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Generator protection system with reverse power relay on 1000 KVA 'Cummins' diesel generator at Cepu Human Resources Development Center

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Abstract

Each generator is designed to create a certain amount of electricity. However, there are situations when the generator cannot handle the current load. The solution is to employ two or more generators to produce as much power as the number of generators operating simultaneously or synchronizing (parallel generator). Several parameters must be configured throughout the synchronization process, including the phase sequence, voltage, frequency, and phase angle, which must be the same. An operation failure can occur if one of the prerequisites is not fulfilled, resulting in reverse power. The motoring condition is a condition that occurs when the primary mover of a parallel generator fails. A reverse power protection mechanism is required to prevent this motoring. When one of the generator's prime movers fails or the operation fails, the voltage and load will drop. The other generator then feeds another generator. The reverse power relay instructs the generator's main circuit breaker to open the circuit so that no additional equipment is harmed. This research aims to investigate and comprehend the reverse power relay protection system's use.

Keywords: Generator; Parallel Generator; Power Reverse Relay; Motoring

1. Introduction

Diesel power plants (PLTD) play a significant role in Indonesia's electricity supply. In general, PLTD is commonly utilized as a backup generator in industry and business and for remote places such as tiny islands (1). The PPSDM Oil and Gas power plant is a diesel power plant that produces electricity for the refinery and utilities. PLTD consists of four generators that run continuously for 250 hours (2). The generators must be maintained and synchronized with one another during operating hours. There may be issues during the synchronization procedure. One of these is reverse power, which can allow the generator to transform into a motor, implying that the generator's production of energy shifts to absorbing energy. This research studies how the generator synchronization process occurs in the presence of possible disturbances that can happen, namely reverse power. These disturbances needed to be resolved with a reverse power relay safety system.

The type of reverse power relay used in the generator at PPSDM Oil and Gas Cepu is "Cummins" 1000 kVA. There are three aims needed in this research. First is configuring the working principle of diesel power plants in PPSDM Oil and Gas Cepu. There is also a need to operate the protection system correctly for the 'Cummins' 1000 kVA generator in the refinery and utilities of the Cepu PPSDM Oil and Gas PLTD Unit. The final aim is to arrange the methodology and simple analysis of power reverse Relay works on the 1000 kVA 'Cummins' generator in the refinery and utilities of the Cepu PPSDM Oil and Gas PLTD Unit. This research limits the subject to the reverse power relay safety system of the 'Cummins' 1000 kVA diesel generator set in the Refinery and Utilities of the Cepu Oil and Gas PPSDM Power Plant Unit.

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2. Theoretical Framework

2.1. Diesel Power Plant (PLTD)

The diesel engine, which serves as the PLTD's prime mover, generates mechanical power that is used to revolve the generator rotor (3). PLTD is typically utilized as a power center to deal with sudden loads that can occur. The PLTD is known as a tapered load power center because of the following benefits:

It can immediately pick up and spread the weight.

The engine speed must be increased from 0 rpm to synchronize with the network, which takes longer.

In comparison to other power plants, the construction costs are relatively inexpensive.

2.2. Working Principle of PLTD

Self-ignition occurs in a diesel engine because the working process relies on pure air being used in the cylinder at high pressure (35 - 50 atm), causing the temperature in the cylinder to rise. The fuel is then sprayed into a cylinder at a high temperature and pressure, exceeding the fuel's flashpoint, causing it to ignite automatically, resulting in a fuel explosion. Figure 1 shows the general design of the diesel power plant.

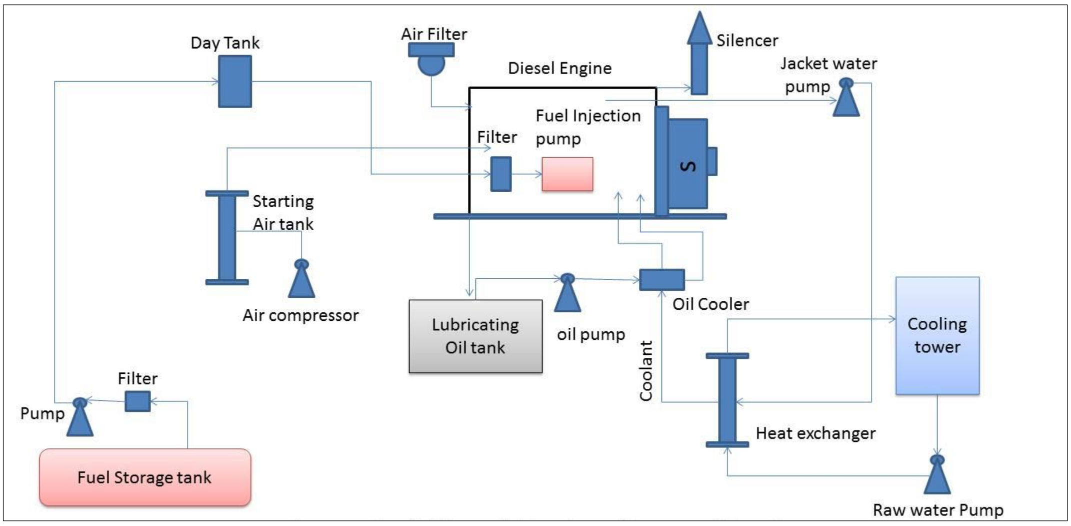

Figure 1 Layout of Diesel Power Plant

The explosion in the combustion chamber moves the piston. The piston is subsequently turned into mechanical energy by the crankshaft. The gas pressure created by fuel combustion and air will force the piston back and forth, which is connected to the crankshaft by a piston rod. The piston's reciprocating action is transferred to rotating motion via the crankshaft. On the compression stroke, the rotating movement of the crankshaft is transferred into the reciprocating motion of the piston.

The diesel engine crankshaft drives the generator rotor shaft. This mechanical energy is turned into electrical energy in the generator, resulting in an electromotive force. A step-up transformer raises the voltage generated by the generator so that the electrical energy produced reaches the load via a transmission line. A step-down transformer (4) lowers the voltage on the load side.

2.3. Fuel System

Only pure air is absorbed and compressed in a diesel engine. The fuel and air are combined in the cylinder, and then the fuel is sprayed into the combustion chamber after the air has been compressed. 1.5-4 MPa (15-40 bar) compressed air pressure is required to raise the air temperature to 700-900°C. The fuel must be finely atomized at pressure by the injection pump (100-250 bar). Figure 2 shows the main fuel tank in the Cepu site. Figure 2 shows the Cepu site's main fuel tank.

Figure 2 Cepu Main Fuel Tank 401

2.4. Cooling System

The cooling system is in charge of maintaining the engine's operating temperature. A cooling system is required because the generator engine will be working at its optimum operating temperature. The cooling system circulates coolant throughout the generator to dissipate the heat created by combustion and friction. It is based on heat transmission. Heat is always transmitted from one source of heat to another source of heat. Metal, liquid, or air can be used as heat sources and targets. The greater the temperature difference occurs at the start, the greater the amount of heat transported. Figure 3 shows the cooling system at the Cepu site.

Figure 3 Cooling System in Cepu Diesel Power Plant System

2.5. Automatic Voltage Regulator (AVR)

AVR stands for Automatic Voltage Regulator. This component's job is to keep the voltage from a generator set, or generator set balanced or stable when dealing with fluctuating electrical loads. In general, each generator unit is now equipped with this AVR component, especially those with capacities of more than ten kVA. AVR generator schematic diagram is shown in Figure 4. Furthermore, each generator brand has its own set of AVR components.

The AVR will boost the current at the exit when the generator's output voltage is lower than the typical voltage of the generator. As a result, if the generator output voltage changes, the AVR will automatically stabilize since it is equipped with automatic equipment such as tools for minimum and maximum constraints. Three AVR circumstances exist, particularly (5):

If the output voltage is too high, the AVR error signal (+) commands the excitation current to be reduced.

If the voltage is equal to the setpoint value (zero), the AVR will not issue any commands.

The error signal will be (-) if the output voltage is low, and the AVR will send the order to add excitation current [5].

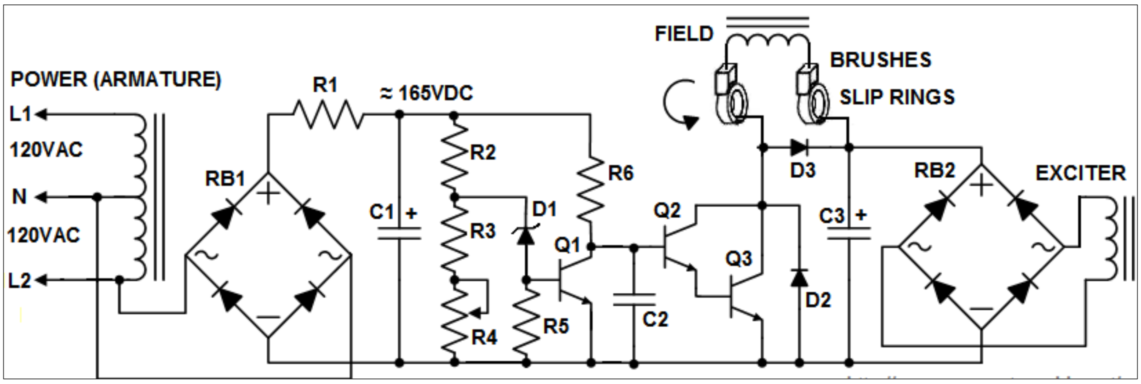

Figure 4 AVR Generator Schematic Diagram

3. Results and discussion

3.1. Generator in PPSDM Oil and Gas Cepu

A generator is an electrical machine that converts mechanical energy into electrical energy using magnetic induction to generate electricity. Because the number of rotations of the rotor equals the number of turns of the magnetic field in the stator, it is called a synchronous generator. Casing, Stator, Rotor, and Exciter make up a generator. Figure 5 shows a 1000 kVA Cummins diesel generator set that powers the PLTD PPSDM Oil and Gas Cepu.

Figure 5 Generator Set 1000 kVA

3.2. Generator Protection System

One or more protective devices and other equipment are arranged to fulfill one or more specialized protective functions (6). A protection system consists of one or more protective devices, a measuring transformer, wiring, a tripping circuit, a power source, and, if available, a communication system.

The primary purpose of the protection system is to detect abnormal conditions in the electric power system. Order a trip on the PMT and separate the disturbed equipment from the health system so that the system can continue to function (7). The basis for the selection of electric power system protection and protection systems are as follows (8):

- Lessens damage to disrupted equipment and equipment next to the fault point
- Lessens general disruption
- Reduces interruption time
- Minimizes human risk
- Increases electricity supply for consumers
- The function of the protective system was:
- Prevent damage to electric power system equipment caused by disruptions or abnormal operating circumstances.
- To safeguard people from the risks of electricity.
- Narrows the affected area, preventing the disturbance from spreading throughout the system.
- It provides consumers with electrical power services that are both reliable and of high quality.

3.3. Reverse Power Disturbance

3.3.1. Reverse Power Definition

The effect of mechanical disturbances generated by the failure of the prime mover on the generator is known as reverse power. The generator provides power to the electric power system under typical circumstances. However, the generator receives an electric power source from the system when there is reverse power, allowing it to turn like a motor. The generator must be equipped with a sensitive reverse power relay to prevent harm from this disruption (9).

The rotor magnetic field will produce a current due to the speed differential between the rotor and the stator magnetic field. This induced current has a low or slips frequency, but higher frequency induced currents might damage the rotor. Operator mistakes, circuit breaker failures while in use, or mechanical failure can all cause these symptoms (10).

3.3.2. Cause of Reverse Power

Reverse power could exist for several reasons, such as

- Generators are linked in a network or connected in parallel with other generators.
- The primary mover's torque (in this case, a steam turbine, water turbine, or diesel engine) is less than the torque required to keep the rotor speed proportionate (concerning the system frequency).
- The prime mover loses torque (the prime mover, such as a turbine or diesel engine, "trips" or fails), but the generator remains linked to the grid. The voltage in the stator induces a rotating rotor winding because there is still a residual speed in the rotor and a voltage from the network on the stator side.

3.3.3. Reverse Power Impact

There are several impacts occurred when reverse power happens, such as:

- An explosion in the combustion chamber of a diesel generator can occur due to the accumulation of unburned fuel while the rotor rotates.
- The gas turbine will harm the gearbox.
- Cavitation will occur in a hydro plant (water turbine).

3.4. Reverse Power Relay

3.4.1. Reverse Power Relay Definition

A reverse power relay (relay power back) is a relay to detect the flow of power, which is usually used to monitor the power of a generator that operates in parallel with other generators or parallel with the system. This relay aims to prevent the flow of electricity from flowing backward from the mainline to the generator.

3.4.2. Reverse Power Relay Working Principles

The power monitor responds to reverse power if the negative % value is altered. Relay FT (Flexitest) can also be used as a minimum load monitor by selecting a positive value. When the reverse power relay is in contact position one, Figure 6 shows when it stays in contact position one or switches to contact position two (11).

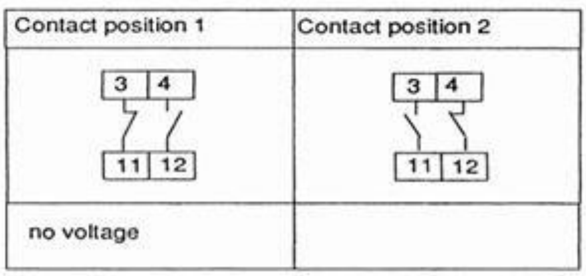

Figure 6 Contact Position

If the setting is in the negative range (-10% to 0%), for example, the relay will stay in contact position one if:

- The reverse power is less than the adjusted value
- The exponent is either zero or one

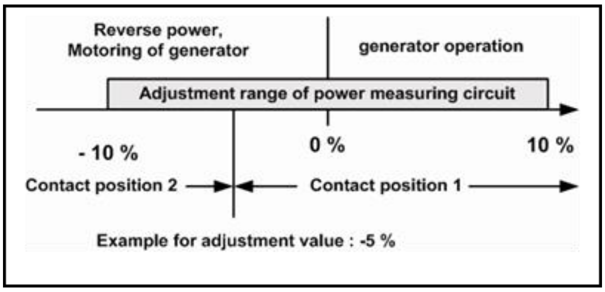

Figure 7 Generator operating area diagram on the reverse power relay RW 1-10

Figure 7 shows the functional area diagram of reverse power relay RW 1-10. When the reverse power exceeds the adjusted value, the switch to contact position two happens. A switching delay of 0 to 30 seconds can be adjusted to skip dynamic reactions in addition to the power meter circuit setting values. This delay is required, for example, in the case of wind turbines, when consumer feedback is occasionally needed.

3.4.3. Reverse Power Relay Configuration

The RW 1-10 reverse power relay features a spindle potentiometer for adjusting the switching point (in percent) and switching delay (in seconds), which may be easily adjusted for connection time lag switching. The relay reacts to a generator with a return power of 10% does not imply that the RW 1-10 adjustment value is 10%. Figure 8 shows the reverse power relay setting process.

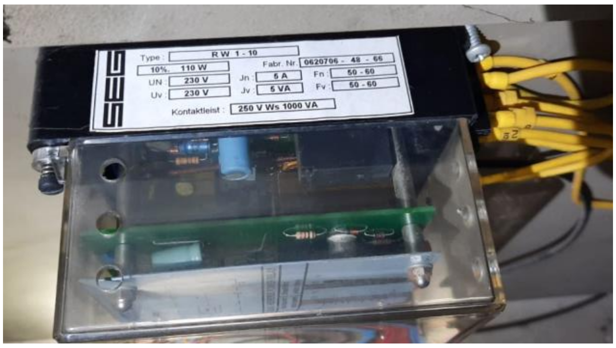

Figure 8 Reverse Power Relay Setting

Due to the transformer ratio, the switching point adjustment value must first be calculated. According to the equation, for a four-wire system (RW Units 1-10):

$$P_{RW1-10} = I_N \times U_N \times ni \times nu \qquad (1)$$

$$\text{Value in \%} = \frac{P_{GEN}}{P_{RW}} \times P_{REV}(\%) \qquad (2)$$

P_{GEN} [kW] : The active power of the generator in kW is calculated from the actual power of the generator
S_{GEN} could be gained from P_{GEN} =SGEN COS ϕ
P_{RW1} [kW] : the reference power of RW1 in kW is calculated from
I_N : Nominal current of time delay
U_N : Nominal voltage of time delay
Ni : Ratio from current transformer
Nu : Ratio from voltage transformer

Based on the generator capacity and reverse power relay, the following calculations can be obtained:

Apparent power of generator S_{GEN} = 1000 kVA

Generator voltage = 400 V
Power factor = 0,8
Generator active power P_{GEN} = 1000 kVA x 0,8 = 800 kW
Nominal current from RW 1-10 I_N = 5A
Nominal voltage from RW 1-10 U_N = 230 V
The ratio of this current transformer = 1000 A / 5A = 200

Reference power per unit according to equation 1:

$$P_{RW1-10} = \sqrt{3} \times I_N \times \sqrt{3} \times U_N \times ni \times nu$$

$$= \sqrt{3} \times 5 \times \sqrt{3} \times 230 \times 200 = 690 \text{ kW}$$

If the relay must respond at 5% reverse power (referring to the active power of the generator), then P_{REV} = -5%, and the adjustment value can be calculated as follows:

$$\text{Value in \%} = \frac{P_{GEN}}{P_{RW}} \times P_{REV}(\%) = \frac{800}{690} \times (-5\%) = -5.797\ \%$$

In the above calculation, the relay RW1-10 switching point must be adjusted to -5.797% so that it responds to generator return power at 5% (corresponding to 40 kW if the generator is powered on 800 kW).

$$\text{kVA} = \sqrt{3} \times V \times A \qquad (3)$$

$$1000 \text{ kVA} = \sqrt{3} \times 400 \times A$$

$$A = 1000 \text{ kVA} / (\sqrt{3} \times 400)$$

$$A = 1443 \text{ Ampere}$$

After calculating the maximum current generated by the generator, we know how much capacity the Current Transformer (CT) and reverse power relay are given to the generator. The incoming reverse current power will not cause damage to the reverse power relay. In PPSDM Oil and Gas Cepu uses CT 2000/5A because the capacity of the Current Transformer is closest to the maximum current value obtained from the calculation, which is 1443 Ampere.

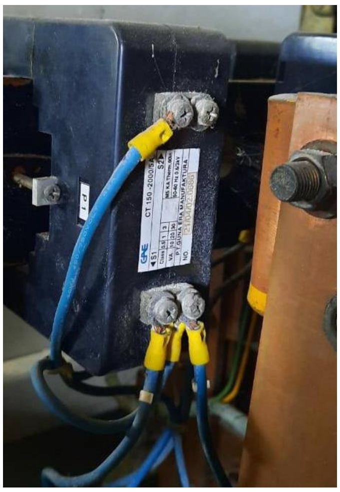

Figure 9 Current Transformer

Figure 10 Reverse Power Relay

Figure 10 exhibits reverse power relay setting data of -5 percent at a time of 5 seconds. The maximum current limit that goes through the relay is calculated using a value of -5 percent. The relay's maximum current limit is 2000 (Current Transformer capacity) minus 5% = 100 Ampere.

When the total reverse power current flowing in the reverse power relay exceeds 100 amperes, the circuit breaker will trip without any response time to improve the power factor. In comparison, when the reverse power relay current is less than 150 amperes, the system has a maximum response time of 5 seconds to improve the power factor, and the circuit breaker will not trip (breaks current).

The reliability will be improved when the reverse power relay setting is set to 10%, but the risk to the equipment will increase. The level offered is virtually 0%. The risk is that if there is a tiny discrepancy when synchronizing the readings on the reverse power relay, it will be more sensitive, but it is safer on the equipment side.

4. Conclusion

A reverse power relay is used to keep a parallel generator from converting into a motor by ensuring that the power flow from the system does not reverse to the incoming generator (load). The incoming generator frequency value is lower than the system frequency and is not quickly increased, causing the generator to convert its function to a motor when it is parallel. Suppose the Reverse Power Relay is working well. It is necessary to perform maintenance on the power factor generator and adjust the speed generator to prevent the circuit breaker from tripping.

Compliance with ethical standards

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Disclosure of conflict of interest

The authors certify that the publishing of this material does not involve any conflicts of interest.

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