller to regulate the output voltage must be designed with the following objectives in this research. In this Research, the inverter is a used circuit to convert the DC voltage source remains a source of AC voltage with a certain frequency. Figure 4 below is a basic circuit of three phase inverter bridge.

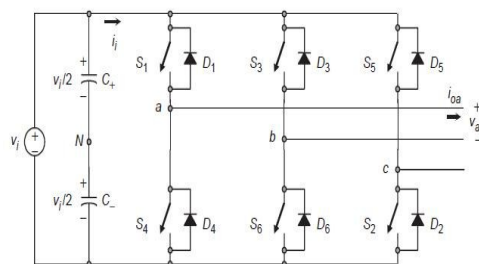


Figure 4. Basic circuit of three phases Inverter Bridge.

From figure 4 above is a basic circuit 3 phase inverter consists of 6 switches. They are S1, S2, S3, S4, S5, and S6 by using thyristor as a switch. Three-phase inverter with angle  $120^\circ$  conduction mode switching allows each component to conduction during  $120^\circ$  with couple different conduction, eg the first  $60^\circ$  between Q1 Q6, and the second  $60^\circ$  between Q1 Q2, and so on. The Model of switching inverter is shown in Table 2.1.

Table 2.1 Inverter switching

sakelar	Q1	Q2	Q3	Q4	Q5	Q6
sakelar	Q6	Q1	Q2	Q3	Q4	Q5
waktu	$0-60^\circ$	$60^\circ-120^\circ$	$120^\circ-180^\circ$	$180^\circ-240^\circ$	$240^\circ-300^\circ$	$300^\circ-360^\circ$

To determine effective output voltage (line to line) use this formula :

$$V_{LL} = \left[ \frac{2}{\pi} \int_0^{\frac{2\pi}{3}} V_S^2 d(\omega t) \right]^{\frac{1}{2}} = \sqrt{\frac{2}{3}} V_S = 0,8165 V_S \quad (7)$$

So, the effective out voltage phase to phase is about 0.8165 Vs

### 3. METHODOLOGY

Static Frequency Converter (SFC) is used for process start-up at Muara Karang power plant. SFC block diagram is shown in Figure 5 below :

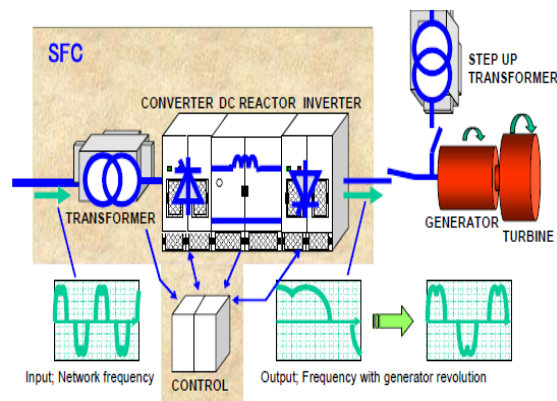


Figure 5 Block diagram of SFC

From the block diagram in Figure 5 above, there is some component of the SFC such as transformers, converters, DC reactor, inverter and control panel. These components are connected to Generator System (Gen-Set). Before Generator operation start-up, the gas turbine is rotated 3 rpm using a turning motor. As in Figure 5 when start-up commands SFC operate to rotate the gas

turbine. Because at first step, there is no combustion air supply. So it need SFC to rotate the compressor which to provide air for combustion. After the air is available then is blended fuels natural gas and given igniton so occur combustion and produce gases combustion with temperature 1350 °C. This high temperature gases combustion is used to rotate the turbine. When the turbine wheel reach 2000 rpm SFC auto off and the gas turbine can spin their own.

The function of SFC transformer is to change or to reduce the medium switchgear voltage of 6.3 kV to SFC rating voltage 3.7 kV. This rating voltage is used as the input voltage to the converter. Output voltage of SFC transformer are rectified by the converter into DC voltage which can be adjusted according to the ignition angle  $\alpha$ . Because this DC voltage has too ripple voltage so it needed DC reactor to reduce the ripple on the output converter. Then, this filtered DC voltage is changed again to AC voltage that can be varied between 0 to 3300 volts which is then supplied to the generator that functions as a synchronous motor for acceleration at start-up power plant.

Equation synchronous motor according to the formula 8 below:  $n_s = \frac{120 \cdot f}{p}$  (8)

$n_s$  = synchronous speed (rpm),  $f$  = frequency (Hz), and  $p$  = pole

## 4. ANALYSIS AND DISCUSSION

### 4.1 Converter operation

This functions of converter is to convert of the AC source voltage of 3.7 kV into a DC voltage that varies between 0 to 4999.29 volt. By using formula 5 can obtained are shown as table 4.1 below. From Table 4.1, if the angle  $\alpha$  is greater then Vdc converter output will be smaller and otherwise. So Vdc maximum is achieved when  $\alpha = 0^\circ$ .

### 4.2 DC Reactor

DC-Link reactors connected between converter and inverter . DC reactor as a filter to reduce harmonic currents and ripple voltage . Depend on SFC rating known the voltage at DC Reactor is 4000 volt and 850 amperes with resistance R is 4.7  $\Omega$  and an inductor L is 30 mH. Inductance on DC-Link Reactor is used to reduce harmonic current, voltage ripple and current ripple, but the inductance L can make delay time of load [4]. Table 4 describes the calculation result of DC-Link Reactor.

Tabel 4.2 The calculation result DC-Link Reactor



$\alpha$	Vdc 1 (Volt)	Vrms 1(Volt)	Vac ripple (Volt)	Idc 1(Ampere)
0°	4.999,29	5.001,71	155,57	1.063,67
10°	4.923,34	4.932,95	307,76	1.047,52
20°	4.697,79	4.729,38	545,71	999,53
30°	4.329,51	4.399,27	780,33	921,17
40°	3.829,67	3.956,88	992,25	814,82
50°	3.213,48	3.423,89	1.181,76	683,72
60°	2.499,64	2.833,09	1.333,49	531,83
70°	1.709,85	2.238,95	1.445,44	363,79
80°	868,11	1.745,27	1.514,05	184,7
90°	0	1.537,17	1.537,17	0
100°	-868,11	1.745,27	1.514,05	-184,7
110°	-1.709,85	2.238,95	1.445,44	-363,79
120°	-2.499,64	2.833,09	1.333,49	-531,83
130°	-3.213,48	3.423,89	1.181,76	-683,72
140°	-3.829,67	3.956,88	992,25	-814,82
150°	-4.329,51	4.399,27	780,33	-921,17
160°	-4.697,79	4.729,38	545,71	-999,53
170°	-4.923,34	4.932,95	307,76	-1047,52
180°	-4.999,29	5.001,71	155,57	-1063,67

### 4.3 Inverter Operation

The converter output voltage changed again to AC voltage by an inverter. The inverter switching with pulse width trigger  $120^\circ$ . To calculate the output voltage of this inverter using the formula 2.7. The results of the calculation of the inverter output is shown in Table 4.1 below. The inverter output voltage is variable based on the trigger angle  $\alpha$  to the converter. So can be adjust depend on system. The voltage is then supplied to the generator as a synchronous motor when starting. If inverter output voltage ( $V_{out}$ ) is 3300 volt, based on the formula 2.7 :

$$V_{out} = \sqrt{\frac{2}{3}} V_s = 0,8165 V_s \rightarrow V_s = \frac{3300}{0,8165} = 4041,641 \text{ Volt}$$

And by formula 2.5 :

$$V_{dc} = \frac{3\sqrt{3} V_m}{\pi} \cos \alpha = 4041,641 = \frac{3\sqrt{3} 3021}{\pi} \cos \alpha$$

$$\alpha = 36,05^\circ$$





So if expected the inverter output voltage is 3300V, the converter must be triggered of angle alpha to 36.05°. For current waveforms at angle  $\alpha = 30^\circ$  and  $90^\circ$  look like Figure 6.

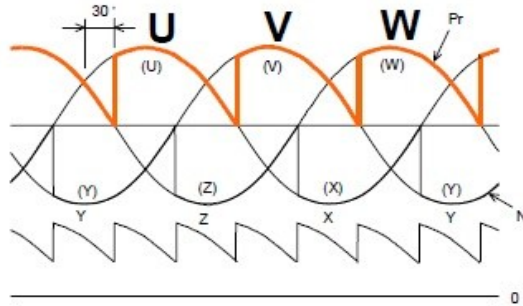


Figure 6 Current waveforms at angle  $\alpha = 30^\circ$

- Condition at angle  $\alpha = 90^\circ$   $V_{dc} = \frac{3\sqrt{3} \cdot 3021}{\pi} \cos 90 = 0 V$

$$V_{rms} = \sqrt{3} \times 3021 \sqrt{\left(\frac{1}{2} + \frac{3\sqrt{3}}{4\pi} \cos 2.90\right)} = 1537 V, I_{rms} = \frac{1537}{4.7} = 327 A$$

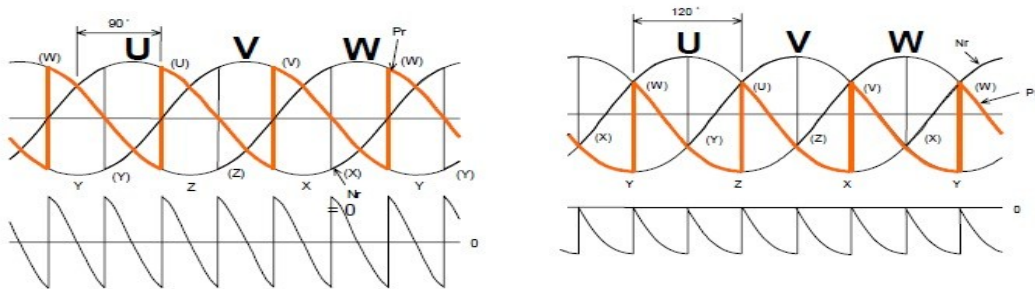


Figure 7 Current waveforms at angle  $\alpha = 90^\circ$  and  $120^\circ$

Table 4.1 Output voltage converter and inverter

$\alpha$	Vout Converter	Vout inverter	$\alpha$	Vout converter	Vout inverter
$0^\circ$	4.999,29	4083,90	$100^\circ$	-868,11	1425,01
$10^\circ$	4.923,34	4027,75	$110^\circ$	-1.709,85	1828,10
$20^\circ$	4.697,79	3861,54	$120^\circ$	-2.499,64	2313,22
$30^\circ$	4.329,51	3592,00	$130^\circ$	-3.213,48	2795,61
$40^\circ$	3.829,67	3230,79	$140^\circ$	-3.829,67	3230,79
$50^\circ$	3.213,48	2795,61	$150^\circ$	-4.329,51	3592,00
$60^\circ$	2.499,64	2313,22	$160^\circ$	-4.697,79	3861,54
$70^\circ$	1.709,85	1828,10	$170^\circ$	-4.923,34	4027,75
$80^\circ$	868,11	1425,01	$180^\circ$	-4.999,29	4083,90
$90^\circ$	0	1255,10			

**CONCLUSION**



To change the output voltage of the SFC is done by setting the the trigger angle  $\alpha$  on the converter. Based on the analysis and calculations, then it could be concluded if the output voltage SFC 3300 volts, then the trigger angle  $\alpha$  to the converter must be set at  $36.05^\circ$ .

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